DEVELOPMENT AND ANALYSIS OF
AN INTERSECTION SAFETY PRIORITIZATION METHOD
FOR THE STATE OF DELAWARE

by

Anna Duryea

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Approved: ________________________________
Earl E. Lee II, Ph.D.
Professor in charge of thesis on behalf of the Advisory Committee

Approved: ________________________________
Harry W. Shenton III, Ph.D.
Chair of the Department of Civil and Environmental Engineering

Approved: ________________________________
Babatunde A. Ogunnaike, Ph.D.
Dean of the College of Engineering

Approved: ________________________________
Ann L. Ardis, Ph.D.
Interim Vice Provost for Graduate and Professional Education
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ABSTRACT

A ranking procedure to identify unsafe intersections is essential to transportation agencies for efficient use of safety improvement resources. The lack of a standard procedure for selecting a safety performance measure for intersections is the cause of discrepancies across agencies. The abundance of performance measures and methodologies further complicates an agency’s development of an accurate procedure. This paper presents the development, application, and analysis of a composite ranking methodology using crash data from two corridors in New Castle County, Delaware. The method combines the use of three performance measures: crash frequency, crash severity, and crash type cost. Four crash severity weighting combinations were applied and compared. While the combination developed through engineering judgment is preferred, the top 25 most unsafe intersections did not change significantly regardless of which crash severity combination was used.
Chapter 1

INTRODUCTION

With approximately 44% of fatal crashes from 2005 to 2013 in New Castle County, Delaware occurring within the limits of an intersection, safety improvements are a major objective of Delaware Department of Transportation (DelDOT).\textsuperscript{1} However, with limited funding, not all safety improvements can be implemented in a fiscal year. In order to best allocate resources, prioritizing intersections based on safety is crucial. While there exist a number of safety performance measures, there is no standard ranking procedure for identifying high accident locations. An efficient procedure is the key to maximizing resources by targeting areas that can most benefit from safety improvements.

There are several objectives of this paper. The first objective was to evaluate current methods used by different transportation agencies and assess alternative methods in an extensive literature review. The second objective was to develop a methodology and analyze the procedure using crash data from two corridors in New Castle County, Delaware. The data included all intersection crashes in Delaware occurring on US 40/US 13 and SR 72 from 2011 to 2013. The results of the suggested intersection prioritization method are presented, followed by conclusions and recommendations.
A comprehensive literature review was conducted before the analysis, data preparation, and model development. The purpose of this literature review was to evaluate current intersection safety prioritization methods, identify issues and concerns, and assess alternative methods.

The literature review revealed several key concerns to address when producing network screening techniques for evaluating crash performance of intersections. The limitations of data and the regression-to-mean (RTM) bias, along with common biases and errors associated with each particular performance measure must be addressed and minimized when developing an intersection safety identification and prioritization method.

Limitations of the data can be impairing when producing an intersection safety evaluation procedure and thus need to be addressed in the methodology. The Highway Safety Manual (HSM) discusses limitations of observed crash data and limitations of data due to randomness and change at length. Crash data, facility data, and traffic volume data are all required for accurate evaluation of locations, however, traffic volume data may be unavailable or not precise. Additionally, data quality and accuracy, crash reporting thresholds, and differences in data collection methods can all contribute to inadequate observed crash. Data quality and accuracy can be affected by imprecise and inaccurate data entry errors, incorrect training, and subjectivity. Additionally, in many states, there is a minimum crash reporting threshold so not all
crashes are reported. More severe crashes are often reported more often and more accurately than lower crash severity accidents, making it difficult to tell if crashes decreased due to safer conditions.\textsuperscript{3} Even when crashes are reported, there are inconsistencies between jurisdictions of how they are reported and classified.\textsuperscript{2-3} Furthermore, pressures on officers can lead to imperfect recording of police reports and observed crash data.\textsuperscript{2}

Limitations of the data due to randomness and change must also be addressed when creating a network screening procedure for evaluating intersection safety performance. Because crashes are random events, they can fluctuate over time, a natural variability in crash frequency.\textsuperscript{3} After a period of high crash frequency it is statistically probable that a period of low crash frequency will follow, and vice versa.\textsuperscript{5} Failure to account for this is called the regression-to-mean (RTM) bias and is the key flaw of many of the screening performance measures.\textsuperscript{3} Using a longer study period can account for these limitations, but a conflict between crash frequency variability and changing site conditions arises.\textsuperscript{3}

Because there is no standard, the number of years of data to use is a key inquiry when developing an intersection safety evaluation procedure. The number of years of data to use significantly influences the outcome of intersection evaluation procedures and must be carefully decided upon.\textsuperscript{3,6,7} This is because site conditions at a location can be altered significantly over a long period of time and thus using too many years of data may result in inaccurate analysis. On the other hand, not using enough years of data does not address the natural fluctuation of crash frequencies.\textsuperscript{3,6,7}

In research conducted by Qin et al., the research found that weights in a composite ranking methodology were not as significant in altering the ranking of
intersections based on safety as the number of years of data used. In the research, the methodology used a composite ranking method (discussed in greater detail later in this paper) that considered three criteria: crash frequency, crash severity, and crash type. Different combinations of weightings of the criterion were applied. A sensitivity analysis was performed on two factors: the number of years of data used, and the different weightings of the three criterions. Rankings changed considerably more when the number of years of data was changed than when the composite ranking weightings were changed. The authors recommended that a minimum of 3 years of data be used.

Other literature also supported the implication that a 3 year study period is optimum. In addition to the research conducted by Qin et al., the Institution of Civil Engineers (ICE) manual also defines sufficient data collection as at least 3 years of accident data. Research conducted by Cheng suggests that a 3 year study period is optimum, although up to 6 years of data can be used if no major site condition changes occurred at the location during the study period. In-use practices of several DOTs varied from 1 and 6 months to 4 years. Of 15 DOTs that were examined, the most common number of years of data used was 3 years.

Another issue of developing an intersection safety prioritization method is the inconsistency of defining the limits of an intersection. The HSM defines an intersection related crash as “a crash that occurs at the intersection itself or a crash that occurs on an intersection approach within 250 feet of the intersection and is related to the presence of the intersection.” Qin et al. defined a crash intersection as any crash located within 0.02 miles (105.6 feet) of each intersecting road. Virginia DOT defines an intersection crash as crashes occurring within 150 feet of an intersection.
Nebraska DOT defines their intersection hotspots as 0.1 miles (528 feet) in each direction. WILMAPCO, the metropolitan planning organization for New Castle County of Delaware, defines an intersection crash as occurring within an intersection’s “sphere of influence”. This “sphere of influence” varies at each location based on factors such as intersection width and acceleration lanes.

Most intersection safety evaluation procedures use crash frequency, crash rate, crash severity, or a combination of these performance measures. Thus, an evaluation procedure must also minimize the common biases and errors associated with crash frequency, crash rate and crash severity. Crash frequency is the number of crashes occurring at a particular location during a given study period. Using crash frequency alone can result in biases towards intersections with high traffic volume. Crash rate attempts to adjust for this bias by calculating the number of crashes per unit of exposure, usually volume. However, crash rates assume “a linear relationship between crash frequency and the measure of exposure, although research has proven the relationships are usually nonlinear”. Crash severity is the level of injury or property damage of a crash, but its sensitivity to weightings can create a bias towards intersections that observed a fatality. Additionally, whereas calculating crash rate and crash frequency is straightforward, there is no standard method of calculating crash severity.

Crash severity ranking methods categorize crashes based on the level of injury and property damage, and then normalize the crashes based on severity. The most commonly used scale of severity is the KABCO scale, where crashes are categorized into five main classes. A crash severity of K refers to a fatality, A to an incapacitating injury, B to a non-incapacitating injury, C to a possible injury, and O to property
The most common crash severity methods are the equivalent property damage only (EPDO) method and the value loss ranking method. The EPDO method assigns a weighting factor to each level of severity whereas the value loss ranking method assigns a dollar value. The EPDO method divides the cost of an accident that observes a fatality by the cost of a property damage only crash. This is done for each crash severity level to determine the weighting of each severity. For example, if the cost of an accident that observed a fatality is $5,800,000 and the cost of a property damage only accident was $4,000, this would result in a weighting of 1450 for a fatal accident and 1 for a PDO. The Federal Highway Administration (FHWA) lists the crash cost by crash severity as $5,800,000, $400,000, $80,000, $42,000, and $4,000 for fatality, incapacitating injury, non-incapacitating injury, possible injury, and PDO respectively. However, the cost of each crash by severity level changes across jurisdictions. The categorization of crashes, and the weightings and value losses associated with each category also changes considerably across jurisdictions.

The bias of crash severity performance measures causes possible dangerous intersections where a fatality did not occur to be overlooked due to heavily weighting fatalities. In an evaluation of Iowa DOT safety improvement candidate list process, Hallmark et al. found that Iowa’s process of value loss ranking is biased towards fatalities based on the dollar value given to them. The process appeared to be influenced by a single fatality at a location. Suggestions in the research to alleviate this issue include treating the first fatality as a severe injury, treating all fatalities as
major injuries, assigning values for major injuries that are closer to fatalities, and using a range of values for the various injury types rather than a dollar value.\textsuperscript{7}

In order to avoid some of these limitations, it is often recommended to group intersections by similar conditions, or reference populations. This can include by traffic control, number of approaches, cross-section, functional classification, area type, traffic volume ranges, or terrain.\textsuperscript{3} The reference populations should change with changes in intersection safety ranking purposes. For example, if evaluating the benefits of adding red-light-running cameras, the reference population would be only signalized intersections.\textsuperscript{3} This reference population could then be further divided based on functional classification, traffic volume ranges, number of approaches, etc.\textsuperscript{3}

Another traditional performance measure that is commonly used is the rate-quality-control (RQC) method. The RQC method uses a statistical test to determine whether the traffic accident rate for a particular intersection is abnormally high when compared with the rate for other locations with similar characteristics.\textsuperscript{11} The critical crash rate for a particular type of intersection can be calculated by the following equation:

\[
R_c = \lambda + k \frac{\sqrt{\lambda}}{m} + \frac{1}{2m} \quad \text{Equation 1}
\]

where

\( R_c \) = critical rate (crash per million entering vehicles)

\( \lambda \) = average crash rate for group of similar intersections (crashes per million entering vehicles)

\( m \) = number of vehicles (entering vehicles in millions)

\( k \) = probability factor determined by the level of statistical significance
The empirical Bayes (EB) method discussed later in this paper, however, is recommended as more appropriate to the calculation of expected crash experience at an intersection.\(^\text{10}\)

In addition to the average crash frequency, crash rate, and EPDO performance measures, there are 10 other performance measures discussed in the HSM. Several of these performance measures use a predictive method to estimate the expected average crash frequency for a specific site type which is then compared to observed data. The three components predictive models use are safety performance measures (SPFs), crash modification factors (CMFs), and a calibration factor. SPFs are statistical models used to estimate average crash frequency at a location with certain conditions.\(^\text{3}\) CMFs are a ratio of the effectiveness of a countermeasure implemented at a given site.\(^\text{3}\) A calibration factor is used to adjust the estimates to account for differences between locations and time periods.\(^\text{3}\)

The predictive method has many advantages and overcomes most of the biases associated with other performance measures. The predictive method addresses the RTM bias, reduces the dependence of crash data which is often unavailable or inadequate, and accounts for the nonlinear relationship between crash frequency and traffic volume.\(^\text{3}\) The main drawbacks of the predictive method are its complexity and that the estimates are only as accurate as the models.\(^\text{3}\) While the SPFs used in the HSM are considered to be among the best available, the expertise required is beyond the expertise of many jurisdictions and agencies.\(^\text{12}\) The predictive model that the HSM uses is the empirical Bayes (EB) method. The HSM defines it as a method that “combines observed crash frequency data for a given site with predicted crash frequency data from many similar sites to estimate its crash frequency”.
The other 10 performance measures described in the HSM are: relative severity index (RSI), critical crash rate, excess predicted average crash frequency using method of moments, level of service of safety (LOSS), excess predicted average crash frequency using SPFs, probability of specific crash types exceeding threshold proportion, excess proportions of specific crash types, expected average crash frequency with EB adjustments, EPDO average crash frequency with EB adjustment, and excess expected average crash frequency with EB adjustments. Each performance measure aims to address or eliminate one or more of the biases and limitations of traditional methods but may result in other limitations. The most commonly used techniques in practice are average annual crash frequency, crash rate, critical rate, EPDO crash frequency, excess predicted average crash frequency using SPFs, and excess expected average crash frequency with the EB adjustment.

RSI is a crash severity performance measure in which a financial crash cost is calculated for each crash type and then the total crash cost is calculated for each site. The average crash cost for each site is then compared to the overall crash cost for the site’s reference population. If a site is experiencing higher than average crash costs, then the site is highlighted for further analysis. Using RSI as a performance measure is straightforward and considers both collision type and crash severity. However, it does not account for the RTM bias, may over-represent locations with a small number of severe crashes, does not account for traffic volume, and can mistakenly prioritize low-volume, low-collision sites.

In the critical rate method, an observed crash rate at each location is compared to a calculated critical crash rate that is unique to each site. The critical crash rate is calculated using the average crash rate of a reference group associated with the site,
the traffic volume of the site, and a selected level of confidence. Sites that exceed the critical rate are then identified for further review. This measure statistically tests how different the crash rate is at a site when compared to a reference group. This measure’s advantages are that it reduces exaggerated effect of sites with low volumes, considers variance in crash data, and establishes a threshold for comparison. However, it does not account for the RTM bias.

The process of the excess predicted average crash frequency using method of moments is to adjust a site’s observed average crash frequency based on the difference in the crash data and average crash frequency for the site’s reference population. The adjusted observed average crash frequency for the site is compared to the average crash frequency for the reference population. This comparison yields each location’s potential for improvement. The advantages of this performance measure are that in establishes a threshold of predicted performance for a site, considers variance in crash data, allows sites of all types to be ranked in one list, and the method concepts are similar to EB methods. However, its disadvantages are that it does not account for RTM bias or traffic volume, sites may be identified because of unusually low frequency of non-target crash types, and sites near boundaries of reference populations may be over-emphasized.

LOSS, another performance measure, assesses sites by comparing the observed crash count to a predicted average crash frequency for the reference population. Each site is classified as one of four LOSS groupings by the degree of difference. LOSS is beneficial in that it considers variance in crash data, accounts for volume, and establishes a threshold for measuring potential to reduce crash frequency. However, it also does fully account for the RTM bias.
Excess predicted average crash frequency using SPFs can more accurately calculate the potential for safety improvement and acknowledging the complex, non-linear relationship between crash frequency and volume. However, this method is complex and does not fully account for the RTM bias. In this performance measure, the average observed crash frequency is compared to a predicted crash frequency. The predicted crash frequency is estimated by an SPF. If the observed is higher than the predicted, the site is identified for further analysis.

The probability of specific crash types exceeding threshold proportion performance measure prioritizes sites based on the probability that the true proportion of a particular crash type or severity is larger than the threshold proportion. Sites are grouped by different attributes, compared, and analyzed to calculate the threshold proportion within that reference population. This method can be used as a diagnostic tool, considers variance in data, and is not affected by the RTM bias. However, it does not account for traffic volume and some sites may be wrongly identified because of unusually low frequency of non-target crash types.

The excess proportions of specific crash types performance measure prioritizes high crash sites based on excess proportion, the difference between the observed proportion of a specific crash type or severity and the threshold proportion from the reference population. It also can be used as a diagnostic tool, considers variance in data, and is not affected by the RTM bias. However, it does not account for traffic volume and also, some sites may be wrongly identified because of unusually low frequency of non-target crash types.

The expected average crash frequency with EB adjustment performance measure weight the observed average crash frequency and a predicted crash frequency
from an SPF to calculate an expected average crash frequency.\textsuperscript{3} This method accounts for the RTM bias, but requires SPFs standardized for local characteristics making it complex and requiring a higher level of expertise to implement.\textsuperscript{3}

The EPDO average crash frequency with EB adjustment performance measure predicts crash severity using the EB method.\textsuperscript{3} The expected crashes by severity are then converted to EPDO crashes using the EPDO method previously described, with the values ranked.\textsuperscript{3} This method also accounts for the RTM bias and also considers crash severity, but it may over represent locations with a small number of severe crashes depending on weighting factors used.\textsuperscript{3}

The last performance measure discussed in the HSM is the excess expected average crash frequency with EB adjustment method. In this method, the observed average crash frequency and the predicted crash frequency from an SPF are weighted together using the EB method to calculate an expected average crash frequency.\textsuperscript{3} This expected average crash frequency is compared to the predicted, and the difference is the excess expected average crash frequency.\textsuperscript{3} If the excess is greater than zero, a site experiences more crashes than expected.\textsuperscript{3} This method accounts for the RTM bias, produces more stable and precise estimates of safety, and allows for estimates over time of expected crashes.\textsuperscript{13} However, it requires SPFs that are localized to the jurisdiction, making it a complex method.\textsuperscript{3}

Each performance measure serves a different purpose and can be used by different jurisdictions. Jurisdictions may use one of the performance measures or multiple, depending on what the objective is. Data availability and input, the RTM bias, and the performance threshold are the main considerations when selecting a performance measure.\textsuperscript{3}
Applying the EB method coupled with safety performance functions, called the EB-SPF method, can mitigate the RTM bias and many of the other limitations of traditional methods. It is viewed as the state of the practice in identifying hot spots. The results of research performed by Cheng illustrate that the EB technique significantly outperforms ranking and confidence interval techniques. The EB-SPF method is also a core component of the HSM, as discussed previously. However, many highway agencies are not able to implement this methodology because of a lack of resources, limited expertise, and the complex integration of various data sources.

When the EB-SPF method cannot be used, the question of the next best performance measure arises. In Lim and Kweon’s research, crash frequency, crash rate, RQC, and EPDO methods were applied to four-leg intersections with either a signal or two-way stop control. It was assumed that the EB-SPF method was the most accurate method of high-crash-risk intersection identification and was used as a basis of comparison for the four traditional methods. The research produced two key findings. First, if EB-SPF method is not available but location-based data are available, the crash frequency most accurately identified the top 1% of unsafe intersections and the RQC method was most accurate for the top 5% and 10% of unsafe intersections. Second, crash rate should not be used for identifying unsafe intersections. It performed poorly in all the study cases, inaccurately identified intersections, and performed worse than the crash frequency method. Despite the crash rate method trying to account for traffic volume biases, it does not function as intended in locating unsafe intersections.

In-practice methods used by state Departments of Transportation (DOTs) from several states were evaluated and summarized. The method used by a metropolitan
planning organization is also discussed as well as suggested methods presented in research. A majority of the DOTs use a method to initially identify high crash locations and then apply a composite ranking methodology to the identified locations. Composite ranking methodologies combine two or more performance measures by weighting each performance measure. Crash frequency, crash rate, and crash severity were most often included in the composite ranking method.

Connecticut DOT uses a program called Suggested List of Surveillance Study Sites (SLOSSS). This is a list of locations that experienced unusually high accident rates in a 3-year period. Each location with 15 or more accidents and whose accident rate is greater than its critical accident rate is included on SLOSSS. SLOSSS uses the ratio of the actual accident rate to the critical accident rate to rank locations. The objective of SLOSSS is to define locations which have the highest potential of accident reduction and provide a comprehensive quantity of highway safety improvements.

Delaware DOT identifies high risk locations as areas that have had at least 15 crashes during the past three years. DelDOT then compares the crash rate at each location to an appropriate critical rate and selects 30 intersections from this list for further analysis.

Florida DOT initially identifies hazardous locations as locations with at least 8 crashes in one year and a crash rate greater than or equal to the average crash rate for similar locations. Once the locations are identified, crash data is further analyzed for the intersection. Florida DOT uses a RQC method to find locations that experience an unusually high number of crashes. Intersections are grouped into reference populations and critical crash rates are calculated for each group. Locations are then
ranked by the ratio of their actual to critical crash rate. Florida DOT also uses citizen complaints, the Florida Highway Patrol, incident reports, fatal crash reports, and district personnel to identify further hazardous locations.\textsuperscript{7,10}

Illinois DOT applies the HSM’s methodology of using SPFs with the Empirical Bayes technique use for crash prediction.\textsuperscript{3}

Nebraska DOT uses the RQC method to identify high crash locations.\textsuperscript{7} Eight reference populations are defined by lane characteristics and by land use, and an average crash rate is calculated for each reference population.\textsuperscript{7} Locations with a crash rate greater than the computed average crash rate are identified and a severity index is then used to calculate a dollar loss per crash to each crash type.\textsuperscript{7} The cost of the crashes is totaled for each location and used to rank the intersections.\textsuperscript{7}

South Dakota DOT has a hazard elimination and safety (HES) program.\textsuperscript{7} Crash maps are created from a crash database and used to identify high crash locations over a three-year period.\textsuperscript{7} A crash rate is calculated from the number and type of crashes at each intersection.\textsuperscript{7} For every location with a crash rate above a specified level, the cost of crashes is compared to the cost of a selected countermeasure and the benefit/cost ratio must be 1:1 or greater for further analysis.\textsuperscript{7}

Washington State DOT only uses frequency to identify high crash locations. Locations are ranked by the total number of crashes over a three-year period.\textsuperscript{7}

Wisconsin DOT used both a statistical process and a comparison method to identify high crash locations.\textsuperscript{7} The statistical process uses algorithms that apply the theory of disproportionate crash rate modeling to identify locations with above average crash rates or severity.\textsuperscript{7} The comparison method compares the existing road
geometry to engineering design standards. Locations with inadequate roadway geometry are marked for further evaluation.

Washington DC DOT uses a composite ranking that includes crash frequency, crash severity, and crash rate. The crash frequency rank is assigned by ranking intersections from highest to lowest based on the total number of crashes that occurred at the location. The crash rate rank is assigned by ranking intersections based on the calculated crash rate. The crash rate equation is:

\[ R = \frac{A \times 1,000,000}{V \times 365} \]  

Equation 2

where

- \( R \) = Crash rate (crashes per Million Entering Vehicles)
- \( A \) = Average number of crashes at the intersection per year
- \( V \) = annual average daily traffic volume entering the intersection (veh/day)

DC DOT uses a crash severity ranking based off the crash costs of a fatality, injury, and PDO. All crashes that observed an injury were grouped in the same classification and fatalities are converted to injury in order to mitigate the random chance effect. The traffic accident costs are computed for each intersection to identify the severity levels. Once the severity levels are determined, the crash locations are ranked in descending order based on the severity index. The three ranks are then weighted and combined, shown by the following equation:

\[ Weighted Score = 0.25 FR + 0.25 RR + 0.5 SR \]  

Equation 3

where

- \( FR \) = Frequency Rank
- \( RR \) = Rate Rank
- \( SR \) = Severity Rank
The final rank is based on the weighted score, in which the highest score has the lowest rank.\textsuperscript{15}

Similar to Washington DC DOT, Georgia DOT, Idaho DOT, Iowa DOT, Minnesota DOT, North Dakota DOT, and Oregon DOT all use a composite ranking method that utilizes the three performance measures crash frequency, crash rate, and crash severity.\textsuperscript{7,10} The initial identification of high crash locations, the final weighting of the three performance measure, and the crash severity methodology are where differences occur amongst these agencies high crash location identification.

Idaho initially identifies high crash locations by determining locations with at least 4 crashes in a three year. From these locations, a crash frequency rank and crash rate rank are weighted at 25\% each and crash severity rank is weighted at 50\%.\textsuperscript{7,10} The severity rankings are based on injury costs calculated from five years of vehicle crash data.\textsuperscript{7,10} These costs are applied to each vehicle involved in each crash and the total at each location is used.\textsuperscript{7,10}

Iowa DOT uses a method called Safety Improvement Candidate List Process.\textsuperscript{10} It initially identifies locations that experience at least one fatal crash, four personal injury crashes, or eight total crashes over a five-year period.\textsuperscript{10}

Indiana DOT uses a Vehicle Crash Records System to identify hazardous intersections.\textsuperscript{10} It uses an electronic mapping method to locate crash locations using reference point data provided by crash reports and intersections with the highest crash

Minnesota DOT uses average crash costs from the four largest insurance carriers in Minnesota to determine the crash severity rank.\textsuperscript{7} They assign a value loss of $4,200, $29,000, $58,000, $270,000, and $540,000 to no injury, possible injury non-capacitating injury, incapacitating injury, and fatality respectively.\textsuperscript{7} However, to
mitigate biases as the result of heavily weighed fatal accidents, Minnesota DOT assigns the $540,000 cost only to the first two fatalities, and $3,400,000 for any additional fatalities.\textsuperscript{7,10}

North Dakota DOT produces a high crash list for both rural and urban areas. The crash severity rank is comprised of an EPDO method which gives a weighting of 1 for property damage only, 3 any injury, and 12 for fatality.\textsuperscript{7,10}

Oregon DOT’s composite ranking method is called the safety priority index system (SPIS). The crash frequency and crash rate are assigned a value between 0 and 25 determined by a logarithmic distribution of total crashes over a three-year period.\textsuperscript{7} The crash severity index is a value between 0 and 50 that is a linear distribution of severity scores of 100 for fatalities, 100 for severe injuries, 10 for moderate injuries, 10 for minor injuries, and 1 for PDO crashes.\textsuperscript{7}

Missouri DOT also uses a composite ranking methodology but combines different performance measures. It first identifies locations with at least 40 crashes in a three-year period, and then the EPDO values, EPDO rate, crash rate, and site evaluations are weighted to prioritize intersections with potential safety improvements.\textsuperscript{7} Missouri DOT uses a value loss of $4,000 for no injury, $21,100 for injury crashes, $1,900,000 for fatality for their crash severity value.\textsuperscript{7,10}

Ohio DOT uses a composite ranking system called the High Crash Location Identification System (HCLIS).\textsuperscript{7} The initial list of locations uses crash frequency, crash rate, delta-change, EPDO, EPDO rate, RSI, and crash density.\textsuperscript{7} A rank is then assigned for each of the seven categories and a hazard index is calculated by weighting the value from each of the seven rankings.\textsuperscript{7}
Maricopa Association of Governments (MAG), a metropolitan planning organization in Phoenix, AZ, uses a somewhat different composite ranking method that excludes crash rate and introduces a crash type performance measure.\textsuperscript{4,16} Scores for crash frequency (CF), crash severity (CS), and crash type (CT) are weighted and combined into an Intersection Safety Score (ISS).\textsuperscript{4,16} MAG recently removed crash rate from the composite ranking since crash frequency is included in the crash rate calculation thus skewing the ISS.\textsuperscript{16} Additionally, the crash rate requires volume data which is often unavailable for many areas. The CF score is the total number of crashes at an intersection divided by the highest number of crashes recorded for any intersection in the network.\textsuperscript{4} The CS score is a ratio between the crash severity value for a given intersection and the maximum crash severity value for the analysis area.\textsuperscript{4} The crash severity value is calculated using a traditional EPDO method for each intersection. The costs for an accident that observed a fatality, incapacitating injury, non-capacitating injury, possible injury, property damage only (PDO) are $5,800,000, $400,000, $80,000, $42,000, and $4,000 respectively.\textsuperscript{4} This resulted in a weighting of 1450 for a fatality crash, 100 for an incapacity injury crash, 20 for a non-incapacitating injury crash, 11 for possible injury crash, and 1 for PDO crash.\textsuperscript{4} The CT cost for each intersection is calculated by multiplying the number of units involved in a crash by the cost per vehicle/pedestrian/bicyclist for each type of collision manner.\textsuperscript{4} In this method, the average injury cost per vehicle was determined for vehicles in nine explored crash types. The CT score is then calculated by dividing the CT cost for the intersection by the maximum CT cost in the network.\textsuperscript{4} As can be seen in the following equation, the process assigns a weighting of 25\% to crash frequency and crash type, and 50\% to crash severity.
\[ ISS = \left( \frac{1}{4} \times \frac{CF}{\text{Max}(CF)} \right) + \left( \frac{1}{2} x \frac{CS}{\text{Max}(CS)} \right) + \left( \frac{1}{4} x \frac{CT}{\text{Max}(CT)} \right) \quad \text{Equation 4} \]

where

\[ \begin{align*}
    CF & = \text{Crash Frequency} \\
    CS & = \text{Crash Severity} \\
    CT & = \text{Crash Type}
\end{align*} \]

The intersections are then ranked by the final score from smallest value to largest.

Qin et al. also developed a composite ranking methodology that eliminates the need for volume data.\(^6\) This methodology considers crash frequency, crash severity, and crash type. The Final Score is calculated and intersections are ranked from highest to lowest. The equation used is:

\[ FS = 100 \left( \frac{1}{5} \times \frac{CF}{\text{Max}(CF)} \right) + \left( \frac{3}{5} x \frac{SI}{\text{Max}(SI)} \right) + \left( \frac{1}{5} x \frac{\text{TypeScore}}{\text{Max}(\text{TypeScore})} \right) \quad \text{Equation 5} \]

where

\[ \begin{align*}
    FS & = \text{the weighted score of scores} \\
    CF & = \text{Crash Frequency}, \text{total crash count over the study period} \\
    SI & = \text{Severity Index for study period} \\
    \text{TypeScore} & = \text{total score of crash type}
\end{align*} \]

The Severity Index in Qin et al.’s methodology was calculated using engineering judgment.\(^6\) The equation is:

\[ SI = 40N_k + 9N_a + 5N_b + 2N_c + N_{PDO} \quad \text{Equation 6} \]

where

\[ \begin{align*}
    N_k & = \text{Number of fatalities} \\
    N_a & = \text{Number of incapacitating injuries} \\
    N_b & = \text{Number of non-incapacitating injuries} \\
    N_c & = \text{Number of possible injuries} \\
    N_{PDO} & = \text{Number of Property Damage only injuries}
\end{align*} \]
The researchers tested different combinations of fatalities weights and evaluated the effect. It was determined that a number weight between 10 and 100 for fatality would lower the influence that fatalities have on ranking if using the 9, 5, 2 and 1 weightings for incapacitating injuries, non-incapacitating injuries, possible injuries, and property damage only respectively.\textsuperscript{6} Based on engineering judgment, they used a weighting of 40 for fatalities. The TypeScore is a method of evaluating crash type in the final score by measuring the cost associated with each crash type.\textsuperscript{6,9} It is the sum of the product of the number of involved vehicles with the approximate cost per vehicle, represented by the following equation:

\[
TypeCost = \sum Cost \times N_v
\]  

Equation 7

where \(Cost\) = cost of each crash type
\(N_v\) = Number of vehicles involved in the crash

The calculation of the crash costs was modeled after the methodology developed by Campbell and Knapp.\textsuperscript{9}

There is a large discrepancy among in-practice crash severity ranking methods throughout jurisdictions and agencies. Crash severity rankings use calculated EPDO weighting as well as calculated comprehensive injury costs, known as the value loss method. The research conducted by Campbell and Knapp determined that the EPDO methods showed more annual stability than the value loss ranking methods.\textsuperscript{9}

This literature review examined current intersection prioritization methods, identified issues and concerns, and assessed alternative methods. From the literature review, the methodology to be applied and analyzed was selected.
Chapter 3

METHODOLOGY

The following section describes the corridor selection, data preparation, and methodology. Once the corridors were selected and the data sets were organized, the ranking methodology was developed. The methodology is based on a composite ranking procedure that incorporates the use of three performance measures: crash frequency, crash severity, and crash type. This methodology was selected based on findings from the literature review and is discussed in further detail in this section.

Corridor Selection

The corridors chosen for analysis are US 40/US 13 and SR 72 in New Castle County, Delaware. These were chosen in order to best incorporate different characteristics of intersections. US 40 ranges from a four- to eight-lane, divided highway and SR 72 is a two-lane, undivided highway.

Data

Three years of crash data was accrued from Delaware Department of Transportation (DelDOT). The decision to use three years of data is based on the literature that supports the implication that a three year study period is optimum.\textsuperscript{2,6-8} The dataset thus included three years of data for each corridor, from 2011 to 2013 and included several fields of information. Each car crash was listed by a unique complaint number, used to identify crashes. Each crash also included information such as the report type, time of crash, primary contribution circumstance, location of
first impact, date of the crash, and longitude and latitude. For each crash, the number of related fatalities, incapacitating injuries, non-incapacitating injuries, possible injuries, and property damage only occurrences were also listed. This data was categorized in accordance with the KABCO scale.

Obtained from WILMAPCO was the file of intersection buffers for New Castle County, Delaware. The intersection buffers are what WILMAPCO uses to define the limits of an intersection. They use an intersection’s “sphere of influence” which varies at each location based on factors such as intersection width and acceleration lanes. All intersection crashes in this research are defined using WILMAPCO’s method.

**ArcGIS**

The six datasets, originally Excel Workbooks, were saved as CSV’s (Comma delimited) in order to plot on ArcGIS. The .csv files were then added onto the data frame in ArcGIS and the crashes were plotted using the “Display XY Data” feature. ArcGIS recognized the latitude and longitude factors and the crashes were plotted in the Geographic Coordinate System of North American 1983. This process was repeated for each dataset. The intersection buffer file obtained from WILMAPCO was also added to the data frame. Then, the plotted car crashes were selected by location, with the intersection buffers used as the source layer and the crash data of each specific dataset used as the target layer. This was to extract crashes located only within the intersection buffers. The crashes were then made into shapefiles by exporting the data. This process was repeated for each dataset. Once all the datasets were exported into shapefiles, the shapefiles were combined into one shapefile, using
the Merge feature in ArcGIS. Thus a final shapefile included all crashes occurring from 2011 to 2013 within an intersection buffer on corridors US 40/US 13 and SR 72.

The original data did not include some information that was required for analysis, such as intersection names or intersection type (signalized or non-signalized). The intersection name was necessary in order to look at crashes by intersection and intersection type was necessary for comparison details in the final analysis. In order to add the needed information into the dataset, the required fields were added to the attribute table of the shapefile. The fields included intersection name and type of intersection code. A ‘1’ was arbitrarily assigned in the field of type of intersection to recognize signalized intersections, and a ‘2’ was assigned for non-signalized intersections. In editor mode, the crashes were then selected within each specific intersection buffer and a corresponding name and type of intersection code was added in the appropriate field. The name of the intersection was based on road names in Google Earth as well as using a basemap, World Street Map, in ArcGIS. The type of intersection was also determined using Google Earth. Flashing lights and railroad crossings were considered as signalized intersections. WILMAPCO’s intersection buffers were used as the final determination of a crash’s designated intersection location.

Once all the intersection information was inputted into the shapefile, the data was extracted from ArcGIS and put into an Excel file. This was done by copying all the information in the attribute table in ArcGIS and pasting into a new Excel file. The dataset includes all intersection crashes on US 40/US 13 and SR 72 from 2011, 2012, and 2013.
Based on the extensive literature review, the composite ranking method was chosen as the methodology applied to the dataset to identify unsafe intersections. Although predictive methods that use safety performance measures, crash modification factors, and a calibration factor are considered to be the most accurate methodology available, the lack of resources, limited statistical expertise and complicated integration of multiple data sources prevented its implementation. The composite ranking method combines three performance measures: crash frequency, crash type, and crash severity. This methodology is explained in detail in this section using the intersection of US 13 & Boulden Blvd as an example.

Applying the composite ranking method, a Final Score and a Final Rank was calculated for each of the intersections. The Final Score combines a crash frequency rank, a crash severity rank, and a crash type rank that is calculated for each of the intersections. The ranks are weighted at 0.25 for crash frequency and crash type and 0.5 for crash severity in the calculation of the final score. This weighting was chosen because it is the most commonly used weighting for composite ranking determined by the literature review. The intersections were then sorted by the final score, from smallest value to largest value. The intersection with the lowest value was then ranked 1, to designate it the most unsafe intersection. The final Top 25 Intersections were the intersections ranked 1-25.

It is important to discuss the choice to use a crash type rank instead of a crash rate rank. As discussed in the literature review, a crash rate rank is often used in composite ranking (DC DOT, Idaho DOT, Illinois DOT, North Dakota DOT, etc.), but as Kweon et al. found in their research, using crash rate was not only ineffective, but resulted in erroneous location identifications. Lack of accurate volume data is
another reason crash rate was not used. Maricopa Association of Governments (MAG), Qin et al., and Knapp et al. all use a crash type cost rank instead of crash rank for similar reasons.

The first step in the calculation was extracting only the necessary information from the dataset, which was done using pivot tables. The first pivot table extracted the sum of the values of K, A, B, C, and O (number of fatalities, incapacitating injuries, non-incapacitating injuries, possible injuries, and property damage only occurrences respectively) as well as count the number of complaints for each intersection (crash frequency). The intersection name was used as the row label while the values were used as the column label. For example, 137 crashes occurred from 2011 to 2013 within the intersection of US 13 & Boulden Blvd that resulted in 2 fatalities (K), 0 incapacitating injuries (A), 16 non-incapacitating injuries (B), 18 possible injuries (C), and 272 property damage only (O). This can be seen in the following table:

Table 1   Example KABCO Values

<table>
<thead>
<tr>
<th>Intersection Name</th>
<th>Sum of K</th>
<th>Sum of A</th>
<th>Sum of B</th>
<th>Sum of C</th>
<th>Sum of O</th>
<th>Total Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 13 &amp; Boulden Blvd</td>
<td>2</td>
<td>0</td>
<td>16</td>
<td>18</td>
<td>272</td>
<td>137</td>
</tr>
</tbody>
</table>

Another pivot table was used to extract information about the manner of impact of each vehicle in all the crashes associated with a specific intersection. Here, the manner impact code was used as the column labels while the intersection name was used as the row label. The count of manner of impact was entered in the values input to determine the number of each manner of collision. For example, of the 137 crashes that occurred within the intersection of US 13 & Boulden Blvd, 0 were a
collision between two vehicles (00), 84 were front to rear (01), 2 were front to front (02), 24 were angle (03), 20 were sideswipe same direction (04), 1 was sideswipe opposite direction (05), 0 were rear to side (06), 0 were rear to rear (07), 5 were unknown (88), and 1 was other (99). This information can be summed up in the following table:

Table 2  
Example Manner of Impact Values

<table>
<thead>
<tr>
<th>Intersection Name</th>
<th>00</th>
<th>01</th>
<th>02</th>
<th>03</th>
<th>04</th>
<th>05</th>
<th>06</th>
<th>07</th>
<th>88</th>
<th>99</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 13 &amp; Boulden Blvd</td>
<td>0</td>
<td>84</td>
<td>2</td>
<td>24</td>
<td>20</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

The count of complaints in the first pivot table was used to assign a crash frequency rank. The crashes were sorted by total crashes, from largest value to smallest value. The intersections were assigned a rank, with the largest value of crash frequency being ranked 1 and so on. For example, US 13 & Boulden Blvd had a total of 137 crash crashes occur within the intersection. Four intersections had a higher crash frequency, giving US 13 & Boulden Blvd a rank of 5.

The sum of each of the KABCO values was used to determine crash severity and apply a crash severity ranking. As discussed in the literature review, there are several options in determining the weight of each level of crash severity. In this analysis, four different combinations of weights were applied to the crashes for comparison reasons. The four combinations were labeled A, B, C, and D. Combination A is a combination used and analyzed by Qin et al. This combination was 40, 9, 5, 2, and 1 for categories K, A, B, C, and O respectively. Engineering judgement was used to determine this combination. The results of Qin’s research
determined that this combination, or one similar, is effective in reducing the influence fatalities have on ranking.\textsuperscript{6} The second combination was 1450, 100, 20, 11, and 1 which was calculated using the common EPDO method. The cost of each crash severity category is divided by the cost of a property damage only crash to determine the weighting. The FHWA recognizes the costs for an accident that observed a fatality, incapacitating injury, non-capacitating injury, possible injury, and property damage only as $5,800,000, $400,000, $80,000, $42,000, and $4,000 respectively. Combination C used the same weightings as combination B, but the first fatality was treated as an incapacitating injury to lessen the bias of K. This was done based on the suggestions from a safety workshop held at the Center for Transportation Research and Education.\textsuperscript{7} Combination D also used the same weights as combination B, but the first two fatalities were treated as incapacitating injuries. The following summarizes the crash severity combinations:

\begin{itemize}
\item[A.] $40K + 9A + 5B + 2C + O$
\item[B.] $1450K + 100A + 20B + 11C + O$
\item[C.] $1450(K-1) + 100(A+1) + 20B + 11C + O$
\item[D.] $1450(K-2) + 100(A+2) + 20B + 11C + O$
\end{itemize}

For example, applying the weightings of combination A to intersection US 13 & Boulden Blvd the calculation of the Crash Severity Score (CSS) by method A would be as follows:

$$CSS_A = 40(2) + 9(0) + 5(16) + 2(18) + 272 = 468 \quad \text{Equation 8}$$

Applying the other three severity combinations to the crashes occurring within US 13 & Boulden Blvd, the crash severity scores resulted in 3690, 2340, 990 for crash severity combinations B, C, and D respectively.
\[ CSS_B = 1450(2) + 100(0) + 20(16) + 11(18) + 272 = 3690 \]
Equation 9

\[ CSS_C = 1450(2 - 1) + 100(0 + 1) + 20(16) + 11(18) + 272 = 2340 \]
Equation 10

\[ CSS_D = 1450(2 - 2) + 100(0 + 2) + 20(16) + 11(18) + 272 = 990 \]
Equation 11

After each crash severity combination was applied, the crashes were sorted by the score, from the largest value to the smallest value. The intersections were then assigned a rank, with the largest value beginning with rank 1 and so on. Thus, each intersection had four crash severity ranks associated with it. For example, US 13 & Boulden Blvd had a rank of 2, 1, 1, and 6 for crash severity combinations A, B, C, and D respectively.

From the recommendations of the research of Qin et al. and Knapp et al., as well as using MAG’s method, a crash cost rank was applied to the data. Again, a pivot table was used to extract information regarding the manner of impact. Each crash had a manner impact code associated with it. For each intersection, the number of each type of accident was tallied. Then a cost associated with each crash type was multiplied by the number of each type of accident. The following equation summarizes the intersection crash cost:

\[ \text{Crash Type Cost} = \sum \text{Cost} \times N_c \]
Equation 12

where
\[ \text{Cost} = \text{Cost of crash type} \]
\[ N_c = \text{Number of crashes} \]

The crash cost of each crash type used by MAG’s Network Screening Methodology for Intersections was applied. It is important to note that these costs were averaged from Arizona’s crash dataset. The crash cost associated with each accident was unavailable for the Delaware data set, thus localized crash costs could not be
calculated. Qin et al. and Knapp et al. provided crash cost data in their research that was localized for their region; however, the crash types varied from Delaware’s. MAG’s crash type was most similar to Delaware’s, thus numbers from the MAG screening process was used. The manner of impact and the related crash cost used in this dataset are presented in the following table:

Table 3  Manner of Impact Costs

<table>
<thead>
<tr>
<th>Manner of Impact Code</th>
<th>Manner of Impact</th>
<th>Average Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Not a collision between two vehicles</td>
<td>$59,428</td>
</tr>
<tr>
<td></td>
<td>(Single vehicle crash)</td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>Front to rear</td>
<td>$12,163</td>
</tr>
<tr>
<td>02</td>
<td>Front to Front</td>
<td>$81,100</td>
</tr>
<tr>
<td>03</td>
<td>Angle</td>
<td>$34,477</td>
</tr>
<tr>
<td>04</td>
<td>Sideswipe, same direction</td>
<td>$8,817</td>
</tr>
<tr>
<td>05</td>
<td>Sideswipe, opposite direction</td>
<td>$17,141</td>
</tr>
<tr>
<td>06</td>
<td>Rear to side</td>
<td>$3,151</td>
</tr>
<tr>
<td>07</td>
<td>Rear to rear</td>
<td>$3,151</td>
</tr>
<tr>
<td>99</td>
<td>Other &amp; Unknown</td>
<td>$38,868</td>
</tr>
</tbody>
</table>

These numbers follow MAG’s numbers closely, with some alterations. MAG had two differences in the impact manner categories. Angle was separated into two categories: Angle right angle, and angle opposite direction. The costs of each of these types of collisions were averaged and used for angle cost for Delaware, since Delaware groups all angle collisions together. The other difference was that MAG did not have a rear to rear category, so the crash cost for rear to side was used for rear to rear. MAG’s original costs for each impact manner is summarized in the following table:
Table 4  MAG’s Collision Manner Costs

<table>
<thead>
<tr>
<th>Crash Type/Collision Manner</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear End</td>
<td>$12,163</td>
</tr>
<tr>
<td>Angle Right Angle</td>
<td>$34,031</td>
</tr>
<tr>
<td>Single</td>
<td>$59,428</td>
</tr>
<tr>
<td>Side Swipe Same Direction</td>
<td>$8,817</td>
</tr>
<tr>
<td>Angle Opposite Direction</td>
<td>$34,923</td>
</tr>
<tr>
<td>Rear to Side</td>
<td>$3,151</td>
</tr>
<tr>
<td>Side Swipe Opposite Direction</td>
<td>$17,141</td>
</tr>
<tr>
<td>Head On</td>
<td>$81,100</td>
</tr>
<tr>
<td>Other &amp; Unknown</td>
<td>$38,868</td>
</tr>
</tbody>
</table>

The crash cost was applied to each accident for each intersection and a total cost for each intersection was calculated. The calculation for the example of US 13 & Boulden Blvd is:

\[
\text{Crash Cost} = 59,428(0) + 12,163(84) + 81,100(2) + 34,477(24) + 8,817(20) + 17,141(1) + 3,151(0) + 3,151(0) + 38,868(6) = 2,438,029
\]

Equation 13

The data was sorted by the crash cost total, from largest values to smallest values. The intersections were then assigned a rank, with the highest crash cost beginning with rank 1 and so on. US 13 & Boulden Blvd had a rank of 5 for crash type.

There were 6 ranks calculated for each intersection: crash frequency rank, 4 crash severity ranks (one for each of the 4 combinations), and a crash type rank. The Final Score had a weighting of 0.25 for crash frequency, 0.5 for crash severity, and 0.25 for crash type. The following equation summarizes the Final Score calculation:

\[
\text{Final Score} = 0.25\text{CFR} + 0.5\text{CSR} + 0.5\text{CCR}
\]

Equation 14

where

- CFR = Crash Frequency Rank
- CSR = Crash Severity Rank
- CCR = Crash Cost Rank
The Final Score was calculated for each of the four crash severity ranks, in combination with the crash frequency rank and crash type cost rank. US 13 & Boulden Blvd had a rank of 5 for crash frequency and 5 for crash type cost. It ranked 2nd, 1st, 1st, and 6th for crash severity combinations A, B, C, and D respectively. An example of the Final Score (FS) calculation for the intersection of US 13 & Boulden Blvd using crash severity combination A is as follows:

\[ \text{FS}_A = 0.25(5) + 0.5(2) + 0.5(5) = 3.5 \]  \hspace{1cm} \text{Equation 15}

The Final Scores of the intersections were then sorted from smallest value to largest value and a Final rank was assigned to the intersections, with the smallest value beginning with 1. US 13 & Boulden Blvd had a final rank of 4, 1, 1, and 6 using crash severity combinations A, B, C, and D respectively. The intersections ranking 25 or below for each crash severity combination were then pulled to determine the top 25 most unsafe intersections.
Chapter 4

RESULTS

The methodology produced a list of the analyzed intersections, ranked from most unsafe to safest. The results focused on the top 25 most unsafe intersections. A map of the top 25 most unsafe intersections by crash severity method A can be found in Appendix A. The following section describes the results from the application of the developed methodology.

Top 25 Most Unsafe Intersections

The Top 25 most unsafe intersections were determined for each crash severity combination. These intersections were identified by taking the top 25 highest ranked intersections in the final rankings. The only difference in the calculation of the final ranks was the crash severity rankings. Each crash severity combination had its own final rank and these ranks were compared to the final rank by crash severity combination A. There was not much variation of the intersections in each of the final top 25; however the specific rankings of the intersections had some variability when looking at the different combinations. The list can be found in Appendix B.

When comparing the other final ranks to final rank by crash severity combination A, overall there was not much variation in the top 25. Among the three combinations, there were at most three intersections that were dissimilar. There was the most variation in final rank B and the least with final rank D. Final rank A included US 13 & Roosevelt Ave, SR 72 & SR 7, and US 40 & Pleasant Valley Rd in
its top 25, whereas final rank B did not. There was less variation in final rank C, with
two intersections of those intersections (US 13 & Roosevelt Ave and US 40 &
Pleasant Valley Rd) in final rank A that were not in its top 25. The least variation was
in final rank D, where only one difference occurred. This was also intersection US 40
&Pleasant Valley Rd.

SR 72 & SR 4 ranked highest when using crash severity combination A, US 13
&Boulden Dr. ranked highest when using crash severity combination B and C, and
US 40 & SR 72 ranked highest when using crash severity combination D. US 13 &
SR 273 and US 40 & US 301 ranked in the top 4 for each of the 4 top 25 lists.

Non-signalized Intersections

One non-signalized intersection made the top 25 most unsafe intersection lists.
US 13 & E Franklin Ave made the top 25 list for each of the four crash severity
combinations, ranking 22nd, 18th, 16th, and 16th for crash severity combinations A, B,
C, and D respectively. US 13 & E Franklin Ave is a separate intersection than US 13
&W Franklin Ave, which is adjacent to E Franklin Ave, separated by the median
between US 13 northbound and US 13 southbound. If these intersections were
combined as one intersection in the calculations and comparisons, this intersection
would rank even higher.
Chapter 5

ANALYSIS

The following analyzes the results of the methodology. An overall examination of the top 25 most unsafe intersections, the crash severity fatality bias, and a look at why non-signalized intersections ranked high on the most unsafe list is discussed in this section. Additionally, the intersection limits, composite ranking, and limitations of the methodology are also analyzed in this section.

Top 25 Most Unsafe Intersections

When looking at the list of the top 25 most unsafe intersections, none seem out of place. Although a majority of the top 25 most unsafe intersections were on US 40/13, several intersections on SR 72 ranked throughout the top 25 as well. More of the intersections that were analyzed are on US 40/13, so more intersections from this corridor ranking in the top 25 can be expected. With intersections on SR 72 ranking throughout the top 25 most unsafe intersections, it is a good indication that the results include unsafe intersections that are inherently different. Not all the intersections were exactly the same; characteristics of the intersections included divided highway and undivided highway, three-way and four-way intersections, signalized and non-signalized, etc. This inclusiveness can be an argument that the methodology was effective in reducing certain biases, such as biases towards high volume areas.
Crash Severity Bias

A key issue to address when using crash severity as a performance measure for identifying unsafe intersections was the fatality bias. Crash severity weightings often create a bias towards intersections that observed a fatality, which can cause possible dangerous intersections where a fatality did not occur to be overlooked. All combinations produced relatively similar lists, with slight variation of which intersections made the top 25 most unsafe intersections list. If analyzed closely, crash severity combination B had a somewhat apparent fatality bias, while combination C slightly overcame this bias, and combination D seemed to understate fatalities. Combination A was most consistent in crash severity rankings and balanced the significance of fatalities with other severity levels.

With differences occurring in the higher rankings on the list when comparing the final rank of B to the other final ranks, the bias put on intersections that experienced a fatality is evident. Crash severity combinations B and C produced the most similar results. This could be due to the fact that very few intersections observed a fatality. The highest number of fatalities observed at any intersection was two. At the locations that observed one fatality, there was slight variability in rankings between Combination B and C, while intersections that observed two fatalities saw a notable difference in rankings between Combination B/C and Combination D. For intersections that did not observe a fatality, which was the majority, the rankings were similar for all combinations.

We can see where the fatality bias occurs when analyzing intersections that observed the most fatalities. US 13 & Boulden Blvd observed two fatalities between 2011 and 2013, and it is ranked first for combinations B and C. Conversely, it is ranked more modestly at 4th and 6th for Combinations A and D respectively. Taking a
look at another intersection that observed two fatalities, SR 72 & Porter Rd, the fatality bias is more obvious. SR 72 & Porter ranked 20\textsuperscript{th} in crash frequency, 21\textsuperscript{st} in crash type, but 3\textsuperscript{rd} for crash severity combinations B and C. The inconsistency of rankings may be an indication of the heavy influence of fatalities. SR 72 & Porter Rd ranked more characteristically at 19\textsuperscript{th} when applying the crash severity combination A, and 23\textsuperscript{rd} when using combination D. Where multiple fatalities occurred, combination D consistently ranked intersections lower than the other three methods. Combination D may under-rank intersections that observed fatalities.

Although combination A produced the most consistent results among the rankings, the top 25 lists produced generally the same intersections. The most unsafe intersections do not change significantly regardless of which combination is used.

**Non-signalized Intersections**

It is important to note one non-signalized intersection, US 13 & E Franklin Avenue, ranked in the top 25 most unsafe intersections. It is useful to investigate why this intersection made the top 25 list. At first glance, it is apparent it was not affected by the fatality bias since it did not observe a fatality. However, it experienced a relatively high number of incapacitating and non-incapacitating injuries. When looking at the physical properties of the intersection, we see that US 13 & Franklin Ave is a six-lane highway in a densely residential area. These factors could explain why it was ranked in the top 25 most unsafe intersections.
When producing a network screening methodology for calculating crash performance of intersections, defining the limits of intersections is a key issue. There is no standard procedure for separating link crashes from intersection crashes. In this analysis, this issue was resolved by using WILMAPCO’s intersection buffers to define the limits of intersections along US 40/US 13 and SR 72. Engineering judgment was used when determining the “spheres of influence” of the intersections, so the limits of the intersections varied from intersection to intersection. Overall, the intersection buffers appeared valid, encompassing all crashes within the intersection without including non-intersection crashes. Only one intersection buffer could be disputed; Eden Circle was broken up into two intersection buffers, although it is one signalized intersection. Additionally, on US 40 and US 13, where the median was large, eastbound and westbound was separate intersections. (US 13 & Franklin Ave, US 13
& Jackson Ave, US 13 & Monroe Ave, US 13 & Parkway Plaza, US 13 & Van Burren Ave, US 40 & Glasgow Ave, US 40 & Peoples Plaza). Most of them are non-signalized intersections, but combining both movements of traffic may have produced different results.

**Composite Ranking**

Using a composite ranking method was most inclusive of available data without needing the expertise for a predictive method. Since it was successful for several agencies as determined in the literature review stage, it seemed most appropriate to use for this analysis. The combination of the three rankings reduced common biases and errors associated with the sole use of each. Consistency among the three rankings may be an argument for accuracy of each of the rankings. Crash frequency and crash type are simple to calculate when given all data but the lack of a standard procedure for crash severity causes complications. A composite rank method reduces the influence of crash severity by balancing it with a crash type and crash frequency rank. This method can also point out inconsistencies. For example, US 40 & LaGrange Ave ranked 40th and 37th for crash frequency and crash type cost respectively, but 3rd for crash severity combinations B and C. This inconsistency of rankings shows that crash severity combination B and C may place too much influence on fatalities. Crash severity combination A ranked it more modestly at 19 and crash severity combination D ranked it 23rd. While it still ranked higher than the other two ranks, it is helpful to see how crash severity plays a role in the total ranking of the intersections, without overstating the influence of fatalities. The composite ranking method keeps a balance among the three performance measures.
The final rank weighting used in this analysis was chosen because it is the most commonly used weighting as determined by the literature review. As discussed in Knapp et al., changes in the weightings of final ranks in composite method had minor influence on the final rankings, thus different weightings for the composite rank were not analyzed.  

**Limitations**

As discussed in the literature review, there are many limitations of observed crash data due to several factors such as randomness and change, imperfect recording of reports, and lack of data. The limitations of the data can be impairing when producing an intersection safety evaluation procedure and thus the limitations were addressed wherever possible. The regression-to-mean (RTM) bias is a major limitation of data due to randomness and change. To address this issue, the optimum number of years of data was used, determined by the literature review. Thus, the procedure needs to be repeated every three years. Lack of accurate volume data and crash cost data were also setbacks in the methodology but were addressed as best as possible. Since there is a lack of accurate volume data on the roads that were analyzed, it was decided to avoid using crash rate as a performance measure. Due to the lack of crash cost data, average crash costs were borrowed from MAG, an MPO in the Phoenix, Arizona metropolitan area. However, as always, crash patterns vary from region to region and the Phoenix metropolitan region observes differences in traffic patterns, roadways, and other characteristics from New Castle County. Using crash cost data specific to the Delaware region would increase the accuracy of crash cost rankings.
Additionally, there is no standard procedure for defining the limits of intersections, and thus the results are dependent on the accuracy of the intersection buffers. The intersection buffers created by WILMAPCO provide a more accurate definition of an intersection than procedures that simply include all crashes within a specific distance from the intersection. WILMAPCO’s intersection buffers take into consideration the intrinsic properties of each intersection. However, the accuracy of the method is dependent on the accuracy of the buffers.

Where the limitations of the data could not be addressed, the accuracy of the results is inherently dependent on the reliability of the data used in the study.
Chapter 6

CONCLUSION AND RECOMMENDATIONS

This paper presented the development and analysis of an intersection safety prioritization methodology using crash data from 2011 to 2013 on corridors US 40/US 13 and SR 72 in New Castle County, Delaware. The ranking methodology uses a composite ranking approach that includes three performance measures: crash frequency, crash severity, and crash type.

Crash severity was calculated using four different combinations. The main difference between the combinations was one weighting was determined through engineering judgment while the other three were based on the EPDO method. The combinations also analyzed the influence fatalities have on rankings. While crash severity calculations using Combination A are preferable, the top 25 most unsafe intersections do not change significantly regardless of which combination is used.

There are several recommendations for further review. It is recommended that if accurate crash cost data becomes available that it be applied in this methodology. This would increase the accuracy of the crash type rankings. Additionally, if the resources and expertise are available, the empirical Bayes (EB) method coupled with safety performance functions (SPFs), called the EB-SPF method, be used over this method. The EB-SPF is widely acknowledged as the most accurate safety prioritization method. Lastly, it is recommended to expand the study area to allow for further comparisons on the accuracy of this methodology.
REFERENCES


Appendix A

MAP OF TOP 25 MOST UNSAFE INTERSECTIONS BY CRASH SEVERITY
METHOD A
## Appendix B

### TOP 25 MOST UNSAFE INTERSECTIONS

<table>
<thead>
<tr>
<th>Intersection Name</th>
<th>Frequency Rank</th>
<th>Cost Rank</th>
<th>Severity Rank</th>
<th>Final Rank by Method A</th>
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<td>1</td>
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