An Extension of the Empirical Bayes Approach for: Measuring Safety at Unsignalized Intersections and Establishing a Process for Determining Traffic Signal Safety Warrants

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16. Abstract

In order to estimate how some countermeasure or treatment might affect the safety of an entity it is necessary that we have the capacity to:

- Estimate what the expected number of consequences (fatality, injury and PDO collisions) would have been in the 'after' period had the treatment not been implemented, and
- Compare this estimate with what the expected level of safety would be in the 'after' period if the treatment had been implemented.

For example, in the case of unsignalized intersections, we would like to be able to measure how the safety of a particular unsignalized intersection would be changed, and by how much, if it were signalized. The capacity to measure this safety differential would provide the information needed in the decision-making process for determining whether the installation of a traffic signal is warranted (from a safety perspective) at a particular unsignalized intersection.

This report outlines a methodology for measuring the safety of unsignalized and signalized intersections and comparing their relative levels of safety, and proposes an objective, quantitative process for determining whether or not a traffic signal is warranted at an unsignalized intersection.

A detailed description is provided of a state-of-the-art scientifically based methodology for measuring the differential in safety levels expected between signalization and non-signalization for a particular unsignalized intersection over a 20-year evaluation period. The methodology is based on an extension of the Empirical Bayes Approach coupled with proven statistical modeling procedures for estimating accurate and unbiased safety impacts of signalizing an unsignalized intersection.

A comprehensive process including all phases and tasks for the design and development of a modeling system is proposed. This system, once implemented, would provide the necessary information for making rationale decisions on whether a traffic signal is warranted at an unsignalized intersection or not.

We therefore recommend that the above methodology and process be considered for establishing a policy and procedures for traffic signal safety warrants. This would ensure that a system for using traffic signal safety warrants would be based on the 'need' according to the actual safety performance of the particular unsignalized intersection being considered for signalization.

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16. **Résumé**

Afin d'estimer certaines contre-mesures et interventions pouvant influer sur le niveau de sécurité d'une entité (p. ex. un point de la route, une intersection), les auteurs doivent être en mesure de :

- estimer le nombre prévu de conséquences (décès, blessures et dommages matériels seulement [DMS]) durant la période « subséquente » en cas d'absence d'une ou de plusieurs interventions, et
- comparer cette estimation avec le niveau de sécurité anticipé durant la période « subséquente » à une ou plusieurs interventions.

Par exemple, à une intersection sans signalisation (ISS) donnée, les auteurs voudraient pouvoir mesurer de quelle façon et dans quelle mesure le niveau de sécurité de cette intersection pourrait être modifié si elle devenait une intersection avec signalisation (IAS). La possibilité de mesurer cet écart de niveau de sécurité permettrait la diffusion de l'information nécessaire à la prise de décisions pour déterminer la pertinence d'installer un dispositif de contrôle de la circulation (du point de vue de la sécurité) à une ISS.

Le présent rapport décrit les grandes lignes pour mesurer et comparer le niveau de sécurité des ISS et IAS. De plus, il propose un processus objectif et quantitatif ayant pour objet d'établir la pertinence d'installer un dispositif de contrôle de la circulation à une ISS.

En outre, il fournit une description détaillée de la méthodologie scientifique de pointe pour mesurer la différentielle du niveau de sécurité des IAS et ISS sur une période d'évaluation de 20 ans. Cette méthodologie repose sur une extension de l'approche empirique de Bayes (AEB) et de procédures de modélisation statistiques éprouvées visant à évaluer les répercussions précises et non biaisées relatives à une ISS.

Le rapport propose aussi un processus global comprenant toutes les phases et tâches nécessaires à l'élaboration d'un système de modélisation. Une fois implanté, ce système fournirait les renseignements nécessaires à la prise de décisions pour la conception et l'élaboration d'un système de modélisation. Le système en question, une fois mis en œuvre, fournirait l'information requise pour la prise de décisions logiques sur la pertinence d'installer un dispositif de contrôle de la circulation quelconque à une ISS.

Par conséquent, les auteurs recommandent que la méthodologie et le processus indiqués ci-dessus soient pris en considération dans l'établissement d'une politique et de procédures de détermination de prescriptions de sécurité des dispositifs de contrôle de la circulation. Ainsi il serait possible d'établir un système fondé sur le besoin de doter d'un dispositif de contrôle de la circulation une ISS, et ce, à la lumière de ses caractéristiques réelles de rendement au plan de la sécurité.

17. Mots clés Contrôle de la circulation, feux de circulation, intersection, analyse Bayesienne, méthodologie		**18. Diffusion**		
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- Compare this estimate with what the expected level of safety would be in the 'after' period if the treatment had been implemented.

For example, in the case of unsignalized intersections, we would like to be able to measure how the safety of a particular unsignalized intersection would be changed, and by how much, if it were signalized. The capacity to measure this safety differential would provide the information needed in the decision-making process for determining whether the installation of a traffic signal is warranted (from a safety perspective) at a particular unsignalized intersection.

This report outlines a methodology for measuring the safety of unsignalized and signalized intersections and comparing their relative levels of safety, and proposes an objective, quantitative process for determining whether or not a traffic signal is warranted at an unsignalized intersection.

A detailed description is provided of a state-of-the-art scientifically based methodology for measuring the differential in safety levels expected between signalization and non-signalization for a particular unsignalized intersection over a 20-year evaluation period. The methodology is based on an extension of the Empirical Bayes Approach coupled with proven statistical modeling procedures for estimating accurate and unbiased safety impacts of signalizing an unsignalized intersection.

A comprehensive process including all phases and tasks for the design and development of a modeling system is proposed. This system, once implemented, would provide the necessary information for making rationale decisions on whether a traffic signal is warranted at an unsignalized intersection or not.

Considerable thought and effort has gone into the design and development of the approach offered in this position paper. We believe that it offers great potential.

We therefore recommend that the above methodology and process be considered for establishing a policy and procedures for traffic signal safety warrants. This would ensure that a system for using traffic signal safety warrants would be based on the 'need' according to the actual safety performance of the particular unsignalized intersection being considered for signalization.

In order to effectively pursue the solutions offered in this position paper the following is proposed.

- The approach and processes presented be critically reviewed.

- If deemed acceptable, a study should be implemented which would include:

  - The full design and development of a computerized model to implement the methods and procedures detailed.

  - The identification of a suitable jurisdiction (e.g., Province, Region) for conducting pilot study case studies.

  - The development/documentation of the required data bases.

  - The application of the process to specific case study evaluations of unsignalized intersections in a selected jurisdiction.

1 INTRODUCTION

In order to estimate how some countermeasure or treatment might affect the safety of an entity (e.g., road location, intersection) it is necessary that we have the capacity to:

- Estimate what the expected number of consequences (fatality, injury and PDO collisions) would have been in the 'after' period had the treatment not been implemented, and

- Compare this estimate with what the expected level of safety would be in the 'after' period if the treatment had been implemented.

For example, in the case of unsignalized intersections, we would like to be able to measure how the safety of a particular unsignalized intersection would be changed, and by how much, if it were signalized. The capacity to measure this safety differential would provide the information needed in the decision-making process for determining whether the installation of a traffic signal is warranted (from a safety perspective) at a particular unsignalized intersection.

This report outlines a methodology for measuring the safety of unsignalized and signalized intersections and comparing their relative levels of safety, and proposes an objective, quantitative process for determining whether a traffic signal is warranted at an unsignalized intersection or not.

2 THE STARTING POINT FOR THE PROCESS -- THE SAFETY PERFORMANCE FUNCTION (SPF)

2.1 Measuring the Safety Performance of an 'Average Intersection'

The development of SPF (safety performance function) curves for signalized and unsignalized intersections provides a starting point for establishing a process for identifying 'high risk' unsignalized intersections and a subsequent policy for traffic signal warrants. SPF curves for unsignalized intersections measure the safety of an *average unsignalized intersection* with traits, characteristics and traffic volume (AADT) similar to a particular unsignalized intersection, the safety of which we are interested in measuring. Similarly, the level of safety for an *average signalized intersection* having traits, characteristics and AADT that are similar to our particular unsignalized intersection of interest is provided by the signalized intersection SPF.

Although essential, the SPFs only provide part of the information needed to measure the safety of our particular unsignalized intersection that is of interest. Neither SPF, on its own, measures the expected 'long term' level of safety for a particular intersection of interest. **Exhibit 1** illustrates the problem.

2.2 The Source Data for Measuring the SPFs -- The Collision Counts

The collision counts for a sample of unsignalized intersections that have similar traits and characteristics but different amounts of annual average daily traffic volume (e.g., AADT) are depicted by the red rectangular data points (**K**). Similarly, the orange diamond shaped data points indicate the collision counts (**L**) for a sample of signalized intersections similar in traits and characteristics to the unsignalized sample, but again with differing amounts of AADT.

2.3 Estimating the SPFs

Multivariate regression models are fitted to these two sets of data yielding the "signalized intersection 'SPF'" and "unsignalized intersection 'SPF'" line graphs shown in **Exhibit 1**. For AADT of about 4,000 the data points **K** (11.5 collisions per unit of time) and **L** (4 collisions per unit of time), and the expected values for each of the SPFs (**E(k)** -- 9.5 collisions per unit of time, and **E(s)** -- 6.5 collisions per unit of time) are depicted.

2.4 Accident Modification Factors (AMFs)

The indicators **E1, E2, E3, E4 and E5** illustrate the effectiveness of an average signalized intersection compared to an average unsignalized intersection for specific levels of AADT (i.e., expected reductions in collisions per unit of time if an average intersection with the specified AADT was changed from unsignalized to signalized). These effectiveness indicators are also known as 'accident modification factors' (**AMFs**) which provide measurements of the expected change in collision frequency (for a given AADT) if a treatment, countermeasure or safety change is made to a road location. For example, in **Exhibit 1** we see that at 7,500 AADT the benefits of signalizing an unsignalized intersection would result in an effectiveness gain depicted by **E4** (a decrease from 13 to 8.5 collisions per unit of time, or 4.5 fewer collisions per unit of time).

2.5 Establishing a Process for Traffic Signal Safety Warrants

Returning to our example above of the unsignalized intersection that has **K (= 11.5)** collisions per unit of time, we would like to determine whether a traffic signal is warranted at this particular intersection. To shed light on this there are a number of questions that need to be answered including:

- How many fatal, injury and PDO collisions per year would we expect over a fixed period in the future (say 20 years) if the intersection remained unsignalized?
- How many fatal, injury and PDO collisions per year would we expect over a fixed period in the future (say 20-years) if the unsignalized intersection was signalized?
- What differential in safety level would prevail for each year of the 20-year future period if the intersection was signalized -- or, in other words, how many fatal, injury and PDO collisions could be avoided per year over the next 20 years by signalizing the intersection?
- What would the costs (capital, operation and maintenance costs) be to convert the unsignalized intersection to a suitable signalized intersection over a 20-year future life span?
- What are the costs of treatment(s) and countermeasure(s) implemented for making improvements to our unsignalized intersection over a 20-year evaluation period <u>if it remains unsignalized</u> or <u>if it is signalized</u>?
- How do the annual and accumulated benefits (i.e., societal savings due to reductions in collisions) compare to the annual and accumulated costs of signalizing the intersection at each of the years over the 20-year future life span of the traffic signal?
- How long would it take to realize a benefit-cost (B-C) ratio that is greater than 1 (i.e., how long would it take to realize a net positive benefit from signalization)?

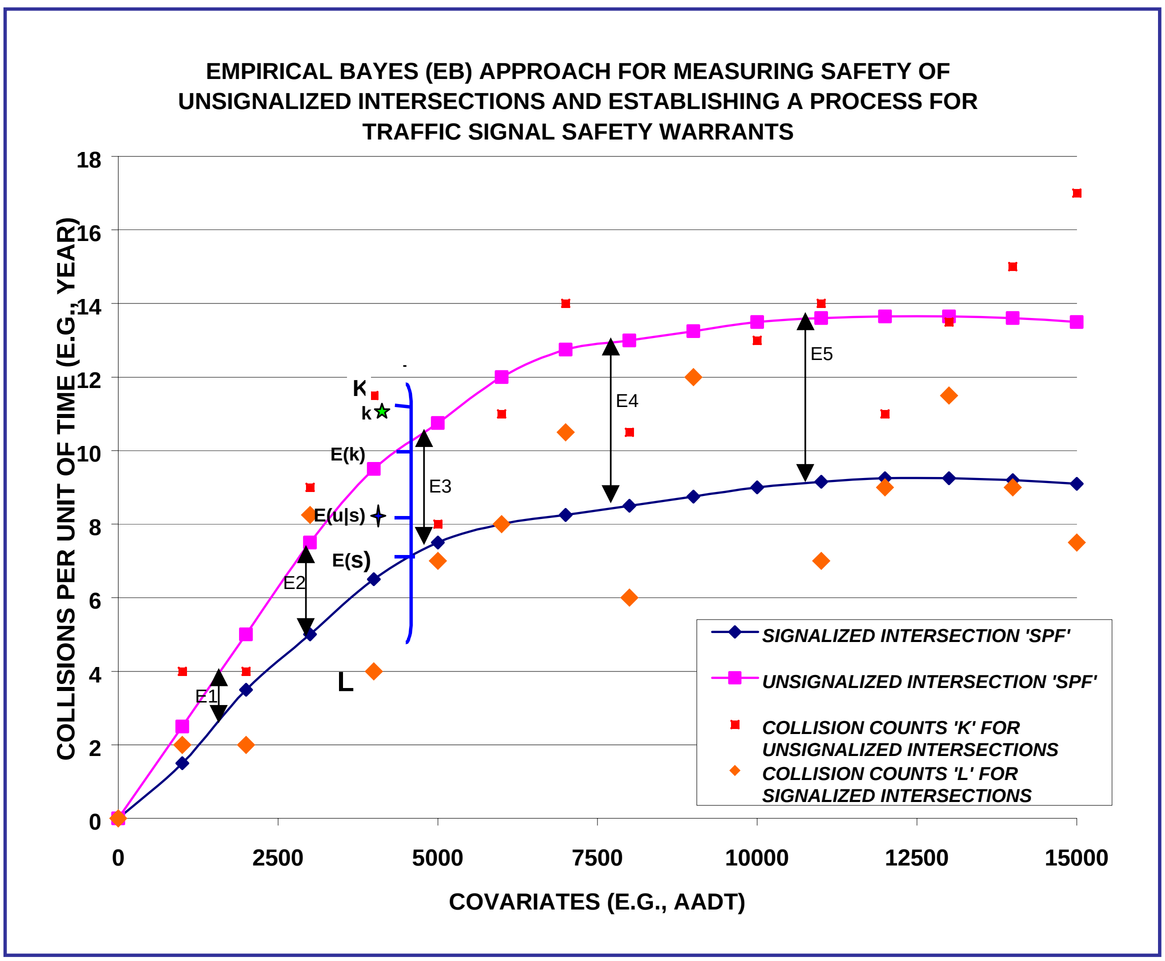
- How do the accumulated benefits and costs (i.e., B-C ratios) compare over the 'life span' of the traffic signal system, i.e., at each year over the 20-year post traffic signal implementation period?

None of the above questions can be answered unless an estimate of **k** (shown between **K** and **E(k)** in **Exhibit 1**) is estimable for each of the years in the 20-year post-signalization period. Now the question becomes: **What is k**?

2.6 Measurement of the 'True' Safety Level of Our Particular Unsignalized Intersection of Interest

In order to determine the net differential in safety that can be expected by signalizing our particular unsignalized intersection the first step involves estimating what its prevailing level of safety is as an unsignalized intersection. This amounts to deriving an estimate of **k**.

EXHIBIT 1



If **K** was a good estimator of **k** then, unsignalized intersections which recorded **K** collisions in one period would record, on the average, **K** collisions in a subsequent period of equal duration (if **k** remained unchanged). However, this is not supported by empirical evidence. It follows that **K** is not a good estimator of **k**. A very simple example proving this fact is given by the following.

Let us say that Mr. X has been driving for 35 years. Mr. X had one accident during his first five years of driving. The question is: how many accidents do we expect Mr. X to have in the future (after his first five years of driving). A rationale estimate would be one accident every 5 years -- based only on his accident history. Therefore, it would be reasonable to predict that Mr. X would have 6 accidents during his next 30 years of driving. That would have been our prediction based only on his collision history 30 years ago. In fact, 30 years have since past and Mr. X has never had another accident. Our prediction 30 years ago, therefore, of Mr. X's expected number of collisions in the future is flawed. We would have predicted 0.20 collisions per year for Mr. X, while in reality Mr. X's safety has actually turned out (**over the long term**) to be: 1/35 = 0.03 collisions per year -- about seven times safer than we would have predicted by only considering his past collision history. This is what is referred to as the **'regression-to-the-mean'** phenomenon, which has been demonstrated to be a significant factor that should be accounted for when making predictions of collisions and their severity. Biased and incorrect predictions of safety will result unless corrective measures are derived and implemented to correct for the regression-to-the-mean in order to measure the 'true' safety of an entity in question.

Returning to our particular unsignalized intersection example, **k** is the 'true' estimate of the expected number of collisions for the unsignalized intersection **over the long-term**. As can be seen its value is somewhere between **K** (the collision history count for the intersection) and **E(k)** - the average count for intersections that have similar traits and characteristics as our particular unsignalized intersection of interest. The problem is: **how do we estimate k**? This is where the Empirical Bayes (EB) Approach comes into play.

3 THE APPLICATION OF THE EMPIRICAL BAYES APPROACH FOR MEASURING SAFETY OF INTERSECTIONS AND ESTABLISHING A PROCESS FOR DETERMINING TRAFFIC SIGNAL SAFETY WARRANTS

3.1 The Essence of the Empirical Bayes Method -- Two Pieces of Information for Measuring Safety

As should be evident from the above discussion, there are two types of information that must be taken into account for measuring the safety of an entity, be it an intersection, road segment, on/off ramp, interchange, etc. The first type of information is found in traits and characteristics of the intersection, e.g., four-legged or three-legged, urban or rural, separate right or left turn lanes, etc. The second type of information giving incite on the safety of the intersection is derived from the history of collision occurrences that have taken place at it. Now what is required is a method for combining these two types of information into one overall estimate (referred to as **'k'** above) that measures the true long-term safety of the intersection in question. To disregard one or the other of these two pieces of information results in estimates that are biased and incorrect (as illustrated in our example concerning Mr. X above), and this is what is done in most safety analyses and evaluations. All conventional methods for measuring safety only use information based on the collision history of the entity being evaluated -- which is now known to be incorrect.

The essence of **The Empirical Bayes approach** is to use both pieces of information to estimate the safety of the intersection. The information of the first type is based on traits and characteristics of the intersection of interest and on the safety of a group of intersections that share these similar traits/characteristics (e.g., 4-legged intersections, 3-legged intersection, two-way left turn lanes). This is the 'average safety' toward which the individual estimates of safety were seen to 'regress'. The second type of information - estimates of safety from the history of collision counts for the intersection -- determine by how much the **k** of a specific intersection deviates from the average estimate of safety for the entire group of similar intersections.

Exhibit 2 shows the logic involved in developing EB estimators (see Hauer, 1997). The pivotal concept behind the EB approach is in a large reference population similar in traits and characteristics to the entity of interest. This reference population is necessary for measuring 'what the expected safety of the entity of interest is'. This is done mathematically by combining the accident history of the entity and the accident history of the reference population entities.

3.2 How to combine the two pieces of information -- the 'accident history of the intersection' and the 'accident history of the reference population of intersections with similar traits and characteristics'

The **E(k|K)** is the expected value of **k** when it is known that the intersection recorded **K** collisions during some unit of time (e.g., in **n** years). This estimate will be some mix of the two pieces of information discussed above, namely the **E(k)** of the reference population of unsignalized intersections and the **K** of our particular unsignalized intersection under consideration, and it will be a quantitative value between **E(k)** and **K**. Therefore, mathematically we have:

$$E(k|K) = w*E(k) + [(1-w)/n]*K \quad \ldots\ldots\ldots\ldots(1)$$

where,

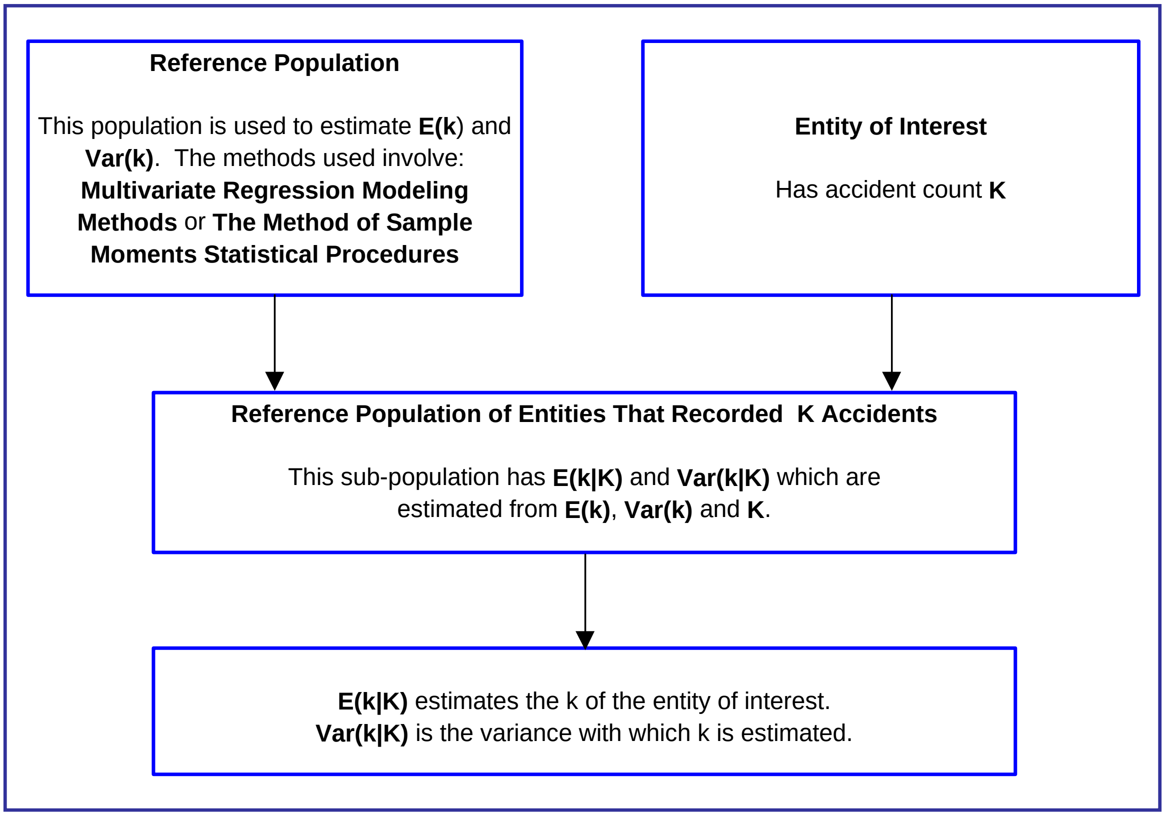
w is a weighting factor between 0 and 1 that needs to be estimated for intersections with **n** years of collision history. Intuitively, if **w** is close to 1, then the **k** of our particular unsignalized intersection of interest (estimated by **E(k|K)**) is close to the mean of the reference population to which it belongs, **E(k)**. On the other hand if **w** is close to 0 then the **k** of the intersection of interest will reflect mainly the recorded count of collisions, **K**. In order to estimate **k** with maximum precision the following relationship is used:

$$w = 1 / [1 + n*(Var(k) / E(k))] \quad \ldots\ldots\ldots\ldots(2)$$

The **Var(k)** and **E(k)** are estimated from the **Method of Sample Moments** or **Multivariate Regression Modeling** statistical procedures.

Therefore, to obtain an estimate of **k** for a specific intersection of interest, denoted as **E(k|K),** first the weight **w** is estimated (using equation (2) above) and the result used in equation (1) above which combines the average of the reference population -- **E(k)**, which is obtained from the SPF, and the collision history of the intersection, **K**.

EXHIBIT 2



3.3 Predicting the Expected Levels of Safety For Our Particular Unsignalized Intersection Over a Fixed Future Period if the Intersection Remained Unsignalized

In order to set the stage for estimating what the expected gains in safety would be by converting an unsignalized intersection to a signalized one it is necessary to select a point in time as the 'planned signalization period' and measure the expected safety levels of the intersection if it remained unsignalized as well as if it were to be signalized. Only then is it possible to estimate and compare the expected differentials in safety over time that would be attributable to signalizing the unsignalized intersection.

If we do not have accurate quantitative estimates of what the expected annual levels of safety would be over a fixed future period if the intersection remained unsignalized, then how is it possible to estimate what the differential in safety would be over the future period if the intersection was to be signalized?

It is first necessary, therefore, to measure 'what the expected level of safety would be for each of the years over a fixed future period if the intersection remained unsignalized'. This 'fixed future period' will be assumed to be a 20-year post-signalization period. This will provide the information necessary for subsequently measuring the differential in safety expected by converting our particular unsignalized intersection to a signalized intersection.

3.3.1 Estimating the Safety of Our Unsignalized Intersection During the First Year After Planned Signalization if the Intersection Remained Unsignalized

The first step involves estimating 'what the expected levels of safety (by severity and year) would be if our particular intersection remained unsignalized' -- $\mathbf{k_{sev,y's}}$, for each year over a fixed future period. For the purpose of the evaluation the 'fixed future period' will be defined as the period following the point at which the intersection would have been signalized.

$\mathbf{k_{sev,1}}$ (the expected level of safety for our particular unsignalized intersection if it remained unsignalized) is estimated using the EB method (discussed above in Section 3.2) and an accident modification factor ($\mathbf{AMF_{unsignalized,sev,1}}$) that may be necessary to reflect the true safety of the unsignalized intersection. This is done to account for any safety treatments or countermeasures that may be implemented for improving the safety of the unsignalized intersection, given that it is not signalized. Mathematically, we have:

$$k_{sev,1} = [w_{sev,1} * E(k)_{sev,1} + (1-w_{sev}) * K_{sev}] * AMF_{unsignalized,sev,1} \quad \text{...............(3)}$$

where,

$\mathbf{k_{sev,1}}$ is the overall estimate of the expected number of collisions of a particular severity (sev = fatal, injury or PDO) for the intersection during the first year of a 20-year post-signalization period if the intersection remained unsignalized ,

$\mathbf{w_{sev}}$, $\mathbf{E(k)_{sev,1}}$ **and** $\mathbf{K_{sev}}$ are estimated for each collision severity type (fatal, injury and PDO) as described in Section 3.2,

$\mathbf{AMF_{unsignalized,sev,1}}$ is the accident modification factor providing an estimate of additional reductions in collisions of severity type 'sev' that would be expected for our unsignalized intersection if it remained unsignalized during the first year of a 20-year post-signalization period and had treatment(s) implemented to improve its safety.

After these estimators are computed, $\mathbf{k_{sev,1's}}$ would provide accurate, unbiased estimates of the number of fatal, injury and PDO collisions expected during the first year after a planned signalization if it remained unsignalized rather than signalizing it.

3.3.2 Estimating the Safety of Our Unsignalized Intersection After the First Year of Planned Signalization if the Intersection Remained Unsignalized

$\mathbf{k_{sev,1}}$ estimators provide realistic, unbiased predictions of fatal, injury and PDO collisions expected during the first year of a post-signalization period at the unsignalized intersection if it was not signalized. The question to be answered is: Do $\mathbf{k_{sev,1's}}$ provide realistic estimates of the expected levels of safety at our unsignalized intersection over a 20-year period in the future if it were to be signalized? The answer to this is emphatically 'no', and it is based on the following rationale.

If $\mathbf{k_{sev,1}}$ was the best estimator of safety for our unsignalized intersection in future years (i.e., over a 20-year future period after planned traffic signal installation) then the following two assumptions would have to be acceptable:

<u>Assumption 1</u>: There would be no increases in AADT expected for the 20-year period after the planned traffic signal implementation.

<u>Assumption 2</u>: No potential treatment(s) or countermeasure(s) for making safety improvements to the unsignalized intersection would ever be entertained over the 20-year period after the planned traffic signal implementation.

Clearly Assumption 1 is certainly not realistic, and to accept Assumption 2 would rule out any possibility of evaluating the potential safety benefits of alternative treatments to the unsignalized intersection other than signalizing it. A proper process for freeing ourselves from these two unrealistic assumptions and estimating the true safety of the unsignalized intersection <u>if it remained unsignalized</u> during the 2nd through 20th year after the planned traffic signal implementation would be as follows.

First, the growth rate of AADT for each of the future years 2 through 20 expected at the unsignalized intersection is estimated. This can be done by considering a number of scenarios. For each scenario there will be particular value of AADT estimated for each of the years 2 to 20 corresponding to the 2nd through the 20th year after planned traffic signal implementation. Therefore we will have 19 AADT estimates, namely -- $AADT_y$, $y = 2,\ldots 20$.

Since $\mathbf{E(k)_{sev,ys}}$ are estimated values from the unsignalized SPF model that are a function of specific values of AADT it is now possible to estimate the $\mathbf{E(k)_{sev,ys}}$ for each of the years 2 to 20 by severity of collision. These are computed as:

$$\mathbf{E(k)_{sev,y} = SPF_{unsignalized,sev,y}} \ldots\ldots\ldots\ldots \mathbf{(4)}$$

This now eliminates Assumption 1 above. In order to nullify Assumption 2 above it is necessary to take into account any changes in safety at our unsignalized intersection due to potential treatments or countermeasures implemented for improving safety (without signalization) over the years 2 to 20 after planned traffic signal implementation.

A planned countermeasure or treatment will be expected to have a safety impact by reducing the number of collisions per unit of time (i.e., year) by xx%. These effectiveness estimators are also known as AMFs (as discussed earlier). For example, a treatment that is expected to reduce collisions by 20% has an AMF value of 0.80. For our unsignalized intersection, the potential treatments that could be considered for making safety improvements over the years 2 to 20 after planned traffic signal implementation are identified, along with their associated AMF estimator values. These values are then used to estimate the true safety of the unsignalized intersection for each of the years 2 to 20 after planned traffic signal implementation as follows:

$$\mathbf{k_{sev,y} = [k_{sev,y-1} / E(k)_{sev,y-1}] * E(k)_{sev,y} * AMF_{unsignalized,sev,y}} \ldots\ldots\ldots \mathbf{(5)}$$

These estimates of $\mathbf{k_{sev,y}}$ are now free of the two limiting assumptions above. $\mathbf{k_{sev,1}}$ and $\mathbf{k_{sev,y}}$ **(y =** 2,…,20) provide the most accurate and unbiased estimates of the true level of safety for our unsignalized intersection for each of the 20 years after the planned signal implementation <u>if the signal were to remain unsignalized</u>.

Notes

i. It should be emphasized that the ratio estimator $[k_{sev,y-1} / E(k)_{sev,y-1}]$ used in the computation of the following year $k_{sev,y}$ estimator is the 'best' indicator of the differential in safety between our particular unsignalized intersection and the average safety of the reference population of unsignalized intersections that have similar traits and characteristics. This ratio basically accounts for the deviation in safety between our particular unsignalized intersection and its similar reference group that can be attributed to extraneous, uncontrollable factors (e.g., vehicle distributions, traffic distributions) other than AADT and geometric traits and characteristics that have been explicitly accounted for in the unsignalized intersection SPF modeling.

ii. The $AMF_{unsignalized,sev,y}$ parameter permits the explicit measurement of changes in safety as a result of treatments implemented at the intersection over the 20-year evaluation period. This allows for alternative treatment scenarios for making improvements to the unsignalized intersection (other than signalization) to be explicitly quantified and included in the safety estimation of the unsignalized intersection for each year of the 20-year evaluation period, and compared to the expected levels of safety if the unsignalized intersection was signalized. If no treatment is planned for a particular year then the $AMF_{unsignalized,sev,y}$ parameter is simply set equal to 1.

The above process for estimating the true safety of the unsignalized intersection over a 20-year evaluation period if the intersection remained unsignalized provides a flexible tool for testing various scenarios for treatment implementation and measuring the effects on the safety of the unsignalized intersection.

This phase of the process answers the first question posed in **Section 2.5 -- How many fatal, injury and PDO collisions per year would we expect in the future (i.e., over a 20-year evaluation period) if the intersection remained unsignalized?**

These estimators must subsequently be compared to the safety changes expected on an annual basis over the 20-year evaluation period if the unsignalized intersection was converted to a signalized one. How to measure these expected safety changes for our particular unsignalized intersection of interest is discussed in the next section.

3.4 Predicting the Expected Levels of Safety For Our Particular Unsignalized Intersection Over a Fixed Future Period if the Intersection Was Converted to Traffic Signals

The next step of the process involves estimating "how many fatal, injury and PDO collisions per year would we expect in the future if the intersection was converted to a suitable signalized one? The answer to this question resides in the combining of two main clues -- the results of the EB estimators derived in the preceding section, and the results from the signalized intersection SPF (see **Exhibit 1**).

3.4.1 Estimating the Safety of Our Unsignalized Intersection During the First Year After Planned Signalization <u>if the Intersection Was Actually Signalized</u>

The **E(s)** (see **Exhibit 1**) is the *expected number of collisions per unit of time for an average signalized intersection with similar traits and characteristics to our unsignalized intersection under investigation* -- not the **E(s)** for our particular unsignalized intersection of interest. The optimum, unbiased estimate of the expected number of collisions per unit of time for our particular unsignalized intersection during the first year post signalization, call it $\mathbf{E(u|s)_{sev,1}}$, is given by Equation (6) as:

$$E(u\,|\,s)_{sev,1} = \frac{k_{sev,1} / E(k)_{sev,1}}{AMF_{unsignalized,sev,1}} * E(s)_{sev,1} * AMF_{signalized,sev,1} \quad \text{.......(6)}$$

where,

$\mathbf{E(u|s)_{sev,1}}$ is the expected safety level of our particular unsignalized intersection during year 1 after signalization,

$\mathbf{K_{sev,1}}$ **and** $\mathbf{E(k)_{sev,1}}$ are estimated for each collision severity type (fatal, injury and PDO) as described in the previous section,

$\mathbf{E(s)_{sev,1}}$ is the estimated number of collisions of severity type 'sev' (fatal, injury and PDO) for year 1 derived from the results of the signalized SPF corresponding to the AADT at our particular unsignalized intersection,

$\mathbf{AMF_{signalized,sev,1}}$ is the accident modification factor providing an estimate of additional reductions in collisions of severity type 'sev' that would be expected for our unsignalized intersection if it was signalized and during the first year of a 20-year post-signalization period there were additional treatment(s) implemented to improve its safety.

The above relationship says that the differential in safety between the particular unsignalized intersection being evaluated and the reference group of unsignalized intersections with similar traits and characteristics will be equivalent if the intersection is signalized and compared to the reference group of the signalized intersections with the same traits and characteristics. The rationale behind this lies in the fact that extraneous factors causing deviation in safety between our particular unsignalized intersection of interest and other unsignalized intersections with similar traits and characteristics will still be present after the unsignalized intersection is signalized.

$\mathbf{E(u|s)_{sev,1's}}$ provide accurate, unbiased estimates of the number of fatal, injury and PDO collisions expected during the first year after signalization of our particular intersection of interest.

3.4.2 Estimating the Safety of Our Unsignalized Intersection After the First Year of Planned Signalization <u>if the Intersection Was Actually Signalized</u>

$\mathbf{E(u|s)_{sev,1}}$ provide realistic, unbiased predictions of fatal, injury and PDO collisions expected during the first year of a post-signalization period at the unsignalized intersection <u>if it was signalized</u>. The question to be answered is: Do $\mathbf{k_{sev,1's}}$ provide realistic estimates of the expected levels of safety at our unsignalized intersection over a 20-year period in the future if it were to be signalized? The answer to this is emphatically 'no', and it is based on the following rationale.

If $\mathbf{E(u|s)_{sev,1}}$ was the optimum estimator of safety for our unsignalized intersection in future years (i.e., over a 20-year future period after planned traffic signal installation) if it were to be signalized then the following two assumptions would have to be acceptable:

<u>Assumption 3</u>: There would be no increases in AADT expected for the 20-year period after the intersection is signalized.

<u>Assumption 4</u>: No potential treatment(s) or countermeasure(s) for making safety improvements to the newly signalized intersection would ever be entertained over the 20-year period.

Clearly Assumption 3 is certainly not realistic, and to accept Assumption 2 would rule out any possibility of including the safety benefits attributable to other potential treatments and countermeasures that could be implemented for making even further improvements to the newly signalized intersection. A proper process for freeing ourselves from these two unrealistic assumptions and estimating the true safety of the newly signalized intersection during the 2^{nd} through 20^{th} year after the traffic signal was installed would be as follows.

First, the growth rate of AADT for each of the future years 2 through 20 expected at the newly signalized intersection is estimated. This can be done by considering a number of scenarios. For each scenario there will be particular values of AADT estimated for each of the years 2 to 20 corresponding to the 2^{nd} through the 20^{th} year after traffic signal implementation. Therefore we will have 19 AADT estimates, namely -- $AADT_y$, **y =** 2,…20.

Since $\mathbf{E(s)_{sev,y's}}$ are estimated values from the signalized SPF model that are a function of specific values of AADT it is now possible to estimate the **E(s)** for each of the years 2 to 20 by severity of collision. These are computed as:

$$\mathbf{E(s)_{sev,y} = SPF_{signalized,sev,y}} \ldots\ldots\ldots\ldots \mathbf{(7)}$$

This now eliminates Assumption 1 above. In order to nullify Assumption 4 above it is necessary to take into account any changes in safety at our newly signalized intersection due to potential treatments or countermeasures implemented for making additional safety improvements (over and above signalization) over the years 2 to 20 post-traffic signal implementation.

A planned countermeasure or treatment will be expected to have a safety impact by reducing the number of collisions per unit of time (i.e., year) at our newly signalized intersection by xx%. These effectiveness estimators are also known as AMFs (as discussed earlier). For example, a treatment that is expected to reduce collisions by 20% has an AMF value of 0.80. For our newly signalized intersection, the potential treatments that could be considered for making safety improvements over the years 2 to 20 after traffic signals installation are identified, along with their associated AMF estimator values. These values are then used to estimate the true safety of the newly signalized intersection for each of the years 2 to 20 post-traffic signal installation as follows:

$$\mathbf{E(u|s)_{sev,y} = [E(u|s)_{sev,y-1} / E(s)_{sev,y-1}] * E(s)_{sev,y} * AMF_{signalized,sev,y}} \ldots\ldots \mathbf{(8)}$$

where **y** = 2,…,20

$\mathbf{E(u|s)_{sev,y}}$ estimators are now free of the two limiting assumptions above. $\mathbf{E(u|s)_{sev,1}}$ and $\mathbf{E(u|s)_{sev,y}}$ (y = 2,…,20) provide the most accurate and unbiased estimates of the true level of safety for our newly signalized intersection for each of the 20 years after the signal installation.

Notes

iii. It should be emphasized that the ratio estimator $[E(u|s)_{sev,y-1} / E(s)_{sev,y-1}]$ used in the computation of the following year $E(u|s)_{sev,y}$ estimator is the 'best' indicator of the differential in safety between our newly signalized intersection and the average safety of the reference population of signalized intersections that have similar traits and characteristics. This ratio basically accounts for the deviation in safety between our particular newly signalized intersection and its similar reference group that can be attributed to extraneous, uncontrollable factors (e.g., vehicle distributions, traffic distributions) other than AADT and geometric traits and characteristics that have been explicitly accounted for in the signalized intersection SPF modeling.

iv. The $AMF_{signalized,sev,y}$ parameter permits the explicit measurement of changes in safety as a result of treatments implemented at the newly signalized intersection over the 20-year evaluation period. This allows for alternative treatment scenarios for making additional improvements to the newly signalized intersection to be explicitly quantified and included in the safety estimation of our newly signalized intersection for each year of the 20-year evaluation period, and compared to the expected levels of safety if the intersection had not been signalized. If no additional treatment is planned for a particular year then the $AMF_{signalized,sev,y}$ parameter is simply set equal to 1.

The above process for estimating the true safety of our newly signalized intersection over a 20-year evaluation period provides a flexible tool for testing various scenarios for treatment implementation and measuring the overall safety impacts on our newly signalized intersection.

By the end of this phase of the process we have an answer to our second question posed in **Section 2.5** -- **How many fatal, injury and PDO collisions per year would we expect over a 20-year period in the future if our particular unsignalized intersection was converted to signalization?**

3.5 Estimating Differentials in Safety Levels If Our Particular Unsignalized Intersection Were Signalized

The estimators developed in **Sections 3.3** and **3.4** can now be used to compare the safety changes expected on an annual basis over the 20-year evaluation period. This provides a quantitative process for measuring the true differential in safety expected if our particular unsignalized intersection were converted to a signalized one.

3.5.1 Estimating the Expected Annual Reductions in Collisions by Severity Over the 20-year Evaluation Period Attributable to Converting Our Unsignalized Intersection to Signalized Intersection

The actual number of fatal, injury and PDO collision reductions per year that can be expected (referred to as FR_y, IR_y, $PDOR_y$ respectively) due to converting the unsignalized intersection to a signalized one are estimated as follows:

$$FR_y = k_{F,y} - E(u|s)_{F,y} \quad \text{..........(9)}$$

$$IR_y = k_{I,y} - E(u|s)_{I,y} \quad \text{............(10)}$$

$$PDOR_y = k_{PDO,y} - E(u|s)_{PDO,y} \quad \text{..............(11)}$$

where,

y = 1,…,20

FR_y is expected number of fatal collision reductions in year y if the particular unsignalized intersection were converted to signalized,

IR_y is expected number of injury collision reductions in year y if the particular unsignalized intersection were converted to signalized,

$PDOR_y$ is expected number of PDO collision reductions in year y if the particular unsignalized intersection were converted to signalized,

$k_{F,y}$ **,** $k_{I,y}$ **, and** $k_{PDO,y}$ are the number of fatal, injury and PDO collisions respectively expected to occur in year y if the particular unsignalized intersection remained unsignalized,

$E(u|s)_{F,y}$ **,** $E(u|s)_{I,y}$ **, and** $E(u|s)_{PDO,y}$ are the number of fatal, injury and PDO collisions respectively expected to occur in year y if the particular unsignalized intersection was converted to a signalized intersection.

At the end of this phase of the process the third major question posed in **Section 2.5** will be answered, namely: **"What differential in safety level would prevail if the intersection was signalized -- or, in other words, how many fatal, injury and PDO collisions could be avoided by signalizing the intersection?".**

3.5.2 Estimating the Accumulative Reductions in Collisions by Severity Over the 20-year Evaluation Period Attributable to Converting Our Unsignalized Intersection to Signalized Intersection

The total accumulated number of fatal, injury and PDO collision reductions that are expected due to signalization of our particular unsignalized intersection of interest can now be estimated. These accumulates can be computed at the conclusion of each of the years over the 20-year evaluation period thereby providing a comparative assessment of the unsignalized vs. signalized intersection treatments over time.

Mathematically, these accumulated estimators would be computed as follows:

$$ACC_{k,sev,n} = \sum_{y=1}^{n} k_{sev,y} \quad \text{.................(12)}$$

$$ACC_{E(u|s),sev,n} = \sum_{y=1}^{n} E(u\,|\,s)_{sev,y} \quad \text{.................(13)}$$

where,

n = 1,…,20

$ACC_{k,sev,n}$ are the accumulated numbers of expected collisions of specified severity (sev) for our particular unsignalized intersection of interest if it remained unsignalized by the end of year n of the 20-year evaluation period (there will be 20 of these accumulative estimators),

$ACC_{E(u|s),sev,n}$ are the accumulated numbers of expected collisions of specified severity (sev) for our particular unsignalized intersection of interest if it was signalized by the end of year n of the 20-year evaluation period (there will be 20 of these accumulative estimators).

By comparing these accumulated estimators for both unsignalized and signalized scenarios for our particular unsignalized intersection of interest it is possible to compare the net accumulated safety benefits attributable to signalizing our unsignalized intersection. These comparisons are computed as follows:

$$NETACC_{sev,n} = ACC_{k,sev,n} - ACC_{E(u|s),sev,n} \quad \text{……….(14)}$$

where,

$NETACC_{sev,n}$ provides the measurement of the numbers of collisions of a specified severity (sev) expected to be avoided by year n (of our 20-year evaluation period) if our particular unsignalized intersection were signalized. There will be 20 of these NETACC estimators for each of the fatal, injury and PDO collision severity levels.

3.6 Estimating the Total Annual and Accumulated Costs of Traffic Signal Implementation and Costs of Other Treatment(s) Implemented for Improving Safety

The next step of the process involves estimating the total costs of converting the unsignalized intersection over a 20-year evaluation period post-signalization. The total costs include capital --C, maintenance -- M, and operating -- O costs. The annual estimates of costs to install the traffic signal will be computed as follows.

3.6.1 Annual Costs of Traffic Signal Implementation Over a 20-Year Evaluation Period

The capital costs, C, will include the installation costs of the traffic signal and these will only be included in the first year of the 20-year life cycle costs associated with implementing the traffic signal. The remaining 19 years of associated costs will include maintenance and operating costs. Therefore, the following two equations represent the total costs of traffic signal implementation over a 20-year evaluation period.

For installation year 1,

$$TSC_1 = C_1 + M_1 + O_1 \quad \text{…………….(15)}$$

$$TSC_Y = M_Y + O_Y \quad \text{………….(16)}$$

where,

y = 2,…, 20.

TSC_y are the annual costs of traffic signal implementation for each year over a 20-year evaluation period.

3.6.2 Accumulated Costs of Traffic Signal Implementation Over a 20-Year Evaluation Period

The total accumulated costs of installing, maintaining and operating the traffic signal installation can then be estimated over time by summing each of the above estimators at the conclusion of each of the years over the entire 20-year period. Mathematically, this is estimated as follows:

$$ACCTSC_n = \sum_{y=1}^{n} TCS_y \quad \text{...............(17)}$$

where,

n = 1,…, 20.

At the end of this process the answer to the fourth major question posed in **Section 2.5** would materialize -- **What would the costs (capital, operation and maintenance costs) be to convert our particular unsignalized intersection to a suitable signalized intersection over a 20-year post-installation evaluation period?**

3.6.3 Annual and Accumulated Costs of Treatment(s)/Countermeasure(s) for Our Particular Unsignalized Intersection

Recalling from **Sections 3.3**. and **3.4** that the modeling process allows for treatment(s) and countermeasure(s) to be considered for potential implementation over the 20-year evaluation period, it is necessary to build into the estimation process costs for these safety improvements. These costs must be itemized separately for treatment(s) implemented to improve both our existing unsignalized intersection if it remained unsignalized over the 20-year evaluation period, and our newly signalized intersection if our unsignalized intersection was converted to traffic signals.

Costs of Treatment(s) if Our Unsignalized Intersection Remained Unsignalized Over a 20-Year Evaluation Period

For each treatment or countermeasure that could be implemented for improving the safety of our unsignalized intersection (given that it is not signalized) the costs must be estimated and inputted into the modeling framework. These costs will be denoted as $UITC_y$, y = 1, …20. There will be 20 of these values corresponding to the 20-year evaluation period. If no treatment was implemented in a particular year, say year i, then the associated $UITC_i$ will be zero (i.e., $UITC_i = 0$).

The accumulated cost of treatment(s) if our unsignalized intersection remained unsignalized (**$ACCUITC_n$**) at the conclusion of each year over the 20-year evaluation period would be estimated as follows:

$$\mathbf{ACCUITC_n = \sum_{y=1}^{n} ACCUITC_y} \text{.............}\mathbf{(18)}$$

where,

n = 1,…, 20.

Costs of Treatment(s) if Our Unsignalized Intersection Was Converted to a Signalized Intersection Over a 20-Year Evaluation Period

For each treatment or countermeasure that could be implemented for improving the safety of our newly signalized intersection (given that the unsignalized intersection was signalized), these costs must be estimated and inputted into the modeling framework as well. These costs will be denoted as **$SITC_y$**, y = 1, …20. There will be 20 of these values corresponding to the 20-year evaluation period. If no treatment was implemented in a particular year, say year i, then the associated SITCi will be zero (i.e., SITCi = 0).

$$\mathbf{ACCSITC_n = \sum_{y=1}^{n} ACCSITC_y} \text{.............}\mathbf{(19)}$$

where,

n = 1,…, 20.

This phase of the process will answer the fifth question raised in **Section 2.5** by **quantifying the annual and accumulated costs of treatment(s) and countermeasure(s) implemented for making improvements to our unsignalized intersection over a 20-year evaluation period <u>if the intersection remained unsignalized</u> or <u>if the intersection was signalized</u>?**

3.7 Estimating Societal Benefits (in terms of dollars) Due to Reductions in Fatal, Injury and PDO Collisions Attributable to Converting Our Unsignalized Intersection to a Signalized Intersection

The next phase of the process requires that the safety benefits of converting our particular unsignalized intersection of interest to a signalized intersection are translated into societal cost savings (SCS) in terms of dollars. This is necessary in order to compare the 'benefits and costs' of converting the unsignalized intersection, and subsequently for conducting benefit-cost analyses for the final determination of whether it is warranted to convert the unsignalized intersection to a signalized one.

Assigning monetary values to the societal costs of 'Fatal', 'Injury', or 'PDO' collisions is a difficult task. Jurisdictions use different values for each of these societal costs of collisions. It is important for this phase of the process that values are agreed upon because the final results are only comparable if the same monetary societal costs are used by all jurisdictions.

The annual societal cost savings for a given year y (**$ASCS_y$**) due to converting an unsignalized intersection to a signalized one is given by the following mathematical relationship:

$$ASCS_y = FR_y * CF_y + IR_y * CI_y + PDOR_y * CPDO_y \quad \ldots\ldots\ldots\ldots\ldots\ldots (20)$$

where,

y = 1,…,20

FR_y, IR_y and $PDOR_y$ are the estimators derived in Section 3.5.1,

CF_y, CI_y and $CPDO_y$ are the agreed-upon annual societal costs of a 'Fatal', 'Injury', and 'PDO' collision respectively.

The total accumulated societal cost savings can then be estimated over time by summing each of the above estimators at the conclusion of each of the years over the entire 20-year evaluation period.

Mathematically, this is given by:

$$ACCSCS_n = \sum_{y=1}^{n} ACCSCS_y \ldots\ldots\ldots\ldots (21)$$

where,

n = 1,…,20

3.8 Comparing the Societal Cost Savings to the Costs of Signalizing Our Particular Unsignalized Intersection of Interest

The final two phases of the process for determining traffic signal safety warrants combines the final results derived in **Section 3** through **Section 7** to:

- Compare the net economic benefits and costs of signalizing vs. not signalizing our particular unsignalized intersection of interest over a 20-year evaluation period by converting the annual benefits and costs to present value using standard economic analyses methods,

- Estimate the annual and accumulative Benefit-Cost (**B/C**) Ratios over the 20-year evaluation period to measure the relative differential between the net economic benefits and costs of signalizing the unsignalized intersection.

These final phases of the process provide an objective, quantitative basis for making a decision on whether a traffic signal is warranted or not.

3.8.1 Annual Net Benefit Returns Due to Signalizing Our Unsignalized Intersection

By comparing the annual societal cost savings (**$ASCS_{y's}$**) to the annual costs of signalization (**$TSC_{y's}$**) and costs of other treatments/countermeasures (**$UITC_{y's}$** and **$SITC_{y's}$**) that could be implemented for improving safety at our particular intersection over the 20-year period post traffic signal implementation it is now possible to measure the net benefits (in dollar terms) of converting the unsignalized intersection to a signalized system.

Mathematically, this would be estimated as follows:

$$\textbf{Net Benefits}_y = \textbf{ASCS}_y - (\textbf{TSC}_y + \textbf{UITC}_y + \textbf{SITC}_y) \ldots\ldots\ldots\ldots\ldots\ldots \textbf{(22)}$$

3.8.2 Accumulated Net Benefits Due to Signalizing Our Unsignalized Intersection

The accumulated net benefits (**ANB_n**) are then estimated over time by summing them at conclusion of each year over the 20-year evaluation period, as follows:

$$\textbf{ANB}_n = \sum_{y=1}^{n} \textbf{Net Benefits}_y \ldots\ldots\ldots\ldots \textbf{(23)}$$

where,

n = 1,…,20

This now provides an answer to the sixth major question posed in **Section 2.5** -- **How do the annual and total accumulated benefits (i.e., societal savings due to reductions in collisions) compare to the annual and total accumulated costs of signalizing the intersection at each of the years over the 20-year evaluation period of the traffic signal installation?**

3.8.3 Benefit-Cost Ratios

The final phase of the process involves combining the net societal benefits and total costs of traffic signal implementation as well as potential treatment costs over the 20-year evaluation period into final C/B ratios. These final ratios provide the quantitative measurements for making rationale decisions on whether to signalize the unsignalized intersection, since they have measured and taken into consideration:

- The level of safety expected at our particular unsignalized intersection of interest if it remained unsignalized at each year of a 20-year evaluation period.
- The level of safety expected at our particular unsignalized intersection of interest if it were signalized at each year of a 20-year evaluation period.
- The net economic safety benefits and costs of signalizing or not signalizing our particular unsignalized intersection of interest, and the net differentials in economic returns at each year of a 20-year evaluation period.

From the results above the final phase of the process would entail the estimation of benefit-cost (**B/C**) ratios at the conclusion of each of the years over the 20-year post-traffic signal implementation.

Mathematically, the annual **B/C** ratios would be estimated as follows:

$$\textbf{B/C}_y = \textbf{ASCS}_y / (\textbf{TSC}_y + \textbf{UITC}_y + \textbf{SITC}_y) \ldots\ldots\ldots \textbf{(24)}$$

where,

y = 1,…,20

The accumulated **B/C** ratios at the conclusion of each year over the 20-year evaluation period would be estimated as follows:

$$B/C_n = ANB_n / (ACCTSC_n + ACCUITC_n + ACCSITC_n) \ldots\ldots\ldots\ldots (25)$$

where,

n = 1,…,20

The B/C_n ratios will provide the information necessary for estimating the net benefits that would be accrued from converting the unsignalized intersection to a signalized system.

This final phase of the process will answer the final two critical questions that need to be answered with respect to determining a traffic signal safety warrant policy, namely --

- **How long would it take to realize a benefit/cost ratio that is greater than 1 (i.e., how long would it take to realize a net positive benefit from signalization)?** and
- **How do the accumulated benefits and costs (i.e., B/C ratios) compare over the 'life span' of the traffic signal system, i.e., at each year over the 20-year post traffic signal implementation period?**

4 EVALUATION OF TRAFFIC SIGNAL SAFETY WARRANT FOR OUR PARTICULAR UNSIGNALIZED INTERSECTION

If a traffic signal is implemented at a particular unsignalized intersection it is imperative that the net safety benefits expected are in fact being received. It is therefore important that the safety of the newly signalized intersection be regularly evaluated.

In order to conduct the evaluations sound scientifically-based statistical methods are available. These include before-after evaluation studies as well as the EB methods. These state-of-the-art evaluation methods should be used to ensure that the traffic signal installation is resulting in the anticipated improvements in the levels of safety that were predicted by the process for determining traffic signal safety warrants (as described in **Sections 2** and **3** above).

5 FINAL CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This report has provided a detailed description of a state-of-the-art scientifically based methodology for measuring the differential in safety levels expected between signalization and non-signalization for a particular unsignalized intersection over a 20-year evaluation period. The methodology is based on an extension of the Empirical Bayes approach coupled with proven statistical modeling procedures for estimating accurate and unbiased safety impacts of signalizing an unsignalized intersection.

A comprehensive process including all phases and tasks for the design and development of a modeling system is proposed. This system, once implemented, would provide the necessary information for making rationale decisions on whether a traffic signal is warranted at an unsignalized intersection or not.

5.2 Recommendations

Considerable thought and effort has gone into the design and development of the approach offered in this position paper. We believe that it offers great potential.

We therefore recommend that the above methodology and process be considered for establishing a policy and procedures for traffic signal safety warrants. This would ensure that a system for using traffic signal safety warrants would be based on the 'need' according to the actual safety performance of the particular unsignalized intersection being assessed, and the potential safety benefits that would be gained if it were to be signalized.

In order to effectively pursue the solutions offered in this position paper the following is proposed.

- The approach and processes presented be critically reviewed.
- If deemed acceptable, a study should be implemented which would include:
  - The full design and development of a computerized model to implement the methods and procedures detailed.
  - The identification of a suitable jurisdiction (e.g., Province, Region) for conducting pilot study case studies.
  - The development/documentation of the required data bases.
  - The application of the process to specific case study evaluations of unsignalized intersections in a selected jurisdiction.