Intersection Accident Prediction with Conflict Opportunity Technology and Traf-Safe™ Software
Architecture, Function & Validation

Table of Contents

Abstract

The theoretical algorithm, example application and software structure are presented for a microscopic Traffic Accident Prediction Software (Traf-Safe) that estimates the number of annual accidents, injuries, and fatalities for any typical highway intersection with widely varying elements. A finite element analysis approach is used to break each intersection into discrete elements such as lanes, turn-bays, traffic flow rates, approach speeds, turning radii, traffic control types, and numerous other factors, and using a statistically-based Conflict Opportunity approach first pioneered by General Motors Research, the total annual conflict probabilities between various permutations of the traffic elements are calculated and summed for the full intersection. The total theoretical annual conflicts are then converted to expected annual accidents using a unique driver vision and speed-based integration for each of the various conflict types, and the annual accident level then converted to estimated annual injury involvement. Validation of the software to numerous signalized intersections indicates an accuracy of approximately 90 percent in comparison to the historical accident record, with approximately 80 percent accuracy for both angle and rear-end accidents which constitute a majority of signalized intersection accidents. Validation to 65 two-way "Stop" controlled intersections indicate the conflict opportunity annual accident estimates were far superior to annual accident estimates developed from typical regression of the on-site historical accident data. **Evidence indicates this technology coupled with qualified engineering judgement may eliminate over 250,000 injuries and 1,000-2,000 fatalities per year.**

I. Background of Traffic Models in General

"Is it Better To Be Dead Than Stuck In Traffic" is a recent article that typifies the current context of highway and intersection traffic safety issues, and presents the subject as not only difficult to quantify but confusing even to academic professionals.(1) However, the recommendation of this article to use the "direct legitimacy" of a jury to define safety questions stands in stark contrast to the current practice of using qualified engineering judgment as a pre-crash surrogate to actual accidents and injuries, and no doubt this is also an obvious preference to any post-crash jury determination of safety issues. But even when relying on qualified engineering judgement for traffic safety decisions, the absence of a microscopic accident prediction capability as well as intersection and corridor safety performance standards may still generate engineering judgments that can be spurious, inconsistent and even consistently wrong. Thus, a clear argument can be made for both intersection and corridor traffic safety prediction models and for injury-based performance standards that can assist engineering judgments in making proper safety choices, and to document the selection of these choices among available options. Historically in the transportation field, the most common

traffic safety prediction models have been exposure or "rate-based" regression models that produce responses such as "accidents per million entering vehicles" for intersections or "accidents per million vehicle miles of travel" for highway corridors between selected termini. But both of these approaches rely on the development of statistical regression techniques that have proven over the years to be entirely unreliable in predicting annual accidents because they lack an underlying operating theory, are non-transferrable to other sites, accept errored input data without question, and with exception to total daily volume are completely inensitive to the myriad of complexities that affect isolated intersection accident occurrence and injuries.

Predicting real-world traffic events using relative models is a common approach in engineering, and probably one of the best known prediction models is that originally developed by Webster to predict delay at signalized intersections.(2) In Webster's model, two distinct types of delay were mathematically developed including "uniform delay" caused by the presence of a traffic signal giving a portion of the green time to a sidestreet, and incremental or "random delay" caused by vehicle queueing in advance of the intersection and the inability of the intersection to clear all waiting vehicles. Today, delay models very similar to Webster's are regarded as the backbone of the Signalized Intersection Chapter of the Highway Capacity Manual (HCM), and from these mathematical models, Delay-based Levels of Service (LOS) are used as standard features for planning, design, and operational timing of intersections.(3) Yet the basic premise for measuring capacity or quality of service still rests upon mathematical models which are only relative, and not exact. After all, it's highly unlikely that any one intersection would produce delay which replicates exactly the delay that the HCM or Webster's model predicts, and DOT studies have shown that typical error between modeled and actual delay-based Levels of Service can be so extensive as to correctly predict only 50 percent of the intersection Levels of Service, and yet even this poor accuracy is still acceptable.(3a) From this, it may be recognized that the prediction of many values in traffic design and operations, whether delay, volumes, or even accidents do not rest upon the need for absolute accuracy (because these are always masked by human, vehicle and/or environmental factors), but upon the need for realistic, relative accuracy with stable precision provided by software.

II. The Probable Conflict Opportunity Algorithms and Assumptions

Numerous studies have reported on the impacts, effects, and correlation of actual on-site conflicts to accidents at specific intersections, but generally these studies reported an at-best 20 percent accuracy compared to historical on-site annual accidents.(4) This is not really unexpected in the modeling of actual on-site events because the definition and observation of any on-road event is subjectively unique among both drivers and observers and influenced and confounded by human, vehicle, environmental and other conflicting factors and effects, not to mention the accident data itself which remains only approximately 60-70 percent reliable.(5) Given these structural and data inconsistencies, it becomes desirable to replace actual on-road conflicts with a more precise theoretical conflict surrogate of "Statistically Probable Conflict Opportunities" (SPCO).

One of the first attempts in the formulation of objective and quantifiable SPCO's began with Perkins and Harris of General Motors Research who introduced the concept for discrete types of conflicts. This study was later followed by other theoretically specific conflict event formations.(6-12) However, while specific conflict events formulations are useful, the integration of these probable event formulations to form a mathematical annual accident expectation and a process to predict annual accidents was first introduced by Kaub using uniquely competing probable event elements to form an annual accident expectation based on the assumed mutually exclusive event probabilities and their calibration to actual annual accidents.(13) Using this approach , the general formulation for any type of conflict event is:

$$SPCO\ (Conflict\ Type)_t = E(Movement\ Opportunities)_{ij} * P(Arrival\ of\ Opposition\ to\ Movement)_{kl}$$

where:

- t = Specific Conflict Type such as passing on two-lane highway, intersection angle conflicts, merging/diverging sideswipe conflicts, rear-end conflicts, fixed object vehicle conflicts, etc. per unit time,
- i = Arrival Movement Type such as the vehicle desiring to pass, the vehicle(s) desiring to turn left, the vehicle(s) desiring to change lanes, the vehicle(s) desiring to stop, etc. per unit time,
- j = Arrival Approach such as one lane of a two lane highway, or one lane of a specific intersection approach which may have two, three or more approaches,

k = Opposition Movement Type such as the vehicle opposing the passing vehicle on a two-lane highway, or the vehicle opposing an angle movement(s) within an intersection, the vehicle opposing a merge/diverge sideswipe movement(s) on a specific intersection approach, the vehicle opposing a vehicle(s) desiring to stop (rear-end), etc. per unit time,

l = Opposition Approach such as the opposing one lane of a two lane highway in a passing maneuver, one lane of a specific intersection approach which is in opposition to a movement produced in another lane or on another approach, and

A. For Angle and Rear-end Conflict Formulations:

E (Movement Opportunities)$_{ij}$ = Expected number of vehicles per unit time from a specific movement type "i" (such as number of vehicles desiring to pass/hour in a given segment on a two-lane highway or the number of vehicles desiring to turn left or right on an approach to an intersection/hour or any other arriving movement) which may be exposed to an opposition movement on any particular roadway segment or intersection approach or adjacent lane "j", where each expectation follows the form:

E = P(Movement Opportunity/unit time) * (Vehicles performing this movement/unit time).
Often the probability of movement opportunity may be 1.0 where the conflict can occur at any particular time, or the probability may be a specific unit as where there exists a finite probability that a following vehicle may desire to pass on a two lane highway and this probability depends on the volume of traffic in one direction on the roadway segment.

P (Arrival of Opposition to Movement)$_{kl}$ = For angle and rear-end accidents, the probability of arrival of one or more vehicles during the specific time period of exposure to a particular type of conflict "k" (or the probability of opposition during the time of exposure of the arriving vehicle to a conflict situation "k"), on any particular roadway segment or intersection approach or adjacent lane "l", where using the Poisson Distribution each Probability follows the general form:

$$P(1 \text{ or more}) = 1-P(0) = 1- \frac{e^{-m}m^{x}}{x!} = 1- \frac{(e^{-m} * m^{0})}{0!} = 1- e^{-m}$$

where:

m = average opposing vehicle arrival rate (q) during exposure time (t) for angle and rear-end conflict types as;

1. for angle conflict average arrival rate:
   m=[(q veh/hour per lane per approach) * (t seconds of exposure time)]/3600,
   For practical purposes, the angle conflict exposure or clearance times of the arrival vehicles are based upon the 1985 Highway Capacity Manual critical gap times for unsignalized intersections, under the assumption that these times adequately estimate vehicle exposures, even though new research continually improves exposure predictions.(14,15) For through movements, exposure times are calculated using safe stopping distances for through vehicles exposed to sidestreet conflicts (such as for an entering sidestreet vehicle stalling on acceleration). And theoretically, t seconds of exposure or clearance time may also be replaced by a continuous distribution of the form: $P(h \geq t_{Li})$ and $P(h \leq t_{Ui})$ where:
   t_{Li} = Lower bound of exposure time on approach "i" (sec)
   t_{Ui} = Upper bound of exposure time on approach "i" (sec), and

2. for rear-end conflict average arrival rate:
   m=[(q rear veh/hour/lane per approach)* (t seconds of exposure time)]/3600,
   For practical purposes, the rear-end conflict exposure time at an unsignalized stop is a duration time which may be replaced by a queueing model of the form: (26)
   Stop Duration(sec)= E(Wait time in system)- E(service time)
   = (Expected # in System/Arrival rate)- Critical Gap
   and:
   Expected Number # in System = P(1)/P(0)
   $= (1-e^{-m})/(e^{-m})$
   $= (1-e^{-m})*(e^{m})$, and thus
   $\text{StopDuration(Unsignalized-sec)}=\{[(1-e^{qt/3600})*e^{qt/3600}]/(q/3600)\}-\text{Crit.Gap}$

where:
q = arrival flow of stopping vehicles (vph)
t = time to service each stopped vehicle (critical gap-sec.), and

Stop Duration(Signalized-sec) = Webster's or similar model of Stop Delay.

B. For Sideswipe Conflict Formulation:

A sideswipe accident involves the probability of any two vehicles being close enough to restrict a third vehicle in the adjacent lane from entering the lane in a given time period, based on an assumption of lane distribution patterns. Lane distribution patterns by assumption are based on the models found in the FHWA "Roadside" Program which relates lane distribution to approach volumes.(17) The “Roadside” Program presents two models of lane distributions (depending upon approach widths) and given these, probable sideswipe conflict opportunities are the result of the given lane distribution and the potential shift to another lane.

The SPCO Sideswipe Model operates similarly to the angle and rear-end models as:
$SPCO(\text{Sideswipe Conf/hr}) = E(\text{Movement Opportunities})_{ij} * P(\text{Arrival of Opposition movement})_{kl}$
where:
E(Movement Opportunity) =P(Sideswipe Arrival Opportunity)* (Vehicles performing movement/ time).

and:
P(Sideswipe Arrival Opportunity) = P(Lane shift) = Either 1.0 for volumes which must shift lanes to make an approaching turn movement or to a conservative surrogate of lane utilization for through volumes in shared lanes where through volumes will shift lanes depending on the utilization of the turn lane, and

P(Arrival of Opposition to lane shift) = Probability of simultaneous arrival of two or more vehicles in the entry lane during the default merge headway. The default merge headway is the Minimum Time Gap required to merge into a defined headway as:

P(Arrival of Opposition to lane shift)= P(> =2) = 1-[(P(0) + (P(1)]
where:
$P(0) = e^{[-q*t/3600]}$
$P(1) = e^{[-q*t/3600]} * [qt/3600]$ and:
q = average arrival rate (left + through + right in entry lane-vph),
t = default merge headway = Minimum time gap required for a vehicle to merge into the adjacent lane. Assuming merge headways for intersections correspond to merge headways for single lane ramps, the minimum time gap required may vary from 2 seconds at saturation to 6 seconds in free flow conditions over the range of 600-1700 vph and speeds from 15-55 mph. In addition, this variable may be user defined. The default merge headway is synonymous with default merge distance since merge distance increases as speed increases.

In other words, the probability of any two vehicles being close enough to restrict a vehicle in the adjacent lane from entering in the hour is the above probability of opposition multiplied by the number of default merge headways (minimum merge time gaps available) in the hour.

C. For Fixed Object/Single Vehicle Conflicts and Accidents:

These accidents represent those type of crashes in which the driver leaves the confines of the outside or near-side pavement lane and strikes a roadside object which may be either fixed or moveable (trees, pedestrians, bicycles etc.). One would appreciate that, in an effort to incorporate roadside (non-intersection) capability, this module could incorporate input from current fixed objection calculation sources, including the FHWA "Roadside" program which is capable of being altered to accept pedestrians and other moveable fixed objects with independent speed sensitive severities. However, because fixed objects are generally small contributors to total intersection annual accidents, it is preferable to use a simplification with a default rate-based (exposure) generator to develop stable Fixed

Object/Single Vehicle Intersection Accident estimates without the need to collect significant additional fixed object type and location data. Use of this method greatly reduces the time necessary to collect data on a particular intersection without sacrificing the predictive abilities of the traffic safety model. The form of the default fixed object model is:

Accidents/hr = [Lane volume/Total Entering volume] *
[Entering Vehicles * Fixed Object Accident Rate (acc/mev)]

where:

Fixed Object Accident Rate (accidents/mvm) = Individualized exposure models from prior research for different traffic control types of the following general form: (18)

$a_1 - b_1$ (Entering ADT) * (Percent Intersectional Fixed Object Accidents)

Excluding Fixed Object/Single Vehicle Accident estimations, each of the above probabilities (P) are calculated under the assumption that the arriving flows are random and at relatively low volumes. Under this assumption, the Poisson Distribution, which is also the most commonly accepted distribution for accident estimation, appears generally adequate recognizing that Poisson may not be as appropriate for heavy traffic conditions since vehicle lengths and thus successive headways are not independent as required by the assumption of random arrivals. Future modifications may refine this approach.

D. Summary of Annual Statistically Probable Conflict Opportunities and Assumptions

With this formulation of competing probable events for each conflict type and its expansion to multiple lanes of one approach and then to all approaches of an intersection, an annual SPCO expectation can be developed representing the summation of individual conflict types. And with the summation of all hours and days in a year, the process of predicting annual intersection accidents may be expressed as:

$$\text{Number of Annual Accidents} = \left[\sum_{1}^{n} \text{SPCO (Conflict Type/hour)}_t \right] * \text{[MODEL SPCO's/Accident]}$$

where:

n = hours of the year,

Conflict Type = Each Angle, Rear-end, Sideswipe and Fixed Object/Single Vehicle SPCO

[MODEL SPCO's/Accident] = a stable, calibrated and validated relationship between all types of summed annual conflict opportunities and annual accidents for <u>each type</u> of traffic control device over typical volumes, typical approach speeds, typical geometry, and typical environments, drivers and vehicles.

To formulate the above theoretical formats into a practical working process for an intersection, a finite element analysis approach to intersection accidents is used which breaks the accident models and each intersection into discrete elements based on the following format and assumptions:

(a) the above similarly formatted accident models (angle, rear-end, side-swipe, and single vehicle/fixed object) each of which use discrete elements such as lanes, turnbays, approach speed, traffic control type, and traffic flow rates (based on normalizing assumptions regarding drivers, vehicles and environments) are used to create the statistical likelihood that two competing vehicles will be on intersecting and conflicting paths of advancing and opposing vehicles but only for a finite and discrete period of time which thereby creates the opportunity for conflict and defines a Statistically Probable Conflict Opportunity,

(b) for each of the Statistically Probable Conflict Opportunity Models, the conflict is defined as the statistical union of the probability of two assumed mutually exclusive events including 1) the probability of vehicle arrival for a particular movement, and 2) the probability of vehicle opposition to the arrival with both probabilities using the Poisson Distribution or similar statistical likelihood function but with the probability defined only during the period of time the arriving vehicle is exposed to conflict,

(c) a mathematical expectation format which uses speed-based weightings calibrated to a typical driver visual peripheral perceptual capability to sum each of the probable conflict opportunity event models into an annual conflict opportunity estimate and from this summation to estimate annual accidents using a stable linear mathematical relationship between total summed annual probable conflict opportunities (regardless of type) and total annual accidents at an intersection as a function of each traffic control type including "Yield" ," Two-Way and All-Way Stop" control and pre-timed or actuated "Signal" control;

(d) mathematical models created from prior research to estimate annual fatal and personal disabling injury involvements given the speed of operation and annual accident involvements,

(e) In addition, a number of assumptions are also required to model both probability events and annual accident expectations as a summation of the probable events including:

1. Each intersection or access opening is assumed to be sufficiently separated from adjacent access and intersection openings such that the driveway or intersection under study is assumed to be an isolated, mutually exclusive entity,

2. The terrain is assumed as level on all approaches such that no driveway aprons, sidewalks, valley gutters, or other obstructions interfere with normal operational maneuvers,

3. Sight distance is assumed as sufficiently clear on all approaches so as not to interfere with normal operational maneuvers,

4. All vehicles are normalized as typical vehicles used in AASHTO driveway, intersection and/or roadway planning and design, and conform to typical vehicle physical and performance characteristics such that the intersections or driveways where this software is used have normal amounts of vehicle induced accidents (e.g. no excessive number or character of vehicle failures such as numerous "bald tires" or "vehicle fires"),

5. All drivers and passengers are normalized as typical drivers and passengers used in AASHTO driveway, intersection, and/or roadway planning designs such that the physical, mental, and emotional characteristics required to safely and efficiently accomplish the basic driving tasks of Control, Guidance, and Navigation are performed, and locations where this software is used have normal amounts of human induced accidents (e.g. no excessive human failures such as alcohol or drug abuse as in low resource areas, or gross age or handicap impairments which may affect operational abilities as in certain retirement areas of Florida either of which may produce non-normal accident expectation responses),

6. The environment is normalized as the typical environment used in AASHTO driveway, intersection and/or roadway planning and design such that the driveways, intersections and/or roadways where this software is used have normal amounts of environmentally induced accidents (eg. no unusual weather conditions such as consistently icy roads in Florida, or excessive fog in Nevada, etc. which produce non-normal accident responses),

7. Other normalizing assumptions pertinent to each particular driveway, intersection or roadway and traffic control type (eg. Drivers Perception/reaction time, vehicle length, stop sign setback, turning radii, turn bays, speeds, signal timing, etc.) which are generally user defined,

8. In the formulation of the conflict/accident relationships, because existing accident data-bases generally segregate accident occurrence into four major categories which include angle, sideswipe, rear-end, and fixed object/single vehicle accidents, only these four accident types are used. Thus the final significant assumptions used in modeling annual accident expectation is the additivity of each of the following assumed mutually

exclusive and independent models which are used to produce total annual expected conflict opportunities:

Accidents/year = f{Conflicts[(Angle)+ (Rear-end)+ (Sideswipe)+ (Fixed Object)]}

The assumed additivity of each of these 4 models is based on the assumption that since each of them are constructed using the same general statistical format, the commonality of format creates a commonality of response,

9. And lastly, given the formation of annual accidents from the above, a stable relationship is also assumed to exist between speeds, annual accidents, and injury and fatality occurrences as:
Severities/year = f{Accidents/yr, speed, accident: injury and injury: fatality ratios}.

Note that the violation of any one or more of the above assumptions should generally lead to an increase in annual accident and injury predictions, and thus the estimates of annual accidents and involvements from this approach should be generally conservative.

In assuring conformance to these assumptions and to examine the predicted vs. actual accident expectancies at individual intersections, it is desirable to either validate the model to individual intersections or to validate the model statistically to areas such as Cities, Counties or State Highway Districts where the above assumptions are expected to remain relatively stable at the local level. For instance, since the software was calibrated using national data-base sources, the model may respond more accurately in locations such as the Midwest where environmental conditions include both icy and dry weather accidents as opposed to southern Florida where no icy accidents occur. In southern Florida, this approach may overestimate annual accident occurrence simply because icy accidents are expected by the models, yet these type of accidents do not occur in southern Florida. Conversely in northern Alaska, this approach may underestimate accident occurrence simply because icy accidents may occur more frequently locally than a model developed from a national database may suggest. And as an alternative to both of these scenarios, human conditioning to the local weather in each local area (such as experienced snow driving capability in Alaska) may counteract the local accident expectancies, such that the national database remains acceptably accurate over all environmental conditions.

With these discrete elements in a software format interacting among all competing probable events, annual accident expectations at both intersections and ultimately within defined highway corridors (a summation of isolated intersections and driveways augmented by ran-off-the road events) becomes possible. However given that such software is only a two-dimensional representation of annual accident events (even with the addition of elevation or grade components), it must be re-iterated that a true 3-dimensional perspective of highway safety and its annual expectations can only be achieved by requiring that the data be input and the interpretation of the output be carefully examined, and properly calibrated where required to existing accident and severity data, by qualified traffic engineering professionals.

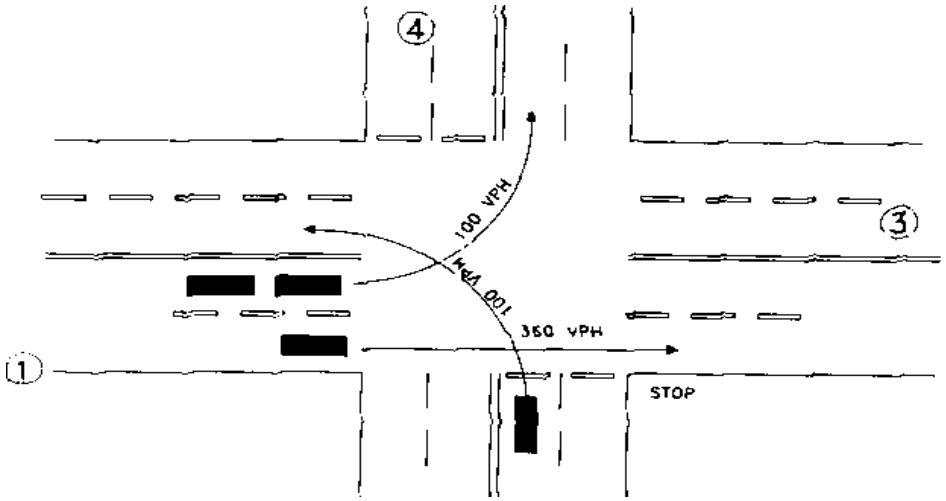
III. Example Software Model Operation

The software program rests upon the development and application of Statistically Probable Conflict Opportunity (SPCO) Accident Event Models where the production of a conflict follows a similar format and all are summed to provide annual SPCO's regardless of type. With this approach, there is no attempt to predict the actual type of accident which may occur as a result of conflicts, but only to produce an estimate of annual theoretical conflicts and from these to predict annual accidents. Thus no relationship is expected between types of conflict opportunities and types of actual accident outcomes simply because accidents often are stimulated by one conflict type only to result in a completely different accident type, where the second conflict type may appear less harmful to one driver than the original conflict.

As an example using Figure 1 which has only three entering movements in the peak hour and no traffic entering from approaches 3 or 4. The only traffic flowing into the intersection are two lanes of traffic from the major approach 1, of which a number of vehicles turn left and a number of vehicles proceed straight through the

intersection. Traffic from minor stop-controlled approach 2 turns left across the main traffic flow paths. Also for the purpose of simplicity, none of the approaches has protected turn bays, and each has two lanes of flow. On the minor stop controlled approach (Direction 2), 100 vph enter (24 foot approach-stop controlled, 30 mph with critical gap = 7.75 sec.) turning left across the path of 100 vph turning left on the major street (critical gap = 5.65 sec.) and also across the path of 360 vph through vehicles on the major street (24 foot approach - no traffic control at 45 mph). Note that traffic flows and opposition flows which are not possible reduce to zero and are left out of the example.

Figure 1
Example Intersection SPCO Calculations



A. ANGLE Statistically Probable Conflict Opportunities with no protected bays, the Angle Conflict SPCO's for all movements are:

1. For the Left SPCO on major(100 vph) roadway due to left(100 vph) on the minor street:

SPCO(Angle Conf./hour) = Approach Volume/hr* P(SPCO-Angle Conf/veh)
= 100 vph * P(SPCO-Angle Conflict/vehicle)

where:
P(SPCO-Angle Conflict/veh) = P(Arrival)* P(Opposition during arrival exposure time)
where:
P(Arrival) = 1.0 and thus this conflict can occur, and
P(Opposition during arrival) = P(1) = $(1 - e^{-qt/3600})$, where:
q = arrival rate of opposing flow(100 vph), and
t = exposure time arrival flow (5.65 sec. critical gap)

P(SPCO-Angle Conf./veh) = $1.0 * [1-e^{-(100 * 5.65/3600)}]$
= 1.0 * [1-0.8547] = 0.1453, and thus

for the Left minor to Left major movement:
SPCO(Angle Conf/hr) = 100 vph * 0.1453 SPCO(Angle Conflicts/vehicle)
= 14.53 SPCO(Angle Conflict Opportunities/hour)

2. For the Through SPCO on major(360 vph) roadway due to left volume (100 vph) on minor:

SPCO(Angle Conflicts/hr) = 360 vph * P(SPCO-Angle Conflict/vehicle)
where:
P(SPCO-Angle Conflict/veh) = P(Arrival) * P(Opposition during arrival exposure time)
where:
P(Arrival) = 1.0 and thus this conflict can occur, and

P(Opposition during arrival) = P(1) = $(1 - e^{-qt})$,
where:
q = arrival rate of opposing flow(100 vph), and
t = exposure time of arrival flow (7.9 seconds), and
the arriving flow (q) on the major street has no traffic control (uncontrolled approach) and is thus exposed to conflict from the sidestreet for a time which is dependent on the time to stop safely given the blockage of the intersection by for example a stalled entering vehicle. The safe stopping time is a function of the approach speed and ranges from 6.8 sec. at 20 mph to 8.5 sec. at 55 mph, thus assume 7.9 sec. at 45 mph.

P(SPCO-Angle Conflicts/veh) = $1.0 * [1 - e^{-(100 * 7.9/3600)}]$
= 1.0 * [1-0.80296] = 0.1965, and thus

SPCO(Angle Conflicts/hr) = Approach Vol/hr* P(SPCO-Angle Conf/Veh)
= 360 vph * 0.1965 SPCO(Angle Conflicts/vehicle)
= 70.74 SPCO(Angle Conflict Opportunities/hour)

3. For the Left SPCO on minor (100 vph) roadway due to left volume (100 vph) on major roadway:
SPCO(Angle Conflicts/hr) = 100 vph * P(SPCO-Angle Conflict/vehicle)
where:
P(SPCO-Angle Conflict/veh) = P(Arrival) *P(Opposition during arrival exposure)
P(Arrival) = 1.0 and thus this conflict can occur, and
P(opposition) = P(1) = $(1-e^{-qt})$,
where:
q = arrival rate of opposing flow(100 vph), and
t = exposure time of arrival flow (7.75 sec. Critical. Gap)
P(SPCO-Angle Conflict/veh) = $1.0 * [1-e^{-(100*7.75/3600)}]$
= 1.0*[1=-0.8063] = 0.1937, and thus

SPCO(Angle Conflicts/hr) = 100 vph * 0.1937 SPCO Angle conf./veh.
= 19.37 SPCO (Angle Conflict Opportunities/hour)

4. For the Left SPCO on minor(100 vph) due to through volume(360 vph) on major:
SPCO(Angle Conflicts/hour = Approach Vol/hr * P(SPCO-Angle Conf/Veh)
=100 vph * P(SPCO-Angle Conflict/vehicle)
where:
P(SPCO-Angle Conflicts/veh)= P(Arrival) * P(Opposition during arrival exposure time)
where:
P(Arrival) = 1.0 and thus this conflict can occur, and
P(Opposition during arrival) = P(1) = $(1 - e^{-qt})$
where:
q= arrival rate of opposing flow (360 vph), and
t= exposure time of arrival flow(7.75 sec critical gap)

P(SPCO-Angle Conflicts/veh) = $1.0 * [1.0 - e^{-(360*7.75/3600)}]$
= 1.0 * [1-0.4607] = 0.5393, and thus

for the Left minor to Through major movement:
SPCO(Angle Conflicts/hour) = 100 vph * 0.5393 SPCO Angle Conf./veh.
= 53.93 SPCO(Angle Conflict Opportunities/hour)

In summary, for the 100 vehicles turning left during the hour from the stop controlled side-street, a total of 158.76 statistically probable conflict opportunities with the 100 lefts from the major street and 360 through vehicles on the major street will occur. Whether from left, through or right movements, each interaction will develop similar conflict opportunities which are then summed for the hour to generate Total Angle SPCO's for the hour. And with the use of k factors (or peak hour/daily ratios or with individual hours of the year), the Angle SPCO's can be extended to daily and annual Angle Conflict Opportunities where the number of days of operation of the driveway or intersection may range from approximately 250 days per year for a driveway

from an office building (8am to 5pm weekdays) up to 365 day per year for a typical intersection uninfluenced by summertime school hours.

B. REAR-END Statistically Probable Conflict Opportunities with no protected bays, the Rear-end Conflict SPCO's for all movements are:

For 100 vph on the minor street (7.75 seconds of left turn critical gap with the Probability of Stop on the minor street = 1.0 waiting to enter a 100 vph left turn and 360 vph through flow on a major street:

1. For the Left SPCO on minor(100 vph) due to left volume(100 vph) on major:

SPCO(Rear-end Confl/hour) = Approach Volume/hr* P(SPCO-Rear Conf/Veh)
= 100 vph * P(SPCO-Rear Conflict/vehicle)

where:
P(SPCO-Rear-end Conf./veh)= P(Stop Arrival)*P(Opposition from Rear)
where:
P(Stop Arrival) = 1.0 for "Stop" control, and
P(Opposition from Rear) = P(1) = $(1 - e^{-qt})$
where:
q = arrival rate of rear flow (99 vph), and
t = exposure time of stopped vehicles or Stop Duration,
and:
Stop Duration = $\{[(1-e^{-m})* e^{m}]/q\}$ - Critical Gap
= $\{[1- e^{-\{100*7.75\}/3600}]*[e^{\{100*7.75\}/3600}]$ / [99 vph/3600]} - 7.75
= ([0.1937]*[1.240]/ 0.0277) - 7.75
= 8.648 - 7.75
= 0.897 seconds

P(SPCO-Rear-end Conf/veh) = 1.0 * $[1.0 - e^{-\{99*.897\}/3600}]$
= 1.0*(1 - 0.9754)
= 0.0246, and thus
SPCO(Rear-end Conflicts/hour) = 100 vph *0.0246 (SPCO-Rear/veh)
= 2.46 SPCO (Rear-end Conflict Opportunities/hr)

2. For the Left SPCO on minor (99 vph) due to through volume(360 vph) on major:

SPCO(Rear-end Confl/hr) = Approach Volume/hr*P(SPCO-Rear Confl/Veh)
= 100 vph * P(SPCO-Rear Conflict/vehicle)

where:
P(SPCO Rear-end Conflicts/veh)= P(Stop Arrival)* P(Rear Opposition)
where:
P(Stop Arrival) = 1.0 for stop control, and
P(Opposition from Rear) = P(1) = $(1 - e^{-qt})$,
where:
q= arrival rate of rear flow(99 vph), and
t = exposure time of stopped vehicles or stop duration,
and:
Stop Duration = $\{[(1-e^{-m})* e^{m}]/q\}$ - Critical Gap
= $[1 - e^{-\{360*7.75/3600\}}]*e^{\{360*7.75\}/3600}$/[360vph/3600])-(7.75)
= ([0.5392]*[2.171]/ 0.100) - 7.75
= 11.706-7.75
= 3.956 seconds

P(SPCO-Rear-end Conflicts/veh) = 1.0 * $[1-e^{-[99vph*3.956)/3600}]$
= 1.0*(1 - 0.8959) = 0.1041 and thus
SPCO(Rear-end Conflicts/hour) = 100 vph * 0.1041 (SPCO-Rear/veh)
= 10.41 SPCO (Rear-end Conflict Opportunities/hr)

In this rear-end conflict opportunity example, 100 vph entering from a minor stop controlled approach into an intersection with 100 vph left turn and 360 vph through volume on the major approach will wait approximately 0.9 seconds due to the 100 vph major street left turn and 3.9 seconds due to the 360 vph

through volume on the major street. Because of this waiting period, each vehicle stopping on the minor approach will experience 2.46 SPCO's due to the major left (100 vph) and 10.41 SPCO's due to the through (360) volume, and thus this approach #2 with 100 vehicles stopping in the hour will have 12.87 statistically probable rear-end conflict opportunities per hour.

C. SIDE-SWIPE Statistically Probable Conflict Opportunities with no protected bays, the Side-swipe Conflict SPCO's for all movements are:

For 460 vph on the major street (with 2 lanes for 360 through and 100 vph turning left) operating at 45 mph, the FHWA "Roadside 4.2" accident model places approximately 14 percent of the through flow (50 vph) in the left lane with 86 percent (312 vph) of the through flow in the right lane. Conversely, 86 percent of the left turn flow (86 vph) is already in the left lane with 14 percent (14 vph) in the right lane. Thus 14 vehicles must move from the right to the left lane where the left lane is already occupied by 50 through vehicles and 86 left turn vehicles. In addition, for 100 vehicles turning left from the sidestreet with no through movement, from "Roadside," it is assumed that 86 vehicles are in the left lane and thus 14 vehicles must merge into the left lane with the possibility of sideswipe. Using a default merge headway of 2.0 seconds (assuming LOS E saturated conditions):

1. For the Right to Left SPCO on the major approach (100 vph left turn) which are vehicles turning left on the major approach in the far right lane and must therefore enter the left lane to turn left:

SPCO(right to left sideswipe Conf)/hour=Rt.to Left Volume/hr * P(SPCO sideswipe Conflicts/veh)
= 14 vph * P(SPCO Rt. to Lt. sideswipe/veh)

where:

P(SPCO Rt.-Lt. sideswipe/veh)= P(Arrival or lane switch) * P(Opposition to switch)

where:

P(Arrival or lane switch) = P(Lane shift)= 1 .0(left turn vehicles must shift left)

and:

P(Opposition to lane shift) = probability of arrival of 2 or more vehicles in the entry lane with less than 2 seconds headway during the hour is:

P(> =2) = 1-[P(0)+P(1)],

where:

$P(0) = e^{-[q*t/3600]}$

and:

q = arrival rate in left lane=136 vph[lefts(86)+ thru's in left(50)],

t = default merge headway = 2.0 seconds thus

$P(0) = e^{-[136*2/3600]} = 0.9272$, and

$P(1) = e^{-[q*t/3600]} * [qt/3600]$

$= e^{-[136*2/3600]} * (136*2/3600)$

$= e^{-[0.07555]}*[0.07555] = 0.9272*0.07555 = 0.0701$

P(Opposition to Lane shift(ht <2)= 1-[0.9272 + 0.7001]
= 0.00270, and per Hour (1800,2 sec. intervals/hour)
= 0.00270*1800 = 4.869, and

P(SPCO Rt. to Lt. Sideswipe/veh) = P(Arrival or lane switch) * P(Opposition to switch)
= 1.0 * 4.869 = 4.869, and thus

SPCO(Rt. to Lt.sideswipe Conf./hr) (eg. from 100 vph-left turn)= Rt. to Lt. Shift/hr *
P(SPCO Rt. to Lt. sideswipe/veh)
= 14 vph * 4.869 SPCO Conflict Opportunities/veh
= 68.16 SPCO(Rt. to Lt. Sideswipe Conflict Opportunities/hour)

2. For the Left to Right SPCO on the major approach (360 vph through). These are through vehicles on the major approach which are in the left lane and will enter the right lane depending on the degree of utilization of the left lane for turning:

SPCO(left-right sideswipe Conf/hr) = Lt.to Right Volume/hr * P(SPCO sideswipe Conflicts/veh)
= 50 vph * P(SPCO Lt. to Rt. Sideswipe Conflicts/veh)

where:
P(SPCO Lt.to Rt. Sideswipe/veh)= P(Arrival or lane switch) * P(Opposition to switch),
where:
P(Arrival or lane switch) = P(Through Vehicles desire to shift out of Left lane)
= Left Lane Utilization Surrogate = (Left Volume/Left Capacity)
= 100 vph / (3600/5.65 sec/veh) = 0.156
where:
5.65 sec/veh is the gap needed to make one left turn from the major to the minor street assuming no opposition to the left turn. This methodology of defining capacity ignores the queue buildup in the left lane due to opposition to the left turns (which may not occur at low volume levels). Through volumes in the shared lane are also ignored since all of these may desire to shift out of the shared lane. Any opposition to the left turn or added through traffic in the merge lane will encourage more lane shifting and sideswipe accidents, thus the above lane utilization surrogate is a conservative approach which minimizes (underestimates) lane shifts and sideswipe conflicts.

and:
P(Opposition to lane shift) = probability of arrival of 2 or more vehicles in the entry lane in less than 2 seconds during the hour
= P(> =2) = 1-[(P(0) + (P(1)]

where:
P(0) = $e^{[-qt/3600]}$,
and:
q = arrival rate in through lane
= 314 vph [310(thru) + 14(lt)vph], and
t = default merge headway= 2.0 seconds or user input.
= $e^{-[324*2/3600]}$
=$e^{-[0.1800]}$ = 0.8352
and:
P(1) = $e^{[-qt/3600]}$ * [qt/3600]
= $e^{-[324*2/3600]}$ * [324*2/3600]
= $e^{-[0.1800]}$*[0.1800 = 0.8352*0.1800=0.1503, and thus

P(Opposition to Lane shift(ht <2) = 1 - [0.8352 + 0.1503]
= 0.0144, and per hour (1800,2 second intervals/hour)
= 0.0144*1800
= 25.90 and,

P(SPCO Lt. to Rt. Sideswipe/veh) = P(Arrival or lane switch) * P(Opposition to switch)
= 0.157 * 25.90
= 4.066 and finally,

SPCO(Lt. to Rt.side)/hr (eg., 100 vph-left turn) = Lt. to Rt. Shift/hr * P(SPCO Lt.to Rt. sideswipe Conf/veh)
= 50 vph * 4.066 SPCO sideswipe conflicts/veh
= 203.3 SPCO(Lt. to Rt. Sideswipe Conflict Opportunities/hour)

3. For the Right to Left SPCO on the minor approach (100 vph left). These are left turning vehicles on the minor approach which are in the right lane and must enter the left to turn left:
SPCO(right to left sideswipe)/hour = Rt. to Left Volume/hr * P(SPCO sideswipe/veh)
= 14 vph * P(SPCO Rt. to Lt. sideswipe/veh)
where:
P(SPCO Rt.to Lt. sideswipe/veh)= P(Arrival or lane switch) * P(Opposition to switch),
and:
P(Arrival or lane switch) = P(Lane shift)
= 1.0 (left turn volume must shift left), and

P(Opposition to lane shift)= probability of arrival of 2 or more vehicles in the entry lane in less than 2 seconds during the hour

$P(>=2) = 1-[(P(0) + (P(1)]$

where:

$P(0) = e^{-[q*t/3600]}$

and where:

q = average arrival rate in left lane [86 vph],

t = default merge headway = 2.0 seconds.

$P(0) = e^{-[86*2/3600]} = e^{-[0.1555]} = 0.9534$, and

$P(1) = e^{-[q*t/3600]}$

$=(e^{-[86*2/3600]1}) * (86*2/3600)$

$=(e^{-[0.1555]}*[0.04778]= 0.9533*0.1555 = 0.0455$

and:

P(Opposition to Lane shift(ht<2)= 1- [0.9533 + 0.0455] = 0.0011,

and since per hour (1800,2 sec. Intervals/hour)= 0.0011*1800 =1.99 , and

P(SPCO Rt.to Lt. Sideswipe/veh)= P(Arrival or lane switch) * P(Opposition to switch)

= 1.0*1.99

= 1.99 , and thus

SPCO(Rt. to Lt.side)/hr (eg., 100 vph-left turn)= Rt. to Lt. Shift/hr * P(SPCO Rt.to Lt. Sideswipe Conf/veh)

= 14 vph * 1.99 SPCO Sideswipe Conflicts/veh

= 27.8 SPCO (Rt. to Lt. Sideswipe Conflict Opportunities/hour)

The sideswipe conflicts from Left to Right are assumed to be zero, since all traffic will be turning left, there is no reason for a normalized driver to switch from the left turn lane to the right lane, and thus no sideswipe accident will occur from left to right traffic on the minor approach. In the above example, the sum of all sideswipe SPCO's is 302.5 total SPCO's per hour.

As with angle and rear-end conflict opportunities, each of the sideswipe movements to and from each of the lanes on each approach are summed to develop an hourly SPCO for all sideswipe maneuvers which may occur and are then summed to generate Total Sideswipe SPCO's for the hour. With the use of k factors (or peak to daily ratios), the Sideswipe SPCO's can be extended to daily and annual Sideswipe Conflict Opportunities.

D. Fixed Object/Single Vehicle Statistically Probable Conflict Opportunities with or without protected turn bays is replaced by an exposure-based model for all movements.

As an example, assume an entering flow of 460 vph on the major approach to a stop controlled intersection where 360 vph proceed through and 100 vph turn left from the major approach and 100 vph enter from the minor approach which has stop control. With the total intersection entering flow of 560 vph, from the embedded stop controlled accident rate models, the accident rate for a stop-controlled intersection at this volume is 1.15 Accidents/mev-yr. Assuming k = 0.10 and 365 days, total annual accidents are:

Accidents/yr = 1.15 Acc/Mev * [560 vph * 365]/[0.10*1,000,000] = 2.35

Since also from prior research, the percent of fixed object/single vehicle accidents at assumed rural stop controlled intersections with this volume level is approximately 9 percent or (2.35*0.09) 0.22 Fixed object/single vehicle accidents for all vehicles on all approaches are estimated to occur annually for these volumes entering the intersection. The distribution of the fixed object/single vehicle accidents back to entering vehicles results in (360/560*0.2123) 0.136 Accidents/year for the 360 vehicles and 0.038 for the 100 vehicles entering from the major through approach, and also 0.038 fixed object accidents per year for the 100 vph entering from the minor approach. However, since each of the approaches are 2 lanes (24 feet), the fixed object/single vehicle accidents may be assumed to occur only to vehicles in the right-most lane, thus all of the annual accident estimates are by assumption

divided by 2.0 (2 lanes exist on each approach) for a total fixed object or single vehicle annual accident estimate of 0.11 (0.22/2).

IV. Summary of Conflict Opportunities and Conversion to Annual Accidents & Severities

Using the above example, the summarization and conversion of SPCO's to annual accidents, injuries and fatalities follow assuming a "peak to daily factor" of 0.10 (or hourly) for 365 (or variable) days:

A1.	Angle	= (100 vph left from major street)	= [(14.5*365)/0.10]	= 53,064
A2.	Angle	= (360 vph thru on major street)	= [(70.7*365)/0.10]	= 258,423
A3,4	Angle	=(100 vph left from minor street)	= [(73.3*365)/0.10]	= 267,601
B.	Rear-end	=(100 vph left from minor street)	= [(12.9*365)/0.10]	= 46,979
C1.	Sideswipe	= (Rt to Lt on Major street)	= [(68.1*365/0.10)]	= 248,772
C2.	Sideswipe	= (Lt to Rt on Major street)	= [(203 *365/0.10)]	= 742,142
C3.	Sideswipe	= (Rt to Lt on Minor street)	= [(27.8*365/0.10)]	= 101,293

Having identified each of the annual Statistically Probable Conflict Opportunities (SPCO's) emanating from individual traffic movements, each of the conflict types must be converted to annual accidents. In this conversion, a family of regression models were developed for each of the traffic control types of "Yield", "Two-way Stop", "4-Way Stop", and "Signals" (referred to as the TSafe Models) using the following form to define the relationship of annual accidents to annual SPCO's:
Annual SPCO Conflicts/Accident =f[(Minor Approach-Vpd)+ (Major Approach-Vpd)+Minor Terms

For brevity, none of the individual Conflict:Accident TSafe models are presented here. For the above example of a "Stop" controlled intersection, the calibrated TSafe Angle Conflict: Annual Accident Model Ratio will require 1,193,756 Angle SPCO's before 1 angle accident will occur. This can be compared to other theoretical conflict to accident studies by General Motors which suggested conflict opportunities per accident ratios range from 1.4 - 4.4 million :1 (depending on the type of conflict) and which indicates that the TSafe "Stop Control" model conflict ratio of approximateely 1.2 million SPCO's : 1 accident is reasonable.(6)

The above sample conversion of annual theoretical angle conflicts to angle accidents is made possible by a unique calibration of SPCO's to numerous historical accident research records for each of the typical traffic control types, over typical traffic volumes and typical geometries and speeds, and also rests upon the capability of the drivers speed-based visual peripheral perceptive capability during each of the theoretical conflict types.(18) This calibration recognizes that angle, rear-end and sideswipe conflicts are each speed dependent phenomena where the drivers visual peripheral perceptive capability diminishes with increasing speed. Using the drivers Angle Conflict peripheral visual capabilities as a base, the calibration of the TSafe model for both rear-end and sideswipe conversion of SPCO's to annual accidents for each traffic control type is based upon:

TSafe Ratio Angle Accidents = TSafe Model /1. Here, 1.0 represents an assumed 180 degree field of frontal peripheral vision (which by assumption collapses to 120 degrees at speeds in excess of 60 mph) with no assumed increase in angle accident expectation as a result of speed induced peripheral collapse.(19) In addition, an assumed 0.3 seconds of visual search time is by assumption required to perceive an incident in this field over all speed ranges with no head movement involved in the visual perceptive function, (20) and

TSafe Ratio Rear-End Accidents =
Conversion of Conflict Opportunities to Annual Accidents cannot be divulged at this time.
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TSafe Ratio Sideswipe Accidents =

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Using the above, the angle, rear-end and sideswipe SPCO conflict to annual accident conversion is:

A1. Annual Angle Accidents/yr = 53,064 SPCO/ (Undisclosed) Conf/Acc = 0.0485
A2. Annual Angle Accidents/yr = 258,423 SPCO/ (Undisclosed) Conf/Acc = 0.2165
A3,4. Annual Angle Accidents/yr = 267,601 SPCO/ (Undisclosed) Conf/Acc = 0.2242
Angle Total = 0.489

B. Annual Rear-end Accidents/yr = 46,979 SPCO / (Undisclosed) Conf/Acc = 0.1476
Speed Variable

C1. Annual Sideswipe Accidents/yr = 248,772 SPCO / (Undisclosed) Conf/Acc = 0.0313
Speed Variable
C2. Annual Sideswipe Accidents/yr = 742,142 SPCO/ (Undisclosed) Conf/Acc = 0.0933
Speed Variable
C3. Annual Sideswipe Accidents/yr = 101,293 SPCO / (Undisclosed) Conf/Acc = 0.0085
Speed Variable
SideswipeTotal = 0.133

And in summary, total annual Traf-Safe Software accidents equal:

Angle Accidents/year	= 0.489
Rear-end Accidents/year	= 0.148
Sideswipe Accidents/year	= 0.133
Fixed Object/Single Vehicle Accident/yr	= 0.11
Total Annual Accidents	= 0.87

Having identified the annual accident estimate of 0.87 accidents per year which are composed of angle, rear-end, sideswipe and fixed object/single vehicle accidents, the next task is to convert the accidents into personal injuries or involvement. To accomplish this, prior research is utilized to separate annual accidents first into persons injured and property damage only accidents, and secondly to separate the persons injured into persons injured fatally and persons injured non-fatally using an Injury/kill ratio, where both models are functions of vehicle speeds using the following:

1. Injuries/yr = Total Annual Accidents* 2[0.228 + (0.00000003 * Speed^4)], for >30 mph
   = Total Annual Accidents * [0.75 * (Speed/100)], for <=30 mph.

   These injury regressions are from Solomon's data and are used for each of the conflict types. However, since injury accidents have an average auto occupancy of 1.7 persons per vehicle(Accident Facts, NSC) and Fixed Object or Single vehicle accidents generally involve only a single occupant, a conservative approach to personal injury estimation is to eliminate Fixed Object/Single Vehicle accidents from the calculation of annual personal injuries and fatalities. With this approach, angle injury estimates are developed from the highest approach speed using individual injury models for speeds above and below 30 miles per hour, and rear-end and sideswipe injuries are developed separately for each approach speed, and all injuries summed for all approaches. Also since Solomon refers to persons injured per 100 accident-involved vehicles, this is assumed synonymous with injuries per 100 vehicles and injuries per 50 accidents, with a further assumption that all such injuries are disabling events which represent approximately 50 percent of total injury (disabling + non-disabling) involvements. (22)

2. Fatalities/year = (Injuries/yr)/)/[(201+(0.00000072* Speed^4) - (25.1 *Sqrt (Speed)] ,
   where:
   Speed = highest approach speed-mph.
   This regression form is from NHTSA data, and is used with the above injury estimates from each approach for each conflict type to estimate annual fatalities which are then summed for all approaches.(23)

While regression statistics are not provided for any of the above models, it may be recognized that the object of this approach is not to provide an absolutely accurate estimate of injury and fatal involvements but rather to provide a realistic accuracy with stable precision, and thus a more responsive overall model to more precisely predict involvements (which may even include driver error in the future).

As an example of this approach, the annual accident total is 0.87 accidents per year with the highest approach speed of 45 mph and 1.7 persons per vehicle, and eliminating the Fixed Object/Single Vehicle accidents from Total Accidents, annual injuries and fatalities are estimated:

Annual SPCO Accidents = Total Accidents - Fixed Vehicle and Single Vehicle Accidents/yr
= 0.87 - 0.11
= 0.76 (excluding fixed object/single vehicle)

However, speeds on the major and minor roadways are 45 and 30 mph respectively, and thus each must be segregated to determine injuries based on their appropriate speeds. For the major roadway, 0.61 annual accidents are caused by all angle, major-direction rear-end and major-direction sideswipe accidents, and 0.15 accidents per year by minor-direction rear-end accidents. Thus for speeds above 30 mph and for the major direction (45 mph):

Injuries per year (>30) = Annual Accidents * 2[0.228 + (0.00000003 * Speed^4)]
= 0.61 Annual accidents * 2[0.228 +(0.00000003 * 45^4)
= 0.61 * 2(0.228+0.00000003*4100625)
= 0.61 * 2(0.228+0.1230)
= 0.61 * 2(0.3510)
= 0.43 injuries per year,

and for the minor direction 30 mph approach:

Injuries per year (<30) = Annual Accidents * [0.75 * (Speed/100)]

= 0.15 Annual accidents * [0.75 * 0.30]
= 0.15 * 0.225
= 0.04

Thus for both approaches, the annual disabling injuries are estimated at 0.47 (or 0.43+0.04) per year.

From the above annual injuries, the estimate of fatalities from all approaches is:

Fatalities/yr = (0.47 Personal Injuries/yr)/[(201+(0.00000072* Speed^4) - (25.1 *Sqrt (Speed)]
= (0.47 Personal Injuries/yr)/[(201+2.9-168.8)
= (0.47 Personal Injuries/yr)/35.112
= 0.013

In summary of the above example, where an intersection with 4600 vehicles per day proceeding in the major direction (3600 through vehicles and 1000 left turning vehicles) at 45 miles per hour is interfered with by 1000 vehicles per day turning left from a two-way "Stop" controlled side-street with an approach speed of 30 miles per hour, 0.87 total accidents are estimated to occur each year these volume levels exist, and of these accidents, 0.47 personal disabling injuries are estimated to occur (or 4.7 injuries in 10 years of operation or approximately 1 every 2 years), which will include 0.013 fatalities per year (or approximately 1 fatality in 100 years of operation). Since 0.87 accidents occur each year with 0.47 personal disabling injuries (including fatalities) from these accidents, under the assumption of 2 injuries per accident, 0.47 injuries by assumption represent 0.23 injury accidents which leaves 0.64 (0.87-0.23) property damage only (PDO) accidents/year.

With respect to Safety Management Cost Impacts, and under the assumption that the above is a new driveway to a new development site, and that each fatality, disabling injury and property damage involvement are valued at $1,000,000; $15,000; and $1,000 respectively (National Safety Council costs-1990's), it may be concluded that the Safety cost of this new driveway is $20,700 annually [(0.013*$1,000,000)+(0.47*$15,000)+(0.64*$1,000)], or for a 20 year lifetime the Safety Impact may be $414,000. However, it must also be recognized that a Safety Impact cost should not be assigned until it has been determined that the new intersection is designed to provide a new access opening which are not "Unsafe". Thus any new driveway or intersection may not be permitted to have new added volumes until it has been shown that the existing and/or proposed driveway or intersection is capable of accepting these new added volumes.

V. Validation of the Conflict Opportunity Technology and Software

While the validation of any accident software is made difficult because of the inaccurate reporting of actual accident data and the variances in reporting procedures from one locality to another (reported to exceed 40 percent inaccuracy), as well as the inaccuracies of volume counting and data collection from each individual intersection or driveway (reported to exceed 30 percent inaccuracy), validation to historic accident data bases remains one of the outstanding methodologies which create credibility in any predictive accident methodology. However in such comparisons of predicted to actual accident histories, and even given the limitations cited above, the selection of statistical testing comparative methodologies can become a point of theoretical contention between competing professionals. And to try and alleviate this statistical contention and present a more clear, concise and simple picture of the validation of the Conflict Opportunity Accident Prediction Validation, Figure 2 presents a simple comparison of predicted versus actual historical (3-year average) police reported accidents for 100 randomly selected signalized intersections from a pool of approximately 1000 signalized intersections within one large urban, east-coast metropolitan area composed of multiple cities and counties, but with all signals controlled by the State DOT.(24)

Figure 2
Comparison Of Actual and Predicted Signalized Total Annual Accidents

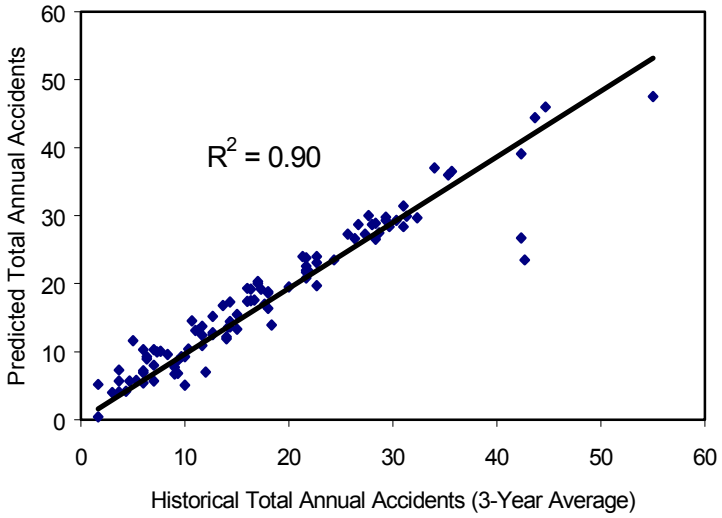
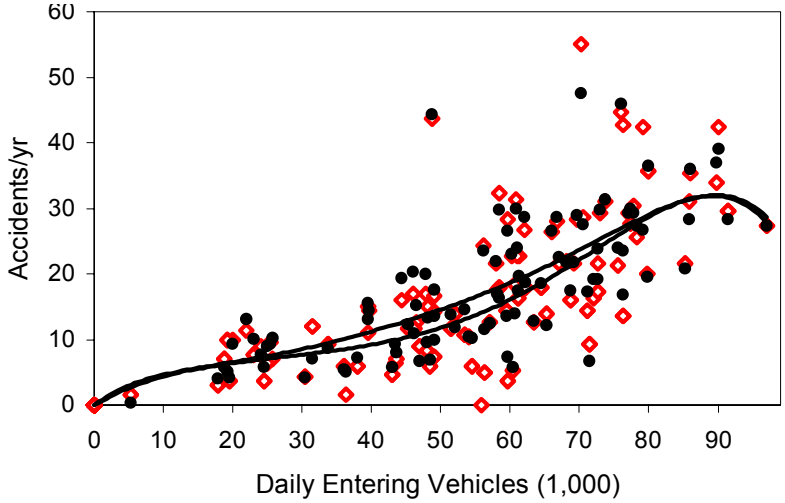


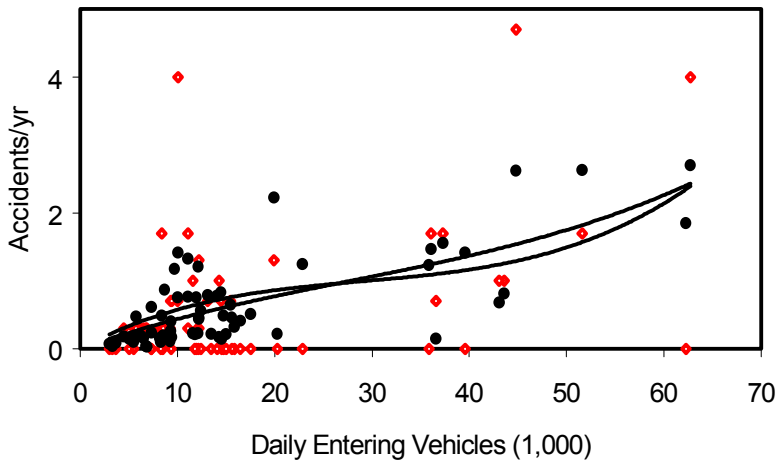
Figure 3
Comparison Of Actual and Predicted Signalized Total Annual Accident Regressions



Of note from Figure 2 is that a comparison of conflict opportunity predicted and the actual 3-year accident history at the 100 signalized intersection sites provides an accuracy (indicated by the R^2) of approximately 90 percent in contrast to a perfect correlation which would be 100 percent if predicted and actual were identical. In a similar manner, Figure 3 presents a comparison of Total annual accidents at each site as a function of entering daily traffic volumes (ADT) and indicates as expected that accidents increase as volume levels increase and more importantly that a comparison of the regression of the predicted data points to an identical regression of historical data points indicates how closely the predicted and actual accident regressions track one another over all volume levels. Both of these are simple and clear indications of the ability of the conflict opportunity technology and software to predict annual intersection accidents with an approximate 90 percent accuracy regardless of the variables of the intersection including variable timings and phasings. A further study of the personal injury involvements estimated by the software in comparison to the original severity data also indicated the general validity of the injury and fatality estimates.

With respect to unsignalized intersection, a validation sponsored by the Florida Department of Transportation (FDOT) for 65 "Two-Way Stop" controlled (TWSC) intersections was performed with all data collected by FDOT from 5 counties in the Tampa Bay region.(25) The sites represented randomly selected TWSC intersections with traffic volumes ranging from 3000-71,000 entering vehicles per day, horizontal geometries from 2-6 lane cross-sections both with and without left and/or right protected turn bays. All sites were intersections of State Highways with both three and four leg intersections. Traffic volumes for all approaches were composed of both 24 hour and 8 hour turning movement counts, which were statistically modeled to assure conformity between 8 and 24 hour count totals for each approach. Site geometries were field verified including turn bay lengths to account for turn bay back-out. The results of this study are present in Figure 4 comparing "On-site Actual" average annual accidents versus total volume.

Figure 4
Comparison Of Actual and Predicted Un-Signalized Total Annual Accident Regressions



The conclusions of this validation were that the conflict opportunity technology and software provided annual accident responses which were within 3 standard deviations of the actual on-site mean annual accidents at approximately 95 percent of the sites, within 2 standard deviations at 90 percent of the sites, within 1 standard deviation at 70 percent of the sites, and within 0.5 standard deviation of the actual "on-site" accident average at approximately 50 percent of the sites. In general, the study concluded the accident predictions provided responses which were superior to even the best statistically formulated annual accident exposure or "rate-based" regression model created from the original accident data because the software through it's construction eliminates statistical "outliers" (non-responsive and irregular data points which become critical elements in "rare-event" regression modeling with few annual accidents), because the software had a wide variety of data input which permitted development of a "Response Envelope" compared to simplistic linear

regression models, and most importantly because the software unlike normal regression required no prior knowledge of actual site accidents. A further validation study of the personal injury involvements estimated by the software in comparison to the FDOT severity data at each site also indicated the general validity of the injury and fatality estimates.

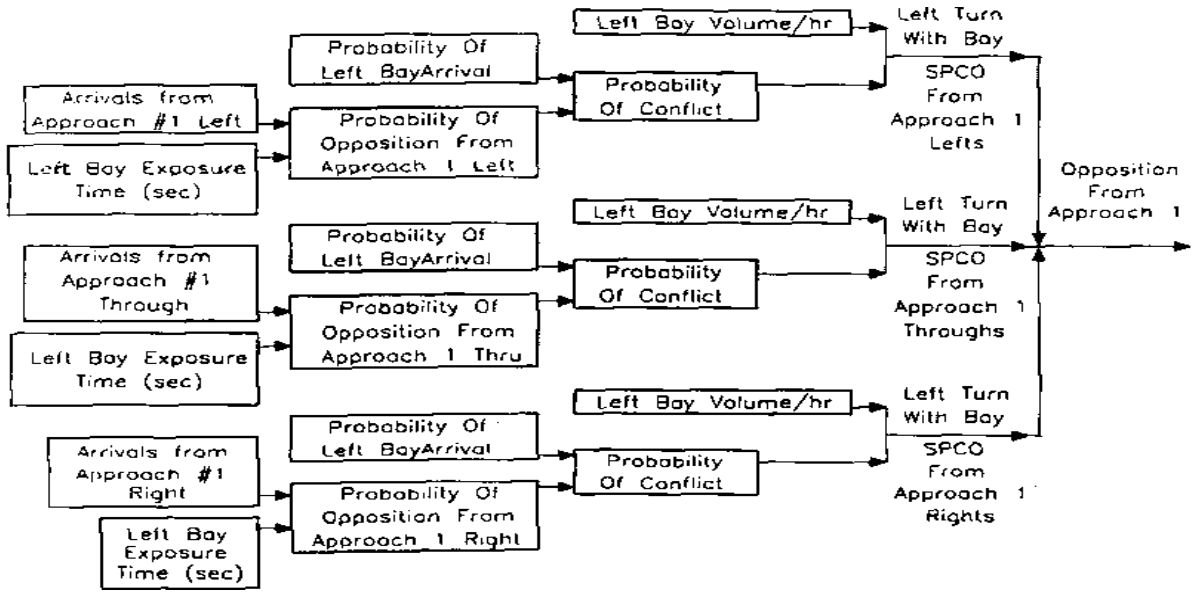
VI. Software Structure and Flowcharts

The construction of annual accidents from hourly conflict opportunities requires a finite element analysis that encompasses each lane and each approach and each of the various permutations and combinations of potential two-dimensional conflicts a vehicle may encounter, whether from ahead, left, right or from the rear and with a variety of further permutations and combinations of variable traffic volumes, speeds and traffic control types among other variables in traversing approach and through lanes.

An example of the flowchart for these finite element analyses and combinations and permutations iare presented in Figures 5-8 with reference to the traffic movements of Figure 1, page 9. Given the specific movement of the left turn from Approach 2 which will conflict with the left turn and through movements from Approach 1, Figure 5 presents a flowchart of the mathematical operation (from the original General Motors Research approach) by which a Conflict Opportunity for a particular combination of opposing movements is created, as a function of the time vehicle #2 is exposed to each conflict. Having defined the degree of probable opposition from Approach #1 to the completion of the Approach #2 left turn movement (which flowchart is identical for all conflict types as angle in this case and similarly for rear-end, sideswipe and fixed-object), Figure 6 presents a flowchart of the methodology for summation of conflict opportunities on one approach with other approaches summarized identically over each lane group. With opportunities defined for each approach (3 or 4 legs), Figure 7 presents a flowchart for the summation and conversion of hourly theoretical conflict opportunities for each accident type to annual accidents for a typical intersection controlled by a traffic signal with red, yellow and green indications, each corresponding to exposure time at a pre-defined speed. Having isolated the individual annual accident types estimates, Figure 8 sums the accident types for each approach and estimates the injuries and fatalities for each approach and the intersection given the respective approach speed and other variables, and also generates a unique injury-based Safety Level of Service for the intersection.

Figure 5

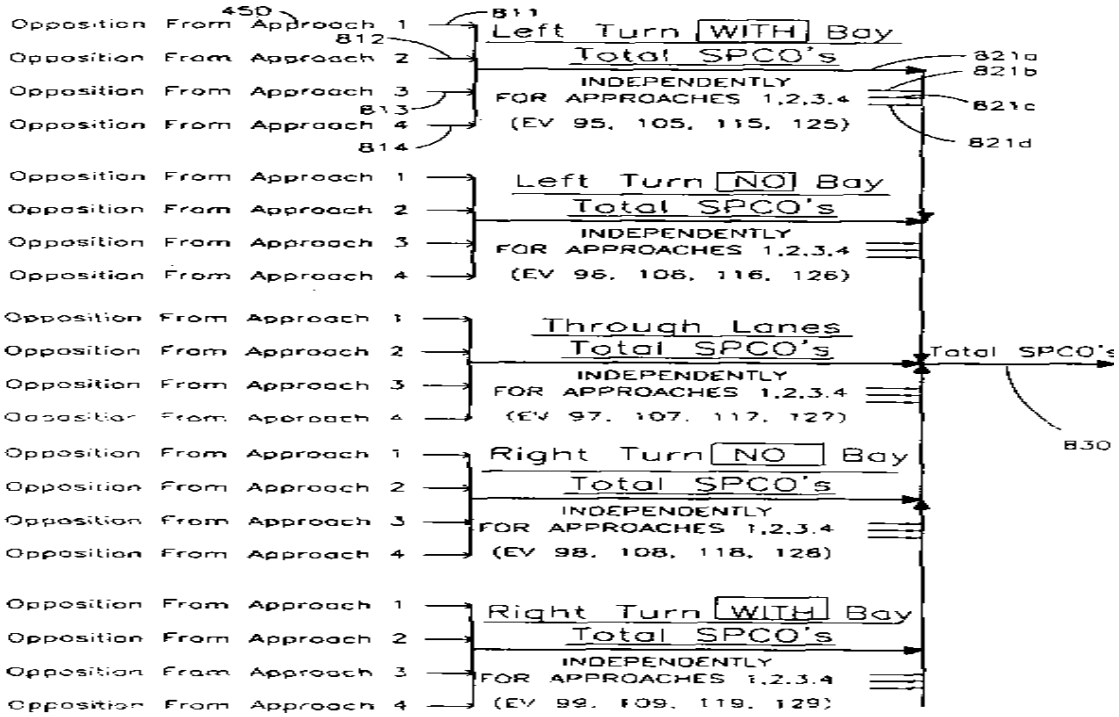
Determination of Hourly Conflict Opportunities for Opposing Approach Lanes and Bays



(This example for Approach #1 Left/Thru/Right in Conflict with Opposing Approach #2 Left from Turn Bay)

Figure 6

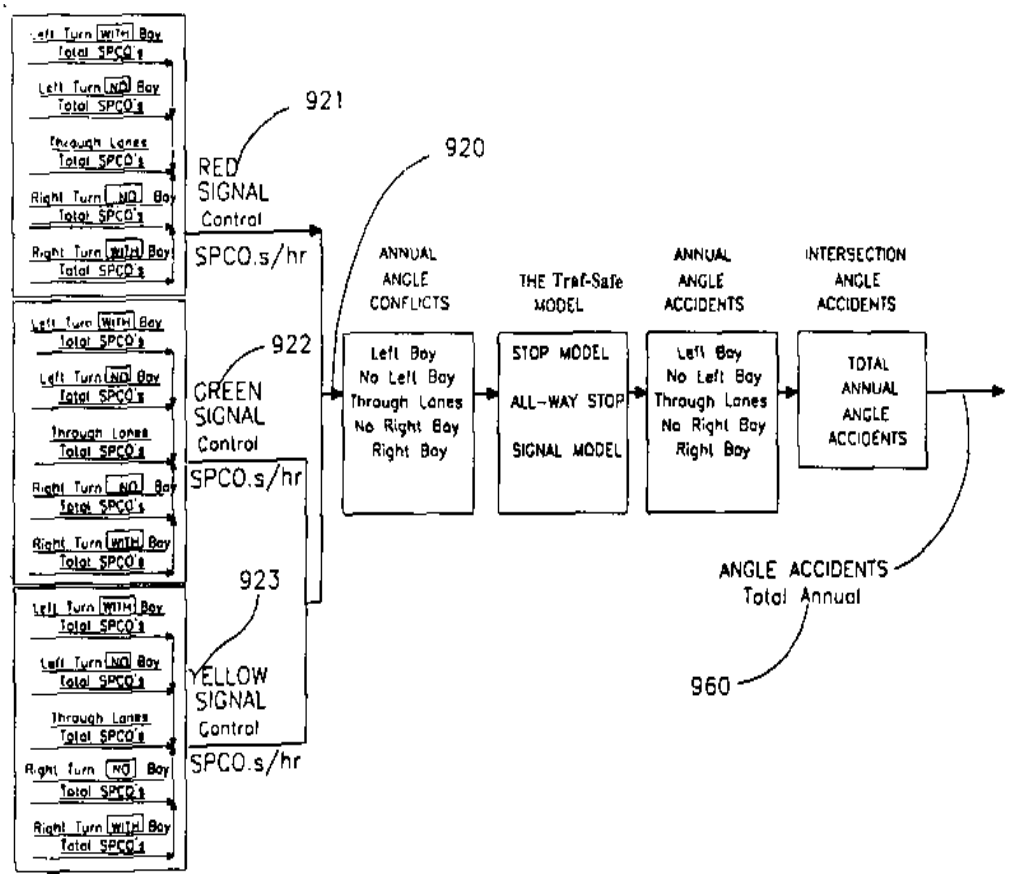
Methodology for Summation of Conflict Opportunities on One Approach



(Numbers conform to Software Patent Processes)

Figure 7

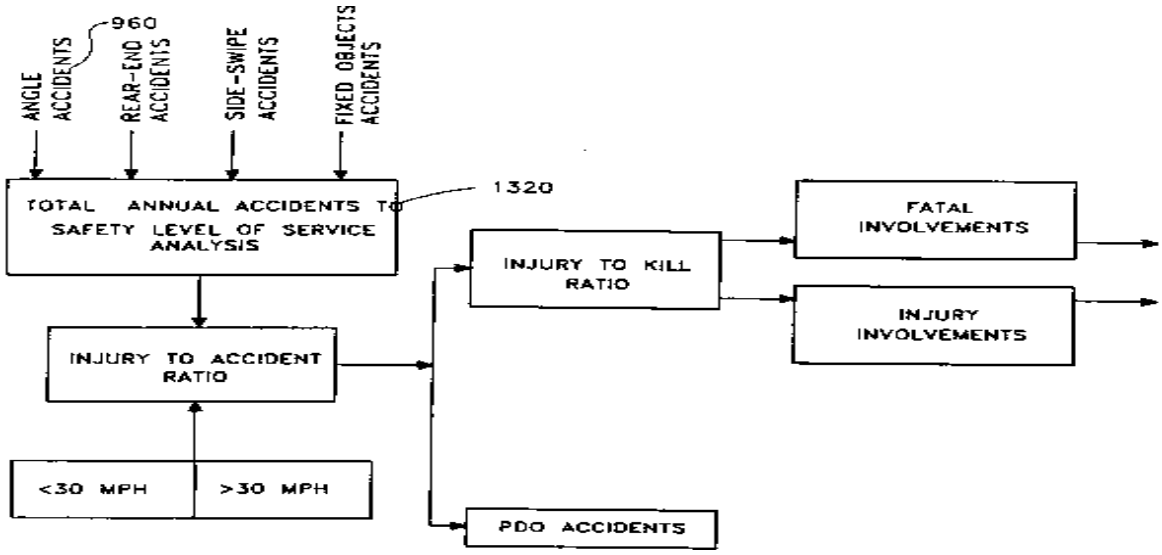
Angle Conflict Opportunity to Annual Accident Conversion Methodology Where Rear-End, Sideswipe and Fixed Object Conversion Methodologies are Identical



(Example for Signal Control where 2-Way and All-Way “Stop” and “Yield” Delays are defined by HCM Probabilities)

Figure 8

Summation of Annual Accident Types and Estimation of Annual Injuries and Safety Levels of Service



VII. Summary

The basic theoretical formats and assumptions are presented for a finite element software structure that estimates annual intersection traffic accidents and severity using a theoretical statistically probable conflict opportunity algorithm originally developed by General Motors Research for angle, rear-end, sideswipe and fixed object/single vehicle events. These estimates of hourly and annual statistically probable conflicts are integrated into a new and unique "Nested Regression" algorithm and calibrated, using both speed and driver visual perceptive capability, to historical intersection related annual accidents thus permitting unprecedented accuracy and precision in estimating annual accidents and injuries at any intersection and over any typical volumes, speeds and geometry, and for typical traffic control type including "Yield", "Two-way Stop", "All-way Stop", and "Pretimed and Actuated Signals". Comparison of the software output to the 5-year historical accident record for 65 unsignalized "2-Way Stop" intersections in Florida indicated the theory and operation were "Superior to existing regression-based accident prediction techniques that relied on historic data". And comparison of the output for numerous signalized intersections to the 5-year accident record indicated that when properly calibrated to the existing accident history (similar to the calibration of HCM software to a specific site), the theory and operation provided annual accident estimates that were approximately 90 percent accurate (within 10-15 percent of the average accident history) with a corresponding accuracy for annual injury estimates.

Conforming with prior research that concluded "Opportunity-based accident measures will yield significantly different estimates and hazard rankings when compared to conventional accident rate expressions"(26), both of the above unsignalized and signalized validations to historical accident data indicate this finite element methodology and the underlying conflict opportunity strategy are capable of providing annual accident and injury estimates of unprecedented accuracy and precision, and offer the ability to examine intersection design and operations "before" actual construction and/or implementation, in contrast to the current practice. **Based on these findings, this new approach appears to offer an exciting and revolutionary opportunity to eliminate ¼ to ½ of all existing intersection related accidents and injuries, and based on the current level of 450,000 injuries per year at signalized intersections (2,600 fatalities) and over 500,000 injuries per year at unsignalized intersections (6,000 fatalities), this technology coupled with qualified engineering judgement may eliminate over 250,000 injuries and 1,000-2,000 fatalities per year.**

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