A STATISTICAL METHODOLOGICAL FRAMEWORK FOR ESTIMATING, ASSESSING, EVALUATING, MONITORING AND INTERPRETING ROAD TRAVEL RISK PERFORMANCE MEASURE INDICATORS : A 'RISK ANALYSIS AND EVALUATION SYSTEM MODEL' COMBINING TRAFFIC COLLISION AND 'EXPOSURE TO RISK' INFORMATION TO IDENTIFY 'HIGH RISK' ROAD TRAVEL PATTERNS AND CHARACTERISTICS

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ABSTRACT

One of the many important tasks facing traffic safety managers is deciding upon which, and of these the 'best/optimum' measures/countermeasures to implement for addressing their main goal -- improving road safety. The ability to make these decisions is largely dependent upon the availability of relevant, accessible, timely and standardized data on the incidence of travel and occurrence of vehicle collisions on the roads and highways. In essence, the Road Safety Directorate of the Canadian federal Department of Transport is continually striving to understand and augment its knowledge with respect to the process of motor vehicle collision causation in order to recognize opportunities for avoiding accidents and reducing casualties. An area crucial to traffic safety research is the development of evaluation methods for measuring and subsequently identifying *'high risk'* road user groups and their associated travel patterns and characteristics. This component of the countermeasure development process is difficult to pursue since the overall *road travel risk of accident occurrence* is directly affected by the joint interactive and ever-changing effects of numerous driver-passenger-vehicle-road-trip-environment-temporal travel pattern *risk levels* existing within the transportation system. Other factors including implemented countermeasure programs, economic conditions, vehicle/driver regulations, and social factors also influence the *prevailing risk levels*, at any given time, for road systems users.

It is useful to define the *risk levels* associated with all of the various factors contributing to accidents by comparing their appearance in accidents with some comparable measure of their appearance in traffic. This latter measure we refer to as the *'exposure to risk'* associated with the factors, i.e., the extent to which they are exposed to the possibility of accidents, by appearing in traffic. Although a variety of *exposure measures* have been advocated (e.g., trip frequencies, driver/vehicle frequencies, travel time, etc.) the most suitable for describing and comparing *road users' exposure* is driver and passenger kilometers of travel -- the *exposure measure* that is recommended and used in this study.

This paper presents the results for five main objectives identified in a recent *road travel risk* research study conducted by Transport Canada. The first objective involved the development and implementation of a statistical methodological framework that combines collision and *'exposure to risk'* data to measure and interpret *risk performance indicators*. Secondly, a *'risk analysis and evaluation system model'* for evaluating, comparing, and monitoring the *relative risks* of collision, injury and fatality encounter associated with the various driver-passenger-vehicle-road-trip-environment-temporal travel patterns and characteristics was developed. The third objective involved the development and implementation of statistical methods and procedures for measuring levels of errors associated with the various types of *road travel risk, relative risk, and relative risk odds-ratio performance indicator estimators* to identify significant differences in *travel risks* prevailing on the roads and highways. Fourthly, using Canadian collision and *'exposure to risk'* data bases, the modeling framework was applied to measure the *relative risks* of collision, injury and fatality encounter for selected road user groups and their travel patterns and characteristics. From these results *'high risk' road travel patterns and characteristics* were identified. Finally, conclusions and recommendations regarding the uses and applications of the *'risk analysis and evaluation system model'* for identifying road travel problem areas/issues and evaluating remedial measures/countermeasures for improving road safety are provided.

INTRODUCTION

The concepts of *'risk'*, *'relative risk'*, and *'relative risk odds-ratio'* estimation; *'risk analysis'* methods; and *'risk assessment/evaluation/management'* have long been recognized as necessary components and techniques for measuring, assessing, monitoring, evaluating and comparing the *level(s) of risk* (i.e., *level(s) of safety*) existing on our roads and highways. This has been well established and advocated for over sixty years by numerous professionals from varied disciplines within organizations with responsibilities in road transport safety [Vey, 1937; Cameron, 1969; Caroll, 1971, 1975; Foldvary, 1975; Accident Causation, 1980; Fernie, 1982; Hauer, 1982; Risk and Shaoul, 1982; Toomath and White, 1982; Wolfe, 1982; Stewart and Sanderson, 1984]. In spite of this 'urgent need' for the capability to assess and evaluate *road travel risks* (on a continuous basis) and the fact that the justification and benefits for doing so have been stated and echoed for decades, there has been no coordinated initiative taken to develop a 'standardized' modeling framework, associated estimation methodologies and analytical systems/procedures for establishing 'standardized' performance measure indicators to use in carrying out *'risk assessments'* [Stewart, 1989, 1996b, 1996c, 1997a, 1997b, 1998a, 1998b]. This begs the obvious question: ***Why?*** Why is this area of *risk analysis research* that has been identified as crucial for measuring, monitoring and comparing *risk level(s)* associated with various driver-passenger-vehicle-road/infrastructure-environment-trip-temporal travel patterns and characteristics, and subsequently identifying profiles of '***high risk***' ***travel patterns*** on our roads and highways not being actively pursued? A large part of the answer to this question would appear to be found in the following three statements --

① There is a 'lack of' relevant, accessible, timely, standardized '*exposure (to risk)*' (road travel) data;
② There is no standardized modeling framework for conducting *risk analyses* (i.e., there is a need for a standardized '*risk analysis and evaluation system model*' for conducting *road travel risk assessments/ evaluations*);
③ There is a 'lack of' standardized mathematical and statistical methodology, techniques and procedures for estimating and interpreting '*basic risk*', '*relative risk*' and '*relative risk odds-ratio*' performance measure indicators and associated level(s) of accuracy.

THE DESIGN AND DEVELOPMENT OF A 'RISK ANALYSIS AND EVALUATION SYSTEM MODEL'

Owing to the serious deficiencies identified above, the Evaluation and Data Systems Division of Transport Canada has been conducting research into the design, development and implementation of a 'standardized' Risk Analysis and Evaluation System Model (RAESM) [Stewart, 1989, 1996c, 1997b, 1998a, 1998b].

Concepts, Methods & Procedures for Standardization

In order to stimulate work in the area of road safety *risk estimation and assessment* and hopefully generate a renewed thrust towards advancing our knowledge of the continuously changing *road travel risks* on Canada's roads and highways six major research initiatives were identified for completion in the first phase of this research, including:

❶ The development of a *standardized road travel 'risk analysis and evaluation system model'* for identifying the steps to be carried out in a *risk assessment/ evaluation* study.
❷ Defining the concepts of *road travel* '*basic risk*', '*relative risk*' and '*relative risk odds-ratio*' and deriving methods and procedures for their 'interpretations'.
❸ Proposing and deriving various statistical/mathematical methodologies, problem formulations and procedures for estimating and computing *road travel* '*basic risk*', '*relative risk*', and '*relative risk odds-ratio*' performance measure indicators. The 'appropriate' methodology depends upon the characteristic(s) of the target entity group's *road travel risk(s)* being measured and compared, and the type of input data available, e.g., 'frequency count' or 'proportional' data from 'incident' (accident, injury, fatality) and '*exposure (to risk)*' databases.
❹ 'Accuracy assessment' (error analysis) methodologies for measuring the statistical level(s) of accuracy associated with the 'estimated' *road travel risk* performance measure indicators are derived.
❺ Procedures for interpreting the various *road travel risk* performance measure indicators are developed.
❻ Finally, examples for each of the various types of *road travel risk (basic risk*, *relative risk*, and *relative risk odds-ratio)* performance measure indicators and associated statistical/mathematical methodology for their respective estimations and accuracy assessment are provided.

This paper presents the major results and findings from the six tasks (identified above) completed in this research.

The Concept of *'Road Travel Risk'* : The Relationships Between *'Risk'* and *'Exposure (To Risk)'* -- We define the *road travel risk level(s)* associated with all of the various factors contributing to accidents by comparing their appearance in road incidents (i.e., accidents, injuries, or fatalities) with some comparable measure of their appearance in traffic [Stewart and Lawson, 1987b]. The latter measure we refer to as the '*exposure (to risk)*' associated with the factors, i.e., the extent to which they are '*exposed*' to the 'possibility' of incidents (accidents, injuries and/or fatalities), by appearance in traffic. One of the main problems thwarting efforts to pursue the design and development of *road travel risk analyses and evaluation system models* arises from an inability to agree upon a suitable *exposure (road travel) measure* - i.e., a measure that 'best' reflects the appearance of road users and their characteristics on the roads and highways or, in other words, a measure that 'best' reflects the *amounts of road travel risk* -- '*exposure (to risk)*' -- encountered by road users and their characteristics. Another very important consideration is that the *exposure measurement* should be capable of providing insight into both the *'(risk of) exposure'* and *'exposure (to risk)'* [Risk, A. and Shaoul, J.E., 1982; Stewart, D.E., and Sanderson, R.W., 1984; Stewart, 1997b, 1998a, 1998b]. Although they sound similar these two concepts are quite different [Stewart, 1998b].

Although different *measures of exposure* have been advocated including: *'kilometers of travel'*, *'numbers of trips'*, and *'duration of travel -- time spent traveling on the roads'*, Stewart (1998a, 1998b) presents arguments favoring the use of *'kilometers of travel'* as the *standardized exposure measure* for the purposes of estimating/assess-ing *risk level(s)* on the roads and highways.

'KILOMETERS OF TRAVEL', THEREFORE, IS THE RECOMMENDED *'EXPOSURE (TO RISK)'* STATISTICAL MEASURE TO USE IN THE DEVELOPMENT· OF A '*RISK ANALYSIS AND EVALUATION SYSTEM MODEL*'.

It is also imperative that a CONSISTENT *MEASURE OF EXPOSURE* BE EMPLOYED AND IT REMAIN COMPATIBLE OVER TIME. What is extremely beneficial, once a *standardized risk analysis and evaluation system model* is implemented, is the capacity to compare the *relative level(s) of road travel risks* over time (i.e., temporal comparisons) for different entity groups and under differing travel conditions. This is one of the most useful benefits received from the system. The most critical factors, therefore, to ensuring that the *road travel risk comparisons* over time are accurate, comparable and unbiased is the consistency, compatibility and accuracy of the *exposure measure estimates* developed.

<u>A Modeling Framework</u> for designing and developing a RAESM requires that we have knowledge of the *exposure (to risk)* for the various human, vehicle, road/infrastructure, environment, trip and temporal factors and their respective characteristics. We would therefore like to estimate *the 'extent' of* driver and passenger *kilometers traveled* for these factors. In other words, our search for *good exposure (to risk) data* is essentially a search for databases containing *detailed descriptions of travel by road users.* This information constitutes one half of the data necessary for designing and developing a *'risk analysis and evaluation system model'* [Stewart, D.E. and Sanderson, R.W., 1984; Stewart, D.E., 1998a, 1998b]. The second half of the information needed involves the availability of incident (collision, injury and fatality) data cross-classified by the various human, vehicle, road/infrastructure, environment, trip and temporal factors and their respective characteristics that are DIRECTLY COMPATIBLE AND CONSISTENT WITH THOSE AVAILABLE IN THE *EXPOSURE (TO RISK)* DATABASES.

With the availability of both of the above two types of databases it is possible to envisage the conceptualization of a *'risk analysis and evaluation system model'* that is <u>capable of measuring, monitoring, comparing, evaluating, and assessing the accuracy of *the level(s) of risk -- level(s) of safety* -- on Canada's roads and highways</u>. Figures 1 and 2 depict the components and their respective relationships that provide a modeling framework for use in the development of a *risk analysis and evaluation system.*

The relationships among the various components that impact upon and measure the *safety level(s)* existing on the roads and highways at any point in time -- program measures/countermeasures, causal factors, *exposure (to risk)*; human-vehicle-environment-road/infrastructure-trip-temporal *risk level(s)* existing on the road and highway systems; and the resultant incidence of accidents, injuries and fatalities occurring on the roads and highways are illustrated in Figure 1. Through examination of Figure 1 it becomes apparent that ALL CAUSAL COMPONENTS IN THE MODEL ARE IMPLICITLY REPRESENTED IN THE *'EXPOSURE (TO RISK)'* COMPONENT. The three key components -- *'exposure : extent, nature and quality of travel'*, *'incidence of accidents, injuries and fatalities'* and *'road travel risk levels existing on road and highway systems'* are therefore dependent upon one another and, from a mathematical perspective, functionally related. In other words, TO DESCRIBE THE *PREVAILING LEVEL(S) OF ROAD SAFETY TRAVEL (LEVEL(S) OF ROAD TRAVEL RISK)* ASSOCIATED WITH ENTITIES TRAVELING ON THE ROADS AND HIGHWAYS, OR CHANGES THEREOF, NECESSARILY REQUIRES A MATHEMATICAL FORMULATION THAT AT A MINIMUM CONTAINS ALL THREE COMPONENTS. This model provides the foundation and rationale for the statistical and mathematical methodology that has been developed and implemented for estimating *'basic risk'*, *'relative risk'* and *'relative risk odds-ratio' performance measure indicators.*

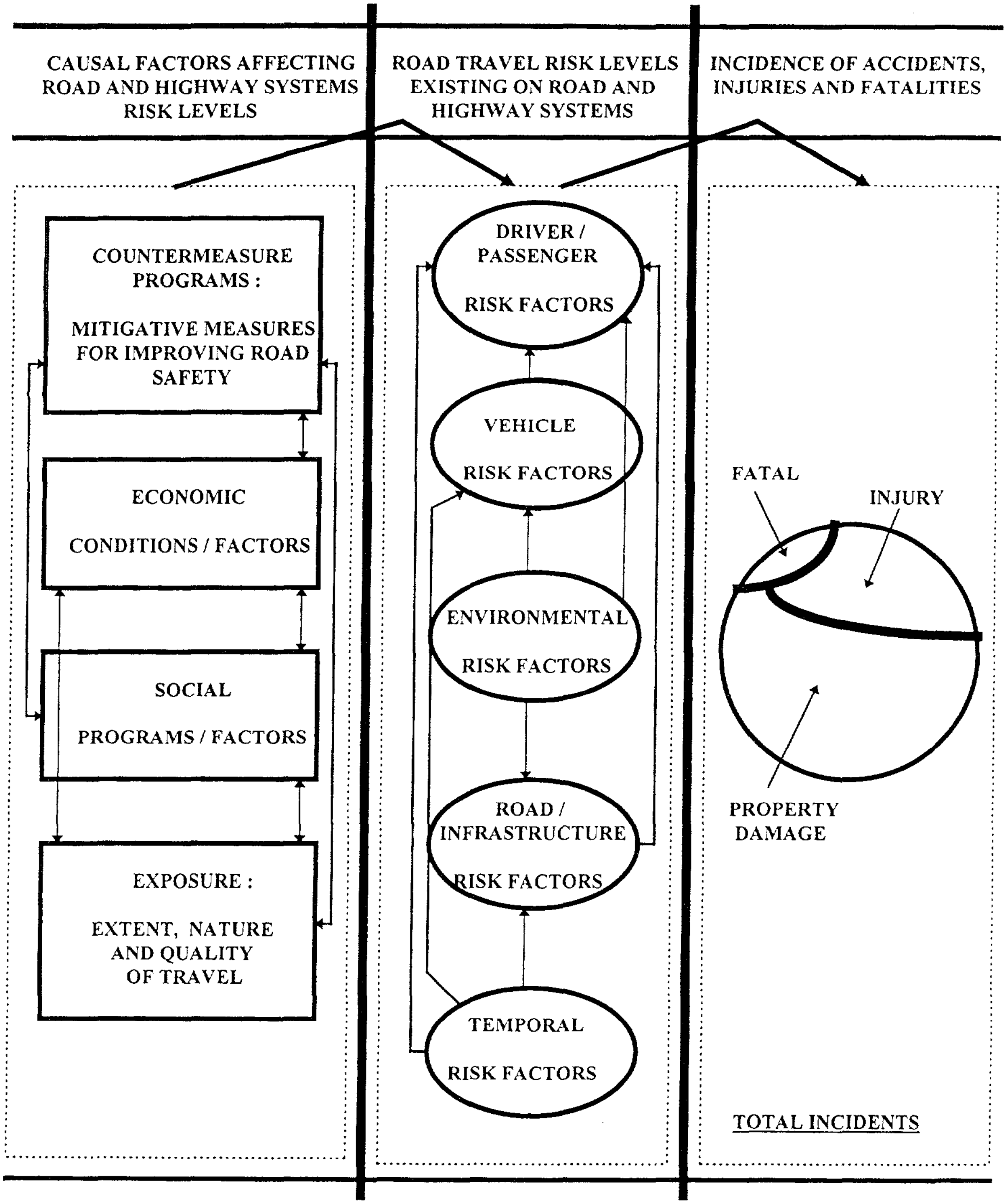

Figure 1. Relationship among causal factors, *risk levels* and incidence of accidents, injuries and fatalities.

Note: The arrows " ⟶ " indicate the road safety impact directions among the programs, causal factors, risk levels and incidence of accidents, injuries and fatalities.

Figure 2 provides a detailed description of the process for improving road safety through the use of a *RISK ANALYSIS AND EVALUATION SYSTEM MODEL -- 'RAESM'*. Existing countermeasure programs, economic conditions, social programs *and 'exposure (to risk)' / '(risk of) exposure'* -- extent, nature and quality of road travel -- all impact on the *prevailing level(s) of risk* for entities traveling on the roads and highways. By combining the 'exposure (to risk)' component (which contains the effects of the other three components, as discussed earlier) with the incidence of accidents/injuries/fatalities in a mathematical formulation, ESTIMATES OF *'BASIC RISK'*, *'RELATIVE RISK'* AND *'RELATIVE RISK ODDS-RATIO'* PERFORMANCE MEASURE INDICATORS ARE DERIVED. By applying appropriate statistical methods for measuring the accuracy of these resultant *road travel risk* performance measure indicators, the *level(s) of risk* associated with the entities analyzed, as well as the *level(s) of risk differential existing between the entities evaluated*, are estimated. The results of the *risk analyses* are *interpreted* leading to *the identification of 'potential' road travel problem areas and issues* for remedial action considerations to improve road safety. Using the KNOWLEDGE OF the *basic risks, relative risks and relative risk odds-ratios* estimated for the various human-vehicle-road/infrastructure-environment-trip-temporal road travel factors and their characteristics, in conjunction with the magnitude of the problems (i.e., accident/injury/fatality incidence representation for the identical road travel factors and their characteristics), and other research information available, PRIORITIZATION OF THE IDENTIFIED PROBLEM AREAS/ISSUES CAN BE DONE. Next, it may be necessary to conduct directed research studies for the purpose of discerning the specific cause(s) of the *'high risk' road travel* associated with the group of entities identified. With the *'high risk' road travel* problem(s)/issue(s) well-identified (i.e., specific cause(s) found) the process of IDENTIFYING NEW COUNTER-MEASURES OR REMEDIAL MEASURES FOR REDUCING THE *'HIGH RISK' TRAVEL* BEING DONE BY THE IDENTIFIED GROUP OF ENTITIES BEGINS. The 'most suitable' countermeasure is then implemented. There are a number of criteria for evaluating and subsequently selecting the 'optimum' countermeasure, but the 'best' countermeasure would be the one that is generally most cost effective (i.e., the countermeasure with the potential for yielding the greatest improvement in road safety -- reduction(s) in *road travel risk level(s)* -- in relation to the costs for its implementation). This is determined by carrying out socio-economic impact analyses (SEIAs) and regulatory impact analyses (RIAs) including comprehensive cost-benefit analyses (CBAs) on the competing countermeasures and mitigative measure programs proposed and (usually) selecting the one that yielded the largest benefit-to-cost ratio. The qualifier 'usually' is to be noted since there are circumstances, once the evaluation is completed, that could result in a countermeasure or mitigative measure that does not have the largest benefit-to-cost ratio being selected for implementation. For example, the costs to implement countermeasure X could be significantly higher than that for countermeasure Y even though the potential road safety benefits compared to the costs (benefit-to-cost ratio) is larger for X. However, the maximum level of funds available for countermeasure development and implementation may be considerably lower than that required for option X, resulting in Y (the option with the lower benefit-to-cost ratio of the two) being implemented. Another type of circumstance could involve cases where the most cost-effective countermeasure may not, for various reasons, be deemed feasible or practical to implement, viz., 4-point seat belt harnesses in passenger vehicles; helmet use by all motor vehicle occupants of passenger vehicles; etc. In cases such as these it is necessary to assess tradeoffs and maximize the road safety improvement benefits by selecting the countermeasure(s) that are not only within the budget limitations available but are also 'practical' and 'implementable' -- i.e., the potential for educating and persuading the majority of the road users to adopt the mitigative measures is large. Having selected a countermeasure or mitigative measure program for addressing the problem area(s) and issues identified it is then implemented. In order to assess the benefit(s) of the countermeasure/mitigative measure programs with respect to their performance in making *improvements to the level(s) of safety (reductions in risk(s))* for road users, *'effectiveness evaluations'* and *'basic risk'*, *'relative risk'*, *'relative risk odds-ratio' performance measure indicator analyses* are conducted. These analyses and evaluations provide the 'knowledge' required for assessing the performance of the newly introduced countermeasures and/or mitigative measures. That is, for the target group(s) of road users affected: are *road safety benefits* being realized?; are the countermeasure or mitigative measure programs effective in *improving road safety*, and if so to what extent?; have the *road travel risk(s)* for the target group(s) been reduced? Finally, as can be seen in Figure 2, the process is iterative -- we return to *the basic risk*, *relative risk* and *relative risk odds-ratio estimation module* to *measure, compare, monitor and assess the level(s) of risk* at a later period in time. The full benefits of *a 'risk analysis and evaluation system model'* are only realized through a continuous iterative process whereby the *level(s) of road travel risk* are being measured regularly over time, i.e., on a fixed temporal schedule (e.g., annually, biannually) -- which is entirely dependent

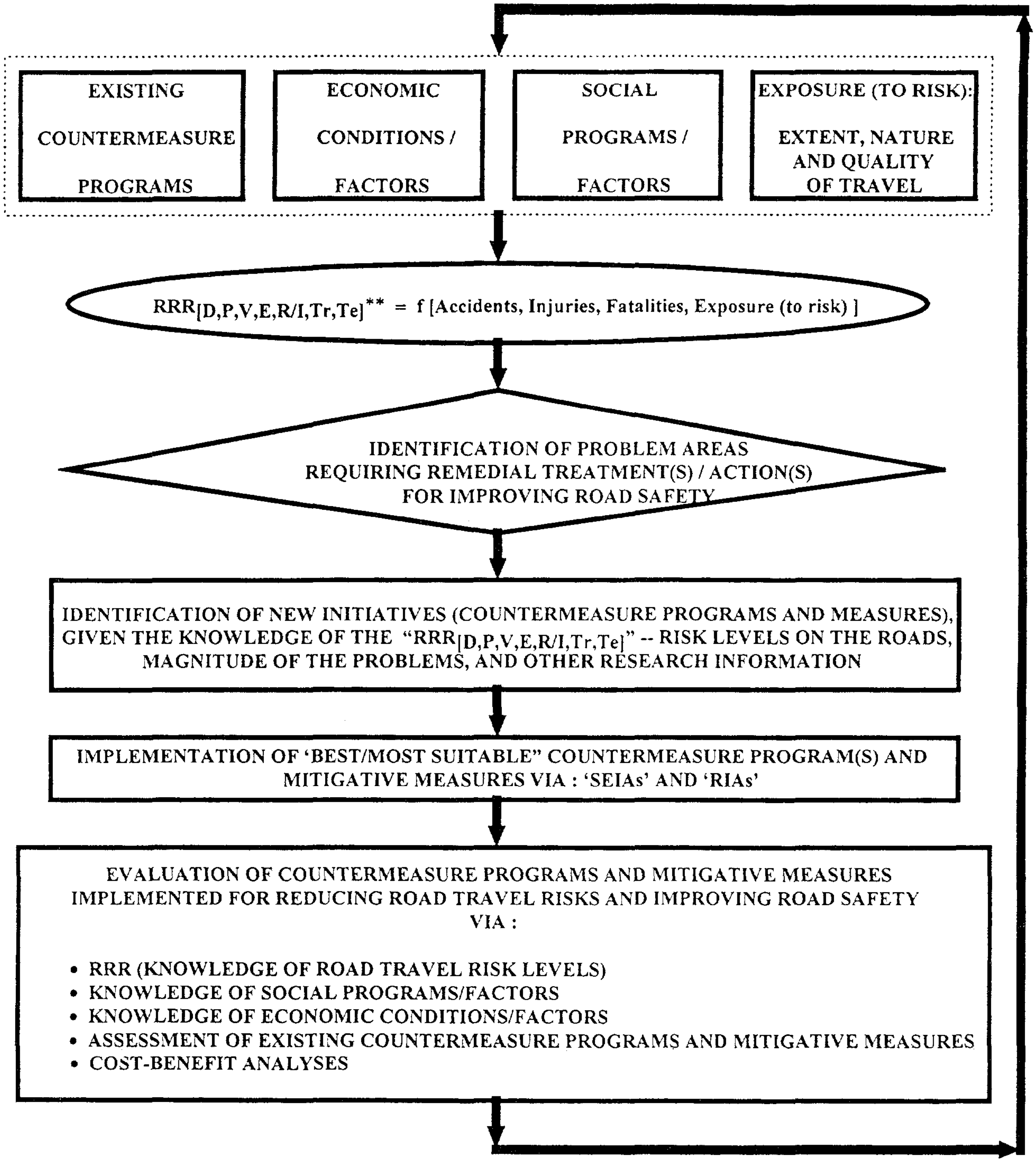

Figure 2. A *"Risk Analysis and Evaluation System Model -- RAESM"* process for measuring, monitoring, comparing and evaluating the *level(s) of road travel risk* on Canada's roads and highways.

** $RRR_{[D,P,V,E,R/I,Tr,Te]}$: *Relative Risk Ratio Road Travel Performance Measure Estimators* for various driver-passenger-vehicle-environment-road/infrastructure-trip-temporal travel pattern characteristics on the roads and highways. $RRR_{[D,P,V,E,R/I,Tr,Te]}$ are measured as a function of accidents, injuries, fatalities and *exposure (to risk).*

upon the priority level and resources made available for realizing, managing and operating such a system.

The previous sections have provided discussions of a modeling framework for standardizing the *road travel risk analysis, assessment and evaluation process*, including foundation principles and rationale for the implementation of *a 'risk analysis and evaluation system'*. The various phases involved in the process, i.e., from problem area(s) and issues identification to final assessment/evaluation of countermeasure/mitigative measure performance towards improving *the level(s) of safety -- reducing the level(s) of road travel risk(s)* -- on the roads and highways, have been described in detail. The remainder of this paper focuses on the *estimation, formulations, accuracy assessment and interpretations of the road travel 'basic risk', 'relative risk', and 'relative risk odds-ratio' performance measure indicators*. Specifically, the various statistical and mathematical methodologies for formulating and computing these various *'risk' performance measure indicators* including the data inputs required for each type of indicator are provided. Also, methods and procedures for measuring *the statistical level(s) of accuracy associated with the estimated risk performance measure indicators* are provided. Mathematical and statistical techniques and procedures for *interpreting the meaning/significance of the various 'estimated' basic risk, relative risk and relative risk odds-ratio performance measure indicators* are given. Lastly, *examples* are provided for *the various types of basic risk, relative risk and relative risk odds-ratio analysis methods along with associated accuracy assessment methods for each.*

THE *'PROPORTIONAL ROAD TRAVEL BASIC RISK'* PERFORMANCE MEASURE INDICATOR -- *R^P : AN ESTIMATOR BASED ON PROPORTIONAL DATA INPUTS*

The Estimator, R^P

The mathematical formulation for this relationship is given by:

$$\mathbf{R^P(I|TG_i,TC_j,T_z) = \frac{p(I|TG_i,TC_j,T_z)}{p(E|TG_i,TC_j,T_z)}} \qquad (1.)$$

where,

$R^P(I|TG_i,TC_j,T_z)$ is the '*basic road travel risk*' performance measure indicator (computed from proportional data inputs on incidents and *exposure*) for a target group of entities i, TG_i, that measures their *road travel risk* of encountering a road incident of type *I*, while traveling under specified target travel conditions j, TC_j, during a specified time period z, T_z;

$p(I|TG_i,TC_j,T_z)$ is the proportional representation of the target entity group i, TG_i, involved in road incidents of type I, while traveling under specified target travel conditions j, TC_j, during a specified time period z, T_z;

$p(E|TG_i,TC_j,T_z)$ is the proportional representation of the target entity group i's, TG_i's, road travel (E) on the roads and highways, i.e., their *'exposure' to the road travel risk(s)*, while traveling under specified target travel conditions j, TC_j, during a specific time period z, T_z;

TC_j is a specified target travel pattern/condition determined by the presence of a combination of specified driver D_j, passenger P_j, vehicle V_j, road/infrastructure RI_j, environmental EN_j, trip TR_j, and temporal TE_j factors and their characteristics for which the *'proportional road travel basic risk'* of potential incident encounter, $R^P(I|TG_i,TC_j,T_z)$, for the target entity group i, TG_i, is being measured. That is, TC_j is a function of the various driver, passenger, vehicle, road/infrastructure, environment, trip and temporal factors present during target entity group i's, TG_i's, travel for a specified time period z, T_z, i.e., mathematically we have,

$$\mathbf{TC_j = f\,(D_j,P_j,V_j,RI_j,EN_j,TR_j,TE_j)} \qquad (2.)$$

For example, the *road travel risks* for occupants 16-19 years old, while traveling in sports cars, on rural roads, when it is raining/roads are wet, for the trip purpose of returning home after a party, between 1:30 a.m. and 3:00 a.m. in the morning, can be measured. Although quite detailed, this particular example illustrates the voluminous amounts and types of *'road travel basic risk' estimation* that can be carried out in the initial processes of *identifying 'potentially high road travel risk'* groups of entities for subsequent consideration (i.e., research, evaluation, assessment) in the countermeasure/mitigative measure prioritization process. In essence, the level of disaggregation of the various human-vehicle-road/infrastructure-environment-trip-temporal factors and their characteristics that can be utilized for *measuring and evaluating road travel risks* is only limited by the amounts and level of detail of incident and *exposure (to risk)* data available for input into the *risk analysis and evaluation system model.* Therefore, estimates of the *road travel basic risk performance measure indicator* can always be computed -- it is their accuracy that is directly affected by the amounts and quality of incident and *exposure (to risk)* data available, in particular for very detailed levels of *road travel risk analyses*, as in the example above.

The Accuracy of R^P

The final mathematical equations for computing the resultant 95% confidence limits for $R^P(I|TG_i,TC_j,T_z)$ are given by:

$$R^P_{[L,95\%]} = e^{\{\ln_e[R^P] - 1.96 * \sigma(\ln_e[R^P])\}} \qquad (3.)$$

for the **lower 95% confidence limit** ; and,

$$R^P_{[U,95\%]} = e^{\{\ln_e[R^P] + 1.96 * \sigma(\ln_e[R^P])\}} \qquad (4.)$$

for the **upper 95% confidence limit** ;

where,

$$\sigma(\ln_e[R^P]) = \sqrt{\left[\frac{[1 - p(I)]}{p(I) * n(I)}\right] + \left[\frac{\sigma^2(p(E))}{[p(E)]^2}\right]} \qquad (5.)$$

and,

$\ln_e[\,]$ is the natural logarithm (to the base e) of R^P ;

$\sigma(\ln_e[R^P])$ **is the statistical 'one standard error' estimate of variability for the natural logarithm (to the base e) of R^P;**

$\sigma^2(p(E))$ **is the statistical 'variance' estimate of variability for $p(E)$;**

$R^P = R^P(I|TG_i,TC_j,T_z)$; $p(I) = p(I|TG_i,TC_j,T_z)$; $p(E) = p(E|TG_i,TC_j,T_z)$; and,

$n(I)$ is the total number of incidents of type I being evaluated that occurred on the roads and highways under target travel conditions, TC_j, during the specified time period z, T_z

The Interpretation of R^P

Assumptions and Limitations -- There are no assumptions that need to be made for justifying or interpreting the resultant values of the *proportional road travel basic risk estimator.*

There are no limitations or restrictions affecting the interpretation of the *proportional road travel basic risk estimators.* Since natural logarithms (to the base e) are used in computing the estimators and their associated 95% confidence limits (for measuring their accuracy), this ensures that a *proportional road travel basic risk estimator* can always be measured and has a logical upper bound, and the confidence limits measuring the *accuracy of the risk estimators* have a logical 'upper bound' and are 'near' symmetrical around R^P. This property is a necessary requirement in the conduction of *effectiveness evaluations* since the **effectiveness estimate** (of a particular countermeasure/mitigative measure) **is measured from the results of the *risk estimator*** as:

$$E = [100 * (1 - R)]\ \% \qquad (6.)$$

where,

E is the ***effectiveness estimator*** (measured as a percentage), and

R is the ***'road travel basic risk' performance measure estimator*** (measured using 'proportional' data on *exposure (to risk)* and traffic incidents).

Therefore, the use of natural logarithms (to the base e) ensures that the *effectiveness estimate E* and the *errors measuring the accuracy of the effectiveness estimate* (e.g., 95% confidence limits) have a logical 'lower bound' of zero and that the error bounds around E are "near symmetrical".

Analytical properties -- The attractive properties associated with *the proportional road travel basic risk performance measure indicator*, R^P, and the proportional data inputs required for its estimation include:

$0 \leq p(I|TG_i,TC_j,T_z) \leq 1$ -- with 0(zero) resulting in the lower bound of zero for *the road travel risk estimator* ;

$0 < p(E|TG_i,TC_j,T_z) \leq 1$ -- the *'exposure (to risk)'* is always greater than zero for meaningful *risk estimation*, i.e., if there is 'zero/no exposure' then there is 'no road travel' which results in *'NO RISK OF INCIDENT ENCOUNTER'* ;

$0 \leq R^P(I|TG_i,TC_j,T_z) < \infty$ -- the *proportional road travel basic risk estimator* has a logical upper bound ;

$R^P(I|TG_i,TC_j,T_z)_{[L,95\%]}$ and $R^P(I|TG_i,TC_j,T_z)_{[U,95\%]}$ are 'near' symmetrical around $R^P(I|TG_i,TC_j,T_z)$ and represent logical 'lower' and 'upper' 95% C.L. (statistical) bounds, respectively ;

$R^P(I|TG_i,TC_j,T_z)$ are UNIT-FREE (i.e., DIMENSION-LESS -- akin to engineering dimensional analysis) which is a 'desired analytical property' ensuring that all comparisons of the various types of *risk performance measure estimators* are always valid ;

$R^P(I|TG_i,TC_j,T_z)_{[EXPECTED]} = 1$. The 'expected value' of a *proportional road travel basic risk estimator* is '1', with the value of '1' meaning that the target entity group is not *'a high risk group'* for the target road travel conditions and time period being evaluated. This is a 'necessary property' for the *risk estimator* to possess *for differentiating among road travel risk level estimators for different entities (and their subgroups, as well)* on the roads and highways.

As will be seen in subsequent sections, the *'relative risk'* and *'relative risk odds-ratio' estimators* offer the same powers of interpretation -- the ability to *identify significant differences in road travel risks between and among entity groups*, and *significant differences in road travel risks between and among entity groups for specified road travel condition comparisons*, respectively.

Interpretation(s) – The following basic rules are used for interpreting the resultant *road travel proportional basic risk estimators*:

If $R^P(I|TG_i,TC_j,T_z) < 1$ ⇒ Then the performance of the target entity or group of entities, TG_i, is potentially a *'low road travel risk' level* under target travel conditions j, TC_j, during a specified evaluation time period z, T_z ;

If $R^P(I|TG_i,TC_j,T_z) > 1$ ⇒ Then the performance of the target entity or group of entities, TG_i, is potentially a *'high road travel risk' level* under target travel conditions j, TC_j, during a specified evaluation time period z, T_z ;

If $R^P(I|TG_i,TC_j,T_z) = 1$ ⇒ Then the performance of the target entity or group of entities, TG_i, is potentially at the *'expected road travel risk' level* (given their *'exposure (to risk)'* representation on the roads and highways) under target travel conditions j, TC_j, during a specified evaluation time period z, T_z .

Although the above interpretations provide *the basic decision rules for assessing the resultant proportional road travel basic risk estimators*, the qualifiers -- "potentially" must be heeded. This is because the final interpretations must take into account the accuracy assessment measurements surrounding the final estimators. The examples provided in Figure 3 demonstrate the *caution that must be exercised when interpreting the final proportional road travel basic risk estimator results*.

Figure 3 gives hypothetical examples for five $R^P(I|TG_i,TC_j,T_z)$ results, indicated by [1], [2], [3], [4], and [5] in the graphical illustration. Result [1] demonstrates a *'high road travel risk' performance measure indicator* for target entity group TG_1. The error bounds for it (as well as for each of the other four indicator examples) are 'lower' and 'upper' 95% confidence limits (C.L.s), denoted as [L,95%] and [U,95%], respectively. Examination of the results shows that, even when the 95% C.L. error bounds of the *road travel risk indicator* for entity group TG_1 are taken into account, the group is still a *'high road travel risk' group*. Examining the results for target entity group TG_2 (result [2]) shows that, without taking the 95% C.L.s into account, they appear to be *a 'low risk road travel' group*. However, when the 95% confidence limits are taken into account, it can be seen that this group is not a *(statistically significant) 'low risk' group*. In other words, it cannot be claimed (at the 95% level of statistical confidence) that *the road travel risk levels* for this group TG_2 are necessarily *'low level'*. Therefore, more and better (more accurate) data and/or further research are needed to make a definitive decision regarding this group's status as a *'low road travel risk group'*. The entity group TG_3 is right on the *'Expected Risk Level'*, i.e., *road travel risk estimator* *value of 1*. However, when the 95% error bounds on the risk estimator are accounted for, it cannot be claimed that this target entity group is *'a high risk'* or *'a low risk'*. As was the case for group TG_2, more and better data and/or research is needed to make a definitive decision as to the status of this group's *'road travel risk level'*. Result [4] for target entity group TG_4 demonstrates a definitive *'low risk road travel'* group. That is, with the 95% C.L.s taken into account, the TG_4 group is a *(statistically significant) 'low risk road travel' group*. Lastly, result [5] shows the target entity group TG_5 that appears to be a *'high risk road travel' group*, but once the error bounds on the *basic risk performance measure indicator* are taken into account, it cannot be determined whether this group *is 'a high risk'* or *'a low risk' road travel group*. Here again, further research and/or more and better quality data are required to draw any definitive conclusions about the *true 'road travel risk level'* of group TG_5.

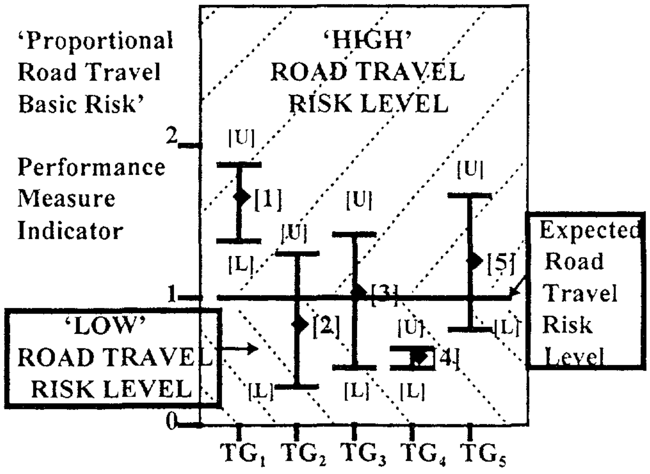

Figure 3. Interpretation of the '*Proportional Road Travel Basic Risk*' performance measure indicator.

It should be noted that a fixed '95% level of statistical confidence' has been used for measuring the error bounds on the *risk estimators* -- which forms the basis for drawing conclusions and arriving at decisions.

Another approach that could be used involves the estimation of the confidence levels, i.e., X% confidence limits, for which the UPPER X% CONFIDENCE LIMIT IS 'STRICTLY LESS THAN' THE *'EXPECTED' ROAD TRAVEL RISK LEVEL VALUE OF 1* (for an *estimated road travel risk indicator that is less than 1*) or, for which the LOWER X% CONFIDENCE LIMIT IS 'STRICTLY GREATER THAN' THE *'EXPECTED' ROAD TRAVEL RISK LEVEL VALUE OF 1* (for an *estimated road travel risk indicator that is greater than 1*). Although this approach will not provide constant 'fixed' confidence limits by which all interpretations, conclusions and decisions are made (for all of the *road travel risk estimators developed*) it does provide a definitive 'level of statistical confidence' for qualifying/supporting decisions made. That is, the results of all *road travel risk estimators* can be interpreted as:

"It can be concluded that, at the x% level of statisitcal confidence, target entity group TG_i is a 'high' (or 'low') (or 'expected level') road travel risk group"

THE '*FREQUENCY ROAD TRAVEL BASIC RISK*' PERFORMANCE MEASURE INDICATOR -- R^F : *AN ESTIMATOR BASED ON FREQUENCY COUNT DATA INPUTS*

There will be occasions where the proportional representations for the road incident (fatality, injury, or collision) involvement and/or *exposure (to risk)* -- kms. of road travel, for the target group of entities being evaluated are NOT KNOWN! Effectively, only the absolute frequencies of road incident encounter *and exposure (to risk)* are KNOWN! This happens when information is not collected or available for all categories or characteristics of a particular target entity group, target conditions and temporal period criterion involved in the evaluation. For example, all age groups (ages) of drivers required for a *risk analysis assessment/evaluation* may not be available in the incident database and/or the *exposure(to risk)* database. This can occur quite frequently in the case of directed studies where many characteristics of the entities being investigated/ studied are not all collected, such as 'only vehicles of certain types being included' in the sampling plan and data collection.

When only frequency count information/data is available the *road travel risk estimator(s)* are simply *'accident rate(s)'* which, from an interpretation perspective, provide no information regarding the *degree or level of risk* for the group(s) of entities and their travel pattern/circumstances being evaluated. That is, there is no capacity to assess whether the target entity group(s) are a *'high risk'*, *'low risk'* or *'at an expected level of risk'*. The only meaningful use of these *frequency road travel risk performance measurement indicators* is in *'relative risk' comparisons* between different group(s) of entities, or *in comparisons made with respect to the same group of entity(s) for two different temporal periods.* Even then, particularly in the latter case, extreme caution is in order owing to a phenomenon known as 'regression-to-the-mean' -- a process whereby entities with higher-than-average (or lower-than-average) accident frequency counts will regress (over time) towards the mean/average frequency count for the entity group(s) being analyzed. Hauer (1983) has demonstrated that the 'regression-to-the-mean' phenomenon is in fact a 'real phenomenon' that occurs with respect to accidents occurring on our roads and highways, and must be corrected for to meaningfully compare incident frequency counts (and rates as well) in a 'before' period to those in an 'after' period for two groups of entities. As can be realized by now, owing to the serious limitations and pitfalls inherent to the incident frequency count method for estimating, monitoring, comparing and evaluating *road travel risk(s)* for entities on the roads and highways, these types of *risk estimation* should be avoided. There would appear to be some merit in using the frequency count method for comparing the *level(s) of risk (i.e., 'relative risk estimators')* for two or more different groups of entities evaluated during the same temporal period.

For completeness, therefore, the mathematical and statistical methodology for computing the *'frequency road travel basic risk performance measure indicator'* and its related accuracy assessment are provided in this paper. For methodology on the other types of 'frequency' data input risk estimators see Stewart (1998). The mathematical formulation for this indicator is given by:

$$R^F(I|TG_i,TC_j,T_z) = \frac{(I|TG_i,TC_j,T_z)}{(E|TG_i,TC_j,T_z)} \qquad (7.)$$

where,

$R^F(I|TG_i,TC_j,T_z)$ is the ***frequency road travel basic risk performance measure indicator*** (computed from **frequency count data inputs** on **incidents** and ***exposure (to risk)***) for a **target group** of entities **i**, **TG_i**, that measures their ***road travel risk*** of encountering a road **incident of type I**, while traveling under specified **target** travel **conditions j**, **TC_j**, during a specific **time period z**, **T_z**;

$(I|TG_i,TC_j,T_z)$ is the **frequency count representation** of the **target** entity **group i**, **TG_i**, involved in **road incidents** of **type I**, while traveling under specified **target** travel **conditions j**, TC_j, during a specific **time period z**, T_z;

$(E|TG_i,TC_j,T_z)$ is the **frequency count representation** (i.e., **kms of travel**) for the **target** entity **group i's**, **TG_i's, road travel (E)** on the roads and highways, i.e., their **'EXPOSURE' to the road travel risk(s)**, while traveling under specified **target** travel **conditions j**, TC_j, during a specific **time period z**, T_z; and,

TC_j is a **specified target travel pattern/condition** (as described earlier in Section 5).

The Accuracy of R^F

The details concerning the mathematical and statistical methodologies developed for deriving the formulae for measuring the accuracy of *the 'frequency road travel basic risk' performance measure indicator* are not provided in this paper. Only final results are given and the reader is invited to contact the author for the formulations and derivations.

The lower 95% confidence limit for $R^F(I|TG_i,TC_j,T_z)$ is given by equation (8.).

$$R^F_{[L,95\%]} = e^{\{\ln_e[R^F] - 1.96 * \sigma(\ln_e[R^F])\}} \tag{8.}$$

and,

the upper 95% confidence limit for$R^F(I|TG_i,TC_j,T_z)$ is given by equation (9.).

$$R^F_{[U,95\%]} = e^{\{\ln_e[R^F] + 1.96 * \sigma(\ln_e[R^F])\}} \tag{9.}$$

where,

$$\sigma(\ln_e[R^F]) = \sqrt{\left[\frac{1}{(I)}\right] + \left[\frac{\sigma^2((E))}{[(E)]^2}\right]} \tag{10.}$$

or, an alternative (but equivalent) formulation for $\sigma(\ln_e[R^F])$ is given by,

$$\sigma(\ln_e[R^F]) = \sqrt{\left[\frac{1}{(I)}\right] + \left[CV[(E)]\right]^2} \tag{11.}$$

$\ln_e[R^F]$ is the **natural logarithm (to the base e) of R^F**;

and,

$\sigma(\ln_e[R^F])$ is the **statistical 'one standard error'** measurement for the natural logarithm (to the base e) of the **frequency road travel basic risk estimator R^F**;
and,

$\sigma^2((E))$ is the **statistical 'variance'** measurement for the **kilometers of road travel done, (E),** by **target** entity **group i**, TG_i, under **target** travel **conditions j**, TC_j, during a specified **time period z**, T_z;
and,

CV(E) is the **statistical 'coefficient of variation'** measurement for the **kilometers of road travel done,** (E), by **target** entity **group i**, TG_i, under **target** travel **conditions j**, TC_j, during a specified **time period z**, T_z;

where,

$(I) = (I|TG_i,TC_j,T_z)$,
$(E) = (E|TG_i,TC_j,T_z)$,
$R^F = R^F(I|TG_i,TC_j,T_z)$.

The Interpretation of R^F

Assumptions and Limitations -- There are no assumptions required for justifying or interpreting the final value of the *frequency road travel basic risk estimator*. Similarly, there are no limitations or restrictions affecting the computation of this estimator, however severe limitations and restrictions with respect to its interpretation and usefulness do exist. These are discussed below.

Analytical Properties – The analytical properties associated with *the frequency road travel basic risk performance measure indicator* include:

$0 \leq (I|TG_i,TC_jT_z) < \infty$ -- the lower bound of the estimator is zero, and it has a logical upper bound;

$0 < (E|TG_i,TC_j,T_z) < \infty$ -- the *'exposure (to risk)'* must always be greater than zero for meaningful *risk estimation*, i.e., if there is *'zero/no exposure'* then there is *'zero/no travel'* which results in *'NO RISK OF INCIDENT ENCOUNTER'*;

$0 \leq R^F(I|TG_i,TC_j,T_z) < \infty$ -- the *frequency road travel risk performance measure indicator* has a logical 'upper bound';

$R^F(I|TG_i,TC_j,T_z)_{[L,95\%]}$ and **$R^F(I|TG_i,TC_j,T_z)_{[U,95\%]}$** are 'near' symmetrical around $R^F(I|TG_i,TC_j,T_z)$ and represent logical 'lower' and 'upper' 95% C.L.s, respectively;

$R^F(I|TG_i,TC_j,T_z)$ are **NOT UNIT-FREE**, i.e., they are **NOT DIMENSIONLESS**. Since the estimators are not unit-free there is **no expected value** or **bench-mark** for ***comparing and assessing frequency road travel risk estimators***. In the case of the *proportional road travel basic risk estimator* the 'expected value' is '1' -- the bench-mark for *identifying 'high' and 'low' road travel risk* entity groups. This is a desired and necessary property for the *risk estimator* to possess for differentiating among *road travel risk levels* for different entities (and their subgroups, as well) on the roads and highways. Unfortunately, the **frequency road travel basic risk performance measure indicator DOES NOT POSSESS this 'interpretative property'**.

As will be seen in subsequent sections, however, *the frequency road travel 'relative risk' and 'relative risk odds-ratio' performance measure estimators* are much more useful. These two estimators offer the same powers of interpretation as the *'proportional road travel 'relative risk' and 'relative risk odds-ratio' performance measure indicators*. This is because the dimensional units of the incident and *exposure (to risk)* frequency count data inputs used to compute the *frequency road travel 'relative risk' and 'relative risk odds-ratio' indicators* cancel one another in the estimation formulae resulting in UNIT-FREE estimators -- the 'desired analytical property' -- resulting in the ability to identify significant differences in *road travel relative risks* between and among entity groups, and significant differences in *road travel risks* between and among entity groups for specified road travel condition comparisons.

Interpretation(s) -- Unfortunately, there are **no meaningful interpretations available from the $R^F(I|TG_i,TC_j,T_z)$** *frequency road travel basic risk estimator* as there were for $R^P(I|TG_i,TC_j,T_z)$ -- the *proportional road travel basic risk estimator*. In essence, $R^F(I|TG_i,TC_j,T_z)$ is simply ***an accident rate*** with no standard or bench-mark to compare it to. Unlike the *proportional road travel basic risk estimator* which had an **'expected standardized value' of 1** with which to compare for identifying ***'high'***, ***'low'*** and ***'expected' road travel risk level(s)***, *the* **FREQUENCY ROAD TRAVEL** ***BASIC RISK ESTIMATOR*** PROVIDES **NO INFORMATION FOR ASSESSING THE *LEVEL(S) OF ROAD TRAVEL RISK* ATTRIBUTABLE TO THE ENTITY GROUPS BEING ANALYZED AND EVALUATED**. As a result, *the frequency road travel basic risk performance measure indicator* is of **limited** use in differentiating among *road travel risk level(s)* and identifying characteristics of road travel entities and groups with *'high' road travel risk*. The only types of comparisons possible involve the comparisons of various target entity groups' *accident rates* with some other standard, e.g., *mean accident rate* for all entities, *accident rate for another control group* of entities, etc.. By their very nature, however, these types of comparisons are done through the use of *'relative risk' and 'relative risk odds-ratio' performance measure indicators* -- not *'basic road travel risk' estimators*. There are, therefore, **no meaningful interpretation(s) for assessing/evaluating the *frequency road travel basic risk estimator* or identifying *'high risk'* road travel entities.**

The examples provided in Figure 5 demonstrate the limited amount of information available for interpretation and assessment of the *frequency road travel basic risk performance measure indicators*. Hypothetical examples for five $R^F(I|TG_i,TC_j,T_z)$, indicated by [1], [2], [3], [4], and [5], are illustrated in the graphical results. Result [1] demonstrates an *accident rate* of about 1.50 *accidents per million driver kms. of travel* for target entity group TG_1. Similarly, results [2], [3], [4] and [5] depict *the accidents per million driver kms. of travel* for target entity groups TG_2, TG_3, TG_4, and TG_5 -- 0.75, 1.00, 0.50 and 1.20 respectively. From an interpretation point of view, all that can be said is that the *accident rates* vary between 0.50 and 1.*5 accidents per million driver kms. of travel* for the five target entity groups and, when the error levels (95% confidence limits) are taken into account, there does not appear to be any significant differences among the *accident rates* with the exceptions of: result [4] compared to result [5] -- it is possible that result [4] is statistically significantly different in value from result [5] ; and result [4] compared to [1]. This can be determined through the application of hypotheses tests and evaluating whether *significant differences in accident rates* exist by comparing the results among the five target entity groups. Although the methods for carrying out these types of comparisons is discussed in the following section, **the major problem with this method remains -- an inability to assess whether any of the (groups of) target entities being evaluated are '*high*' or '*low*' or '*at their expected level of*' *road travel risk*.**

THE 'PROPORTIONAL ROAD TRAVEL RELATIVE RISK' PERFORMANCE MEASURE INDICATOR -- RR^P : *AN ESTIMATOR BASED ON PROPORTIONAL DATA INPUTS*

The concept behind the 'road travel *relative risk*' estimator seeks to compare the *risks of incident involvement* for two (groups of) entities represented on the roads and highway systems. In essence, the *'road* *travel basic risk' estimator* (as described in section 5) is computed for both (groups of) entities. Then, these *two road travel basic risk performance measure indicators* are then compared through the computation of a *relative risk ratio* (i.e., the division of the one *basic risk* estimator by the other). The resultant *road travel relative risk performance measure indicator* is a measure of any *differential in road travel risk level(s) (i.e., level(s) of safety) existing between the two (groups of) entities.*

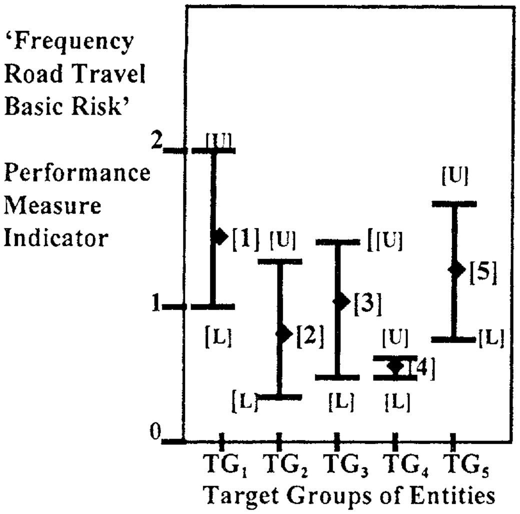

Figure 4. Interpretation of the '*Frequency Road Travel Basic Risk*' performance measure indicator.

The mathematical formulation for detecting any *road travel risk differential* existing between the two entity target groups, say 'target group 1' -- TG_1 , and 'target group 2' -- TG_2 , is given by:

$$RR^P(I|TG_{1:2},TC_j,T_z) = \frac{R^P(I|TG_1,TC_j,T_z)}{R^P(I|TG_2,TC_j,T_z)} \qquad (12.)$$

where,

$$R^P(I|TG_1,TC_j,T_z) = \frac{p(I|TG_1,TC_j,T_z)}{p(E|TG_1,TC_j,T_z)} ,$$

$$R^P(I|TG_2,TC_j,T_z) = \frac{p(I|TG_2,TC_j,T_z)}{p(E|TG_2,TC_j,T_z)} ,$$

and,

$RR^P(I|TG_{1:2},TC_j,T_z)$ is the *proportional* **road travel *relative risk* performance measure estimator** of the **<u>differential in road travel risk existing between entity groups TG_1 and TG_2</u>**, under specified **target travel conditions j**, TC_j, during an evaluation **time period z, T_z**

The Accuracy of *RR^P*

The **lower and upper 95% confidence limits** for the $RR^P(I|TG_{1:2},TC_j,T_z)$ estimator are given in equations (13.) and (14.) respectively.

$$RR^P(X)_{[L,95\%]} = e^{\{\ln_e[RR^P(X)] - 1.96 * \sigma(\ln_e[RR^P(X)])\}} \qquad (13.)$$

$$RR^P(X)_{[L,95\%]} = e^{\{\ln_e[RR^P(X)] + 1.96 * \sigma(\ln_e[RR^P(X)])\}} \qquad (14.)$$

where,

$$\sigma(\ln_e[RR^P(X)]) = \sqrt{\sigma^2(\ln_e[RR^P(X)])} \qquad (15.)$$

and,

$$\sigma^2(\ln_e[RR^P(X)]) = \sum_{k=1}^{2} \left\{ \left[\frac{1}{p(I_k)}\right]^2 * \sigma^2(p(I_k)) \right\}$$

$$+ \sum_{k=1}^{2} \left\{ \left[\frac{1}{p(E_k)}\right]^2 * \sigma^2(p(E_k)) \right\} \qquad (16.)$$

where,

$X = (I|TG_{1:2},TC_j,T_z)$,
$I_k = (I|TG_k,TC_j,T_z)$,
$E_k = (E|TG_k,TC_j,T_z)$.

The Interpretation of *RR^P*

<u>Assumptions and Limitations</u> -- There are no assumptions that need to be made for justifying or interpreting the resultant values of the *proportional road travel relative risk estimator.* There are no limitations or restrictions affecting the interpretation of *the proportional road travel relative risk estimator.* Similar to the *proportional road travel basic risk estimator*, natural logarithms (to the base e) are used thereby ensuring that the RR^P can always be measured, has a logical upper bound and the confidence limits measuring its accuracy are 'near symmetrical' around RR^P and have a logical upper bound as well.

<u>Analytical Properties</u> -- The proportions of incidents and *exposure (to risk)* for both groups TG_1 and TG_2 must

be greater than zero for meaningful *relative risk estimation and comparisons*, i.e., $p(I|TG_1,TC_j,T_z) > 0$, $p(I|TG_2,TC_j,T_z) > 0$, $p(E|TG_1,TC_j,T_z) > 0$, $p(E|TG_2,TC_j,T_z) > 0$.

$RR^P(I|TG_{1:2},TC_j,T_z)$ are UNIT-FREE, i.e., DIMENSIONLESS, ensuring that comparisons of RR^Ps are valid and meaningful.

$0 < RR^P(I|TG_{1:2},TC_i,T_i) < \infty$. The value of the *proportional road travel relative risk estimator* is always greater than zero and has a logical 'upper bound'.

The 95% lower and upper confidence bounds, $RR^P(I|TG_{1:2},TC_j,T_z)_{[L,95\%]}$ and $RR^P(I|TG_{1:2},TC_j,T_z)_{[U,95\%]}$, are 'near' symmetrical around $RR^P(I|TG_{1:2},TC_j,T_z)$ and have logical lower and upper bounds as well.

$RR^P(I|TG_{1:2},TC_j,T_z)_{[EXPECTED]} = 1$. The expected value of a *proportional road travel relative risk estimator* is '1' with the value of '1' meaning that *the road travel risk level of incident encounter of type I* is potentially equivalent for both target entity groups TG_1 and TG_2 under target travel conditions j, TC_j, during a specified evaluation time period z, T_z. This 'expected value' of 1 implies that if the ratio of the representation of entity group TG_1 in incident involvement to its *exposure (to risk) representation* on the roads is equivalent to target entity group TG_2's incident involvement to *exposure (to risk) representation ratio*, then *the road travel risk level* for the two target entity groups is *'relatively' the same.* In other words, the *level of safety* being experienced by the two groups of entities is equivalent. In a similar fashion as the *'proportional road travel basic risk' estimators*, however, the *proportional road travel relative risk estimators* must only be interpreted by taking into account their accuracy levels, i.e., 95% C.L.s.

Interpretation(s) – The following rules govern the decision-making from the computed road travel relative risk estimators:

If $RR^P(I|TG_{1:2},TC_j,T_z) < 1 \Rightarrow$ Then the ***road travel risk level of incident encounter of type I*** is potentially ***'lower'*** for the **target** entity or **group** of entities, TG_1, then it is for **target** entity **group** TG_2 under **target** travel **conditions** j, TC_j, during a specified **time period z**, T_z;

If $RR^P(I|TG_{1:2},TC_j,T_z) > 1 \Rightarrow$ Then the ***road travel risk level of incident encounter of type I*** is potentially ***'higher'*** for the **target** entity or **group** of entities, TG_1, then it is for **target** entity **group** TG_2 under **target** travel **conditions** j, TC_j, during a specified **time period z**, T_z;

If $RR^P(I|TG_{1:2},TC_j,T_z) = 1 \Rightarrow$ Then the ***road travel risk level of incident encounter of type I*** is potentially ***'equivalent'*** for **target** entity **groups** TG_1 and TG_2 under **target** travel **conditions** j, TC_j, during a specified **time period z**, T_z.

The above decision rules provide the basic guidelines for *interpreting the relative risk estimators*, but their results cannot be fully interpreted without taking into account their accuracy assessment measurements. The hypothetical examples given in Figure 5 that follow demonstrate the care that must be taken for properly interpreting the resultant *proportional road travel relative risk estimators.*

Five target group *relative risk comparisons* estimating the differential in *road travel risk* between target group 1 (TG_1) and target groups TG_2, TG_3, TG_4, TG_5 and TG_6 are illustrated. Result [1] shows an RR^P value of about 1.6 comparing entity target groups 1 and 2, implying that target group 1 has a *road travel risk level* that is about 1.6 times higher than that of target group 2. Even when the 95% C.L. error bounds for the *relative risk estimator* are taken into account it can be concluded that target group 1 is *a 'higher road travel risk' group* than entity group TG_2. Examining the *road travel relative risk comparison* between TG_1 and TG_3 -- result [2] = 0.75 -- it can be readily seen that TG1 has a *definitive 'lower road travel risk level'* than TG2, and this conclusion is true at a 95% level of statistical confidence. Result [3] measuring the *relative risk* of TG_1 compared to TG_4 is equal to 1.0 indicating that TG_1 appears to be *an equaivlalent 'road travel risk group'* to group TG_4. However, when the 95% C.L.s are taken into account it cannot be determiined which of the two groups is a *(statistically significant) 'higher risk group'* than the other, if either. Therefore, more and better (more accurate) data and/or further research are needed to make a definitive decision regarding whether a *significant road travel risk differential* exists between entity groups TG_1 and TG_4. The *relative risk estimator* comparing target groups 1 and 5 (result [4]) is 0.6 with the upper 95% C.L., [L,95%], smaller than the value of 1. The conclusion can therefore be drawn that TG1 is *definitively a 'lower road travel risk group'* than TG_5 -- this is known to be true at the 95% level of statistical confidence. Finally, the last example (result [5]) comparing entity groups TG_1 and TG_6 has *a relative risk estimator* value of 1.2 indicating that TG_1 *appears to be a higher road travel risk than group* TG_6. However, when the 95% C.L.s are considered it cannot be determined which group, if either, is *a lower risk group* compared to the other. In this instance more and better (more accurate) data and/or further research is necessary to make a definitive decision regarding any *road travel* *risk differential* that may exist between entity groups TG_1 and TG_6.

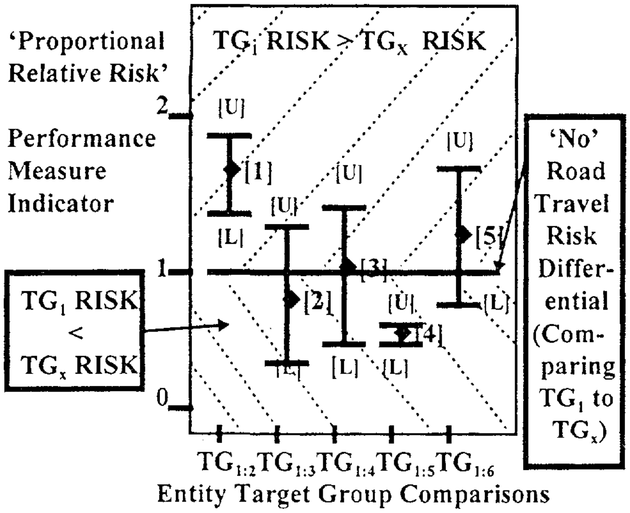

Figure 5. Interpretation of the '*Proportional Road Travel Relative Risk*' performance measure indicator.

An Example of the 'Relative Road Travel (Proportion) Risk' Estimator, RR^P --

Problem Formulation :
We would like to determine whether any significant road travel risk differential exists between two particular target groups of entities, TG_x and TG_y. The target conditions, TC_y , associated with the evaluation are for night-time travel only; on rural roads and highways; and the temporal period z, T_z, being covered is for the first six months of the calendar year in 1994. We have all of the necessary input data (proportion estimates of injury incidents -- injuries are being evaluated. proportion estimates of exposure (to risk), and measures of variability on all proportion estimates in terms of CVs -- coefficients of variation). The specific data inputs are given in the following section.

Data Input Requirements :
**(1) $p(I|TG_x,TC_i,T_i) = 0.4$; (2) $p(I|TG_y,TC_i,T_i) = 0.5$; (3) $p(E|TG_x,TC_i,T_i) = 0.2$; (4) $p(E|TG_y,TC_i,T_i) = 0.3$; (5) $CV[p(E|TG_x,TC_i,T_i)] = 0.2$; (6) $CV[p(E|TG_y,TC_i,T_i)] = 0.1$;
(7) $n(I) = 200{,}000$ injuries.**

The above information provides all of the 'data input requirements' for estimating the 'relative road travel (proportion) risk' performance measure estimator for measuring the road travel risk differential that exists between target entity groups TG_x and TG_y.

Estimation, Accuracy Assessment and Interpretation -- Applying the proportional data inputs to equation (12.) we get the estimate of the 'relative road travel (proportion) risk' performance measure indicator:

$$\mathbf{RR^P(TG_{x:y}, TC_i, T_i) = 1.2}$$

Next, inputting the appropriate quantities into equation (16.) and computing it yields:

$$\sigma^2(\ln_e[RR^P(I|TG_{x:y},TC_i,T_i)]) = 0.0500125$$

Now, computation of equation (15.) gives:

$$\sigma(\ln_e[RR^P(I|TG_{x:y},TC_i,T_i)]) = 0.223635$$

And finally, computation of equations (13.) and (14.) yields the lower and upper 95% C.L.s for $RR^P(TG_{x:y}, TC_i, T_i)$ respectively, given by:

$$RR^P(I|TG_{x:y},TC_i,T_i)_{[L,95\%]} = 0.774140$$

$$RR^P(I|TG_{x:y},TC_i,T_i)_{[U,95\%]} = 1.860127$$

Summary of Results/Interpretations --

Conclusion :
The target entity group TG_x **appears to be a "higher road travel risk group" than group** TG_y . However, when the error limits for the risk differential estimator are taken into account, **it cannot be concluded that a significant differences in road travel risk differential** exists between the two groups of entities. **This statement is known to be true at a 95% level of statistical confidence.**

Recommendation :
It is **recommended that** more/better data be obtained and/or further research be conducted to determine whether a significant risk differential exists between the two entity groups. **No definitive decision for remedial treatment(s) (i.e. mitigative measures and/or countermeasure programs)** for target entity group TG_x to reduce their road travel risk of injury encounter for the target conditions and temporal periods evaluated **can be supported at the present time.**

NOTE: The 'Relative Road Travel (Frequency) Risk' Estimator, RR^F, is not presented in this paper. For its details see Stewart (1998b).

THE 'RELATIVE ROAD TRAVEL (PROPORTION) RISK ODDS-RATIO' PERFORMANCE MEASURE INDICATOR : AN ESTIMATOR BASED ON PROPORTION DATA INPUTS, RROR^P

The concept behind the RROR performance measure estimator involves the comparison of the relative road travel risks for a target entity group, say TG_x, during target travel conditions TC_i as compared to travel conditions TC_k to the relative road travel risks for a target entity group, say TG_y, during target travel conditions TC_i as compared to travel conditions TC_k. In essence, the final relative risk odds-ratio (RROR) performance measure estimators provide a measure of the differential in road travel risks being experienced by the target and comparison groups of entities for the selected target and comparison travel conditions being evaluated.

The mathematical and statistical formulation for the RROR estimators are given by:

$$\mathbf{RROR^P(I|TG_{1:2},TC_{1:2},T_i) = \frac{RR^P(I|TG_1,TC_{1:2},T_i)}{RR^P(I|TG_2,TC_{1:2},T_i)}} \qquad (17.)$$

where,

$\mathbf{RROR^P(I|TG_{1:2},TC_{1:2},T_i)}$ is the relative road travel risk odds-ratio proportion estimator measuring the differential in road travel risk of encountering incidents of type I, between entity groups TG_1 and TG_2 under travel conditions TC_1 compared to travel conditions TC_2, for a specified evaluation time period i, T_i;

$\mathbf{RR^P(I|TG_1,TC_{1:2},T_i)}$ **and** $\mathbf{RR^P(I|TG_2,TC_{1:2},T_i)}$ are the relative road travel proportion risk estimators of encountering incidents of type I for entity groups TG_1 and TG_2 respectively under travel conditions TC_1 compared to travel conditions TC_2 for a specified evaluation time period i, T_i.

Accuracy of the 'Road Travel (Proportion) Relative Risk Odds-Ratio' Estimator, RROR^P

The lower and upper 95% C.L.s for $RROR^P(I|TG_{1:2},TC_{1:2},T_i)$ are given in (18.) and (19.).

$$\mathbf{RROR^P(X)_{[L,95\%]} = e^{\{\ln_e[RROR^P(X)] - 1.96 * \sigma(\ln_e[RROR^P(X)])\}}} \qquad (18.)$$

$$\mathbf{RROR^P(X)_{[L,95\%]} = e^{\{\ln_e[RROR^P(X)] - 1.96 * \sigma(\ln_e[RROR^P(X)])\}}} \qquad (19.)$$

where,

$$\sigma(\ln_e[\mathbf{RROR^P(X)}]) = \sqrt{\sigma^2(\ln_e[\mathbf{RROR^P(X)}])} \qquad (20.)$$

and,

$$\sigma^2(\ln_e[RROR^P(X)]) = \sum_{L=1}^{2}\left[\frac{1}{n(I,TG_L,T_i)}\right] x \left\{\sum_{J=1}^{2}\left[\frac{[1 - p(I|TG_L,TC_J,T_i)]}{p(I|TG_L,TC_J,T_i)}\right]\right\} + \sum_{L=1}^{2}\sum_{J=1}^{2}\left[CV[p(E|TG_L,TC_J,T_i)]\right]^2 \qquad (21.)$$

where,
$\mathbf{(X) = (I|TG_{1:2},TC_{1:2},T_i)}$,
$\mathbf{n(I,TG_L,T_i)}$ is the number of incidents of type I that entity group L, TG_L, is involved in during the evaluation time period i, T_i;
$\mathbf{p(I|TG_L,TC_J,T_i)}$ **and** $\mathbf{CV[p(E|TG_L,TC_J,T_i)]}$ are proportion data and coefficients of variation respectively for the various entity target groups and travel conditions being evaluated (as defined in previous sections).

Interpretation of the 'Relative Road Travel (Proportion) Risk Odds-Ratio' Estimator, RROR^P

As with the previous types of road travel risk estimators, logarithms (to the base e) are computed for all 'basic road travel risk' components of the RROR^P estimator to ensure that logical lower bounds of zero exist resulting in a logical lower bound of zero for the RROR^P estimator. Also, RROR^P estimators possess the nice analytical property of being dimensionless -- i.e. unit-free, and therefore comparisons between and among them are always valid.

IF $RROR^P(I|TG_{1:2},TC_{1:2},T_i) < 1 \Rightarrow$ THEN the road travel risk level of incident encounter of type I is potentially lower for the target entity or group of entities TG_1 than it is for target entity or group of entities TG_2 for travel conditions TC_1 compared to travel conditions TC_2 during a specified evaluation time period i, T_i;

IF $RROR^P(I|TG_{1:2},TC_{1:2},T_i) > 1 \Rightarrow$ THEN the road travel risk level of incident encounter of type I is potentially higher for the target entity or group of entities TG_1 than it is for target entity or group of entities TG_2 for travel conditions TC_1 compared to travel conditions TC_2 during a specified evaluation time period i, T_i;

IF $RROR^P(I|TG_{1:2},TC_{1:2},T_i) = 1 \Rightarrow$ THEN the road travel risk level of incident encounter of type I is equivalent for the target entity or group of entities TG_1 and target entity or group of entities TG_2 for travel conditions TC_1 compared to travel conditions TC_2 during a specified evaluation time period i, T_i;

As in the case of the previous road travel risk estimators the relative road travel risk odds-ratio estimators must only be interpreted by taking into account their accuracy levels (i.e. 95% C.L.s) for deriving conclusions and making decisions for road travel safety improvements, as illustrated in the following example.

An Example of the 'Relative Road Travel (Proportion) Risk Odds-Ratio' Estimator, $RROR^P$ --

Problem Formulation :
We would like to determine whether any significant road travel risk (of injury) differential exists between two particular target groups of entities TG_x and TG_y with respect to their travel during conditions TC_i as compared to conditions TC_J. The travel conditions being compared for the two groups are nighttime vs. daytime travel. The temporal period z, T_z, for the evaluation period is the years 1992-1994 inclusive. The data inputs needed for carrying out the risk evaluation are given in the following section.

Data Input Requirements :
For target entity group TG_x : (1) $p(I|TG_x,TC_i,T_i)= 0.4$; (2) $p(I|TG_x,TC_J,T_i) = 0.2$;(3) $p(E|TG_x,TC_i,T_i) = 0.15$; (4) $p(E|TG_x,TC_J,T_i)=0.3$;(5) $CV[p(E|TG_x,TC_i,T_i)]=0.05$; (6) $CV[p(E|TG_x,TC_J,T_i)]=0.1$; (7) $n(I,TG_x,T_i) = 100{,}000$ injuries ; T_i = 1992-1994.

For target entity group TG_y : (1) $p(I|TG_y,TC_i,T_i) = 0.3$; (2) $p(I|TG_y,TC_J,T_i) = 0.5$;(3) $p(E|TG_y,TC_i,T_i) = 0.3$; (4) $p(E|TG_y,TC_J,T_i) =0.4$; (5) $CV[p(E|TG_y,TC_i,T_i)]= 0.15$; (6) $CV[p(E|TG_y,TC_J,T_i)]=0.05$; (7) $n(I,TG_y,T_i))= 50{,}000$ injuries ; T_i = 1992-1994.

Estimation, Accuracy Assessment and Interpretation :
Computation of equation (17.) yields the estimate for the relative road travel (proportion) risk odds-ratio performance measure indicator, given by:

$$\mathbf{RROR^P(I|TG_{x:y},TC_{i:J},T_i) = 5.0}$$

Next, computing equations (21.) and (20.) (in that order) yields,

$$\sigma^2(\ln_e[\mathbf{RROR^P(I|TG_{x:y},TC_{i:J},T_i)}]) = \mathbf{0.037622},$$

and

$$\sigma(\ln_e[\mathbf{RROR^P(I|TG_{x:y},TC_{i:J},T_i)}]) = \mathbf{0.193964}$$

And finally, computation of equations (18.) and (19.) yields the lower and upper 95% C.L.s for $RROR^P(I|TG_{x:y},TC_{i:J},T_i)$ respectively, given by:

$$\mathbf{RROR^P(I|TG_{x:y},TC_{i:J},T_i)_{[L,95\%]} = 3.418728}$$

$$\mathbf{RROR^P(I|TG_{x:y},TC_{i:J},T_i)_{[U,95\%]} = 7.312663}$$

Summary of Results/Interpretations :

Conclusion :
The road travel risks for target entity group TG_x are significantly higher than those of target entity group TG_y for travel under conditions TC_i compared to conditions TC_J. This finding is known to be true at the 95% level of statistical confidence.

Recommendation :
It is recommended that target entity group TG_x be considered for remedial treatment(s) (i.e. mitigative measures and/or countermeasure programs) for reducing their 'high road travel risk of injury encounter' during travel in conditions TC_i, in order to improve their level(s) of road travel safety.

NOTE: The 'Relative Road Travel (Frequency) Risk Odds-Ratio' Estimator, -- RR^{F}' is not presented in this paper. For its details see Stewart (1998).

CONCLUSIONS

In order to continuously work towards improving the levels of travel safety on our roads and highways it is first necessary to identify the circumstances under which 'unsafe levels' of road travel are occurring. To this end there is a requirement to continuously measure, monitor, assess, evaluate and compare the prevailing levels of road travel risks being experienced by various road users and their associated vehicle-road/infrastructure-environmental-trip-temporal travel characteristics. As discussed this is only possible when compatible and consistent 'exposure to risk (amounts of travel)' and 'incident (accident, injury, fatality)' databases are both available for the various road users and their travel/use characteristics.

This paper presented methodologies for formulating the three main types of road travel risk performance measure estimators that lend themselves to measuring, interpreting and comparing the levels of risk on the roads for entities and their travel condition char-acteristics. The best methods require 'proportion' data on 'exposure to risk' and road collision incidents,-- the use of frequency counts (or rates) is not recommended due to the serious limitations in interpretation powers of the resultant estimators for assessing and evaluating the risk levels. This is also supported by Hauer (1983, 1995) discussing the potential flaws and limitations in using incident rates when non-linear relationships exist between incident and exposure frequencies, in which cases a he maintains 'safety performance functions' should be used. The key to proper interpretation of road travel risk estimators requires that accuracy estimates (e.g. confidence limits) be formulated and computed for them and taken into account to derive correct conclusions regarding the risk levels and subsequently to make sound decisions on any policy and/or programs (countermeasures/mitigative measures) to pursue for improving levels of road travel safety.

With these concepts and methodology in place, it is possible to incorporate them into a 'Risk Analysis and Evaluation System Model' (RAESM) [Stewart, 1998b]. A system such as this would provide the ability to measure, compare, monitor and evaluate the levels of risk (levels of safety) on the roads and highways on a continuous basis thereby providing the means for identifying and prioritizing 'high road travel risk' problems and issues for remedial treatment(s) in order to reduce road travel risk levels. Presently, the Evaluation and Data Systems Division, Road Safety Programs, Transport Canada is working on a project (entitled "The Design and Development of a 'Risk Analysis System' for Measuring and Monitoring Road Travel Risks") which has the expressed objectives of designing and developing an RAESM for future implementation.

In summary, **there are numerous benefits to be realized from the development of a comprehensive and continuous** ***national exposure (to risk) data collection system and database***, including:

- An ability to *analyze and interpret incident (collision, injury and fatality) data bases to the fullest extent possible, particularly the measurement of changes in incidents as the result of changes in: social and economic factors, existing and planned program measures and countermeasures, and exposure (to risk) levels*

- A significantly enhanced capacity to *develop models on accident causation and injury severity for determining the effects of contributing factors and countermeasure programs on accident and casualty risk levels, which is necessary in order to enhance our knowledge and understanding of the accident causation process*

- An ability to *implement a 'national risk analysis and evaluation system'*

- An ability to *effectively measure, monitor, compare and evaluate the levels (degrees) of risk / levels of safety* for road travel factors and characteristics (i.e., human, vehicle, road/infrastructure, environment, trip and temporal) *that cause the incidents of collisions, injuries and fatalities (i.e., the consequences of road travel risk levels) on Canada's roads and highways*

- An ability to *identify the 'high risk' road travel problems and issues* requiring remedial treatment(s) and/or action(s) in order *to reduce these risk levels and improve road safety*

- An ability to *conduct proper socio-economic impact analyses (SEIAs) and regulatory impact analyses (RIAs) for measuring and substantiating the benefits and costs of potential mitigative measures/countermeasures selected for reducing the risks on the roads and highways*

- An ability to *conduct proper cost-benefit analyses studies in support of SEIAs and RIAs*

- A significantly increased ability to *carry out effective assessments/evaluations of both present and potential impacts of various countermeasure programs and mitigative measures implemented for reducing road travel risks, or of projected changes in transport patterns*

- A significantly enhanced capacity to *provide expert and knowledgeable advice/guidance to senior management on the priority problems and issues that are adversely affecting the safety of travel on Canada's roads and highways*

- A significantly increased ability to *provide advice and guidance to senior management on the level of effort required for reducing road travel risk problems and issues, which could result in the inefficient use of the limited resources available for road safety work*

- An ability to *monitor the levels of transportation activity (and changes thereof) thereby reducing our effectiveness to address various transportation and safety issues whether it involves planning, design,*

operations, control, education, enforcement, management, or research

REFERENCES

Vey, A., "Relationship Between Daily Traffic and Accident Rates", American City, 1937.

Cameron, M.H., "Accident Risk-Concept and Analysis", M.Sc. Thesis, University of Melbourne, Australia, 1969.

Caroll, P.S., "The Meaning of Driving Exposure", University of Michigan, Highway Safety Research Institute, HIT-LAB Reports, Ann Arbor, Michigan, April, 1971.

Caroll, P.S., "Classification of driving exposure and accident rates for highway safety analysis", Accident Analysis and Prevention, Volume 5, pp.81-94, 1975.

Foldvary, L.A., "Road accident involvement per miles traveled - I", Accident Analysis and Prevention, Volume 7, pp.191-205, 1975.

Society of Automotive Engineers, Inc., "Accident Causation", February, 1980.

Fernie, B.E., "Multi-Level Road Accident Exposure Sampling System for South Africa", Accident Analysis and Prevention, Volume 14, No. 5, pp.413-415, 1982.

Hauer, E., "Traffic Conflicts and Exposure", Accident Analysis and Prevention, Volume 14, No. 5, pp.359-364, 1982.

Hauer, E., "A Common Bias in Before and After Accident Comparisons and Its Elimination", Transportation Research Board, 905: pp.164-174, 1983.

Hauer, E. "On Exposure and accident rate", Traffic Engineering and Control, 36(3): 134 - 138, 1995.

Risk, A. and Shaoul, J.E., "Exposure to Risk and Risk of Exposure", Accident Analysis and Prevention, Volume 14, No. 5, pp.353-357, 1982.

Toomath, J.B. and White, W.T., "New Zealand Survey of Driver Exposure to Risk of Accidents", Accident Analysis and Prevention, Volume 14, No. 5, pp.407-411, 1982.

Wolfe, A.C., "The Concept of Exposure to the Risk of a Road Traffic Accident and An Overview of Exposure Data Collection Methods", Accident Analysis and Prevention, Volume 14, No. 5, pp.337-340, 1982.

Stewart, D.E. and Sanderson, R.W., "The Measurement of Risk on Canada's Roads and Highways", paper presented and published at Transport Risk Assessment Conference, Proceedings of a Symposium on Risk in Transport, Third Symposium of Institute for Risk Research, Waterloo, Ontario, pp.1-21, 1984.

Stewart, D.E., "Exposure to the Risk of an Accident : The Canadian Department of Transport National Driving Survey and Data Analysis System, 1978-79", Report TMSE 8102, Ottawa : Transport Canada, April, 1981. Also, paper presented and published in Computer Science and Statistics, Proceedings of the 13th Symposium on the Interface, Pittsburgh, PA, pp.336-339, 1981.

Stewart, D.E., "Evaluating the Motorists' Risk of Encountering An Accident, Injury and Fatality On Our Canadian Roads and Highways : How Safe Are We?", paper presented and published in the Canadian Association of Applied Social Research, Learned Societies Conference, University of Ottawa, Ontario, June 5-7, 1982.

Stewart, D.E., "The Concept and Measurement of 'Accident Risk' in Road Transportation", paper presented and published in the Second Canadian Multi-disciplinary Road Safety Conference, University of Manitoba, Winnipeg, Manitoba,
June 6-8, 1983.

Stewart, D.E., "Risk Analysis : Methodology for Comparing Different Driver, Vehicle and Environment Factors", paper presented to the National Public Safety Organizations (NPSO), Ottawa : Transport Canada, October, 1985a.

Stewart, D.E., "Relative Risk Index Analysis : A Comparison of Occupant Fatality Risks Between Passenger Automobiles and Motorcycles", Report TMSE 8502, Ottawa : Transport Canada, November, 1985b.

Stewart, D.E., "The Risk of Fatal Injury Encounter for Passenger Automobile Occupants and Motorcyclists", Transport Canada Leaflet TP2436, CL 8505 (E/F), Ottawa : Transport Canada, September, 1985c.

Stewart, D.E., "Relative Risk Index Analysis : A Case Study Comparing Fatality Risk Levels for Passenger Automobile Occupants and Motorcyclists", paper presented to the National Public Safety Organization (NPSO), Ottawa : Transport Canada, October, 1985d.

Stewart, D.E., "The Documentation of Transport Canada's 1978-1979 National Driving (Exposure) Survey, a research proposal, Ottawa : Transport Canada, January, 1996a.

Stewart, D.E., "Road 'Exposure' Information : A Necessity for Measuring, Monitoring and Evaluating Road Traffic and Safety", paper presented to the National Task Force on Road Safety Data and Research, Toronto : October, 1996b.

Stewart, D.E., "The Design and Development of a 'Risk Analysis System' for Measuring, Monitoring and Evaluating Road Accident Risk Levels", a research proposal, Ottawa : Transport Canada, November, 1996c.

Stewart, D.E., "The 'Risk of Death' Associated with Drinking and Driving in Canada : An Evaluation of the Problem Over the Past Two Decades", paper presented to: Canadian Multidisciplinary Road Safety Conference X, Toronto, Ontario, June 9, 1997, and the International Conference "Traffic Safety on Two Continents", Lisbon, Portugal, September 23, 1997, paper published IN Proceedings of the International Conference "Traffic Safety on Two Continents", Lisbon, Portugal, September, 1997a.

Stewart, D.E., "Statistical Analytical Methodology for Measuring, Comparing and Interpreting Road Travel Risks : The Relationships Between Data Input Requirements and Analytical Frameworks", paper presented to and published IN Proceedings of the Canadian Multidisciplinary Road Safety Conference X, Toronto, Ontario, June, 1997b.

Stewart, D.E., "A Proposal for the Development of Exposure Information for Measuring and Monitoring Road Accident Risks : A 'Risk Analysis System' for Improving Road Safety", Report TP13185 (E/F), Ottawa : Transport Canada, January, 1998a.

Stewart, D.E., "Methodological Approaches for the Estimation, Evaluation, Interpretation and Accuracy Assessment of Road Travel 'Basic Risk', 'Relative Risk', and 'Relative Risk Odds-Ratio' Performance Measure Indicators : A 'Risk Analysis and Evaluation System Model' for Measuring, Monitoring, Comparing, and Evaluating the Level(s) of Safety on Canada's Roads and Highways",Transport Canada Publication TP 13238(E/F), Ottawa : Transport Canada, May, 1998b.

Lawson, J.J. and Stewart, D.E., "Consumption of Alcohol in Night-time Driving by Young Drivers in Canada", paper presented to the International Symposium on Young Drivers' Impaired by Alcohol and Other Drugs, Amsterdam, Netherlands, September 13-15, 1986, and published in International Congress and Symposium Series, Number 116, Royal Society of Medicine Services, London NewYork, pp.55-63, 1987a.

Lee-Gosselin, M.E.H, McLean, K.G., Richardson, A.J., Lawson, J.J., and Stewart, D.E., "The Use of Traffic Count Data to Obtain National Estimates of Exposure to Road Accident Risk", paper presented and published at Canadian Multidisciplinary Road Safety Conference (CARSP) V, Calgary, Alberta, June 1-3, 1987.

Stewart, D.E., ASFB Staff Presentation Series : "Presentation #1: Development of a Methodology For Measuring Exposure to Risk"; "Presentation #2: Future Directions - CANNES System Design", Report TMSE 8904, Ottawa : Transport Canada, March, 1989. A presentation given to RAAQ : Quebec City, December, 1988; a presentation given to Road Safety Program Branch, Ottawa : Transport Canada, March, 1989.

Stewart, D.E. and Lawson, J.J., "Results and Inferences from the 1986 Night-time Surveys of Drivers' Alcohol Use", paper presented and published AT Proceedings of the Canadian Multidisciplinary Road Safety Conference (CARSP) V, Calgary, Alberta, June 1-3, 1987b.