ADVANCES IN PROACTIVE ROAD SAFETY PLANNING

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Abstract

There are two main transportation engineering approaches to improving road safety: reactive and proactive. The traditional reactive approach consists of implementing the necessary improvements to existing hazardous (black-spot) sites in order to improve safety at these sites. The proactive approach is a collision prevention approach that tries to prevent unsafe road conditions from occurring in the first place. While the traditional reactive approach has proven to be very successful, it requires that a significant collision history exist before any action is taken to address the road safety problem. Moreover, retrofitting countermeasures in reaction to problems in existing road networks can be costly. Therefore, there is a need for transportation professionals to take a proactive approach that addresses road safety problems before they are allowed to emerge. There is a growing appreciation in the road safety community for the need to implement a more proactive approach to road safety. Geometric design guides in many countries now present explicit relationships between road design decisions and safety consequences, moving road engineering away from reliance on minimum standards without regard to safety. The focus of this paper is on proactive engineering initiatives that can be employed to improve road safety. An overview of emerging trends in proactive road safety planning will be provided. These emerging trends include: the use of safety conscious planning models, the explicit evaluation of safety in road design, and the automated safety analysis of video data.

Résumé

Il existe deux grands types d'approches pour améliorer la sécurité routière: l'approche proactive et l'approche réactive. L'approche réactive traditionnelle consiste à faire les aménagements nécessaires à des sites dangereux existants (points noirs) afin d'améliorer la sécurité à ces endroits. L'approche proactive est une approche de prévention des collisions qui vise en premier lieu à éviter l'occurrence de conditions routières dangereuses.

Bien que l'approche réactive traditionnelle a eu de nombreux succès, elle nécessite qu'une grande quantité de données historiques de collision soit disponible avant de pouvoir agir pour résoudre un problème de sécurité routière. En outre, des mesures de rénovation en réaction à des problèmes dans les réseaux routiers existants peuvent coûter cher. Par conséquent, il est nécessaire pour les professionnels du transport d'adopter une approche proactive qui résout les problèmes de sécurité routière avant qu'ils n'apparaissent. Les guides de conception routière de nombreux pays présentent désormais des relations explicites entre les décisions de conception des routes et leurs conséquences sur la sécurité: l'ingénierie des routes ne repose plus seulement sur des normes minimales qui ne tiennent pas compte de la sécurité. Cet article présente des initiatives proactives d'ingénierie qui peuvent être utilisées pour améliorer la sécurité routière. Il donne un aperçu de tendances émergentes dans la planification proactive de la sécurité routière: l'utilisation de modèles de planification qui tiennent compte de la sécurité, l'évaluation explicite de la sécurité dans la conception des routes, et l'analyse automatique de la sécurité à partir de données vidéo.

1.0 INTRODUCTION

Traditional road safety improvement programs (RSIPs) focus on the identification, diagnosis and remedy (improvement) of collision-prone locations or “black spots”. The main assumption of RSIPs is that the road design plays a contributory role in the occurrence of many traffic collisions. Thus, improving the engineering elements of collision-prone locations can avert a significant proportion. While RSIPs or “black spot” programs are vital and have proven to be very successful, this type of program is reactive in nature, such that a significant collision history must exist before any action is taken. Moreover, retrofitting countermeasures in reaction to problems in existing road networks can be costly. Therefore, there is a need for transportation professionals to take a proactive approach that addresses road safety problems before they are allowed to emerge. This proactive approach should complement the more traditional, reactive methods commonly in use. Significant progress will be realized when safety professionals can shift their focus from fixing problems on the road to helping plan roads that will be problem free. The net result should provide for a safer road system. The focus of this paper is on proactive engineering initiatives that can be employed to improve road safety. An overview of emerging trends in proactive road safety planning will be provided. These emerging trends include: the use of safety conscious planning models, the explicit evaluation of safety in road design, and the automated safety analysis of video data.

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2.0 SAFETY CONSCIOUS PLANNING

In recent years, attention to the management of road safety has surfaced in the area of road planning. Early efforts have attempted to minimize the road safety hazard by making safety a priority from the outset of the transportation and land use planning process. The goal is to ensure that road safety is explicitly addressed and used as one of the factors to evaluate transportation projects, thus reducing the subsequent need for reactive mitigation measures. One obstacle associated with the delivery of proactive road safety measures is the lack of a systematic process or framework necessary to support safety conscious planning initiatives. Recently, however, there have been efforts to develop guiding principles for supporting safety conscious planning initiatives (Wegman, 1997; de Leur and Sayed, 2003). These guiding principles aim to achieve a sustainably safe road system using concepts such as:

1. Rationalizing and deploying the functional use of the road network with the objective of preventing the unintended use of a roadway.
2. Ensuring the homogeneous use of the road network by preventing large differences in vehicle speed, vehicle operating characteristics, and vehicle travel direction.
3. Building predictability into the road system to prevent uncertainties among road users thereby improving driver reaction and judgment and the overall behavior of all road users.

de Leur and Sayed (2003) proposed a framework for proactive road safety planning that addresses the obstacles in the current process of considering road safety within the traditional planning process. The framework should enable engineers and planners to apply proactive strategies when planning for new roadways or when planning for major improvements to the existing road infrastructure. Three components were used to define road safety risk, namely exposure, probability, and consequence. Under each were a number of specific elements with several guiding principles formulated to explicitly consider road safety. This provides the framework for proactive road safety at the first opportunity within the planning process: during the formulation of planning options. At the post-planning stage, proposed planning options could be further improved by deploying an optimization process known as a multiple accounts evaluation (MAE) process and (or) by deploying a road safety audit process. The different elements are represented schematically in Figure 1.

However, one main obstacle associated with the delivery of a proactive road safety measure is the lack of the necessary methodology and reliable tools to evaluate road safety in a proactive manner (de Leur and Sayed, 2003). This obstacle can be characterized by a lack of a credible and consistent method to estimate the impact on road safety performance arising from a planned improvement. In 2006, using a refined methodology, Lovegrove and Sayed (2006a) developed 47 community-based, macro-level CPMs for the Greater Vancouver Regional District (GVRD) using input variables selected from a list of over 200 identified in the literature. Using the three broad data stratifications below, the 16 CPM groups in Table 1 were created, based on statistical associations between collision frequency and input variables (traits), as follows:

- Four themes of neighborhood traits (exposure or traffic density, road network, socio-demographics, and TDM).
- Two classes of predominant land use (rural or urban). Urban includes urban and suburban.
- Two sources of exposure data derivations (modeled or measured). “Modeled” exposure variables are output from transportation planning models, such as Emme/2 (e.g., VKT). “Measured” exposure variables are derived from geo-referenced mapping (e.g., TLKM).

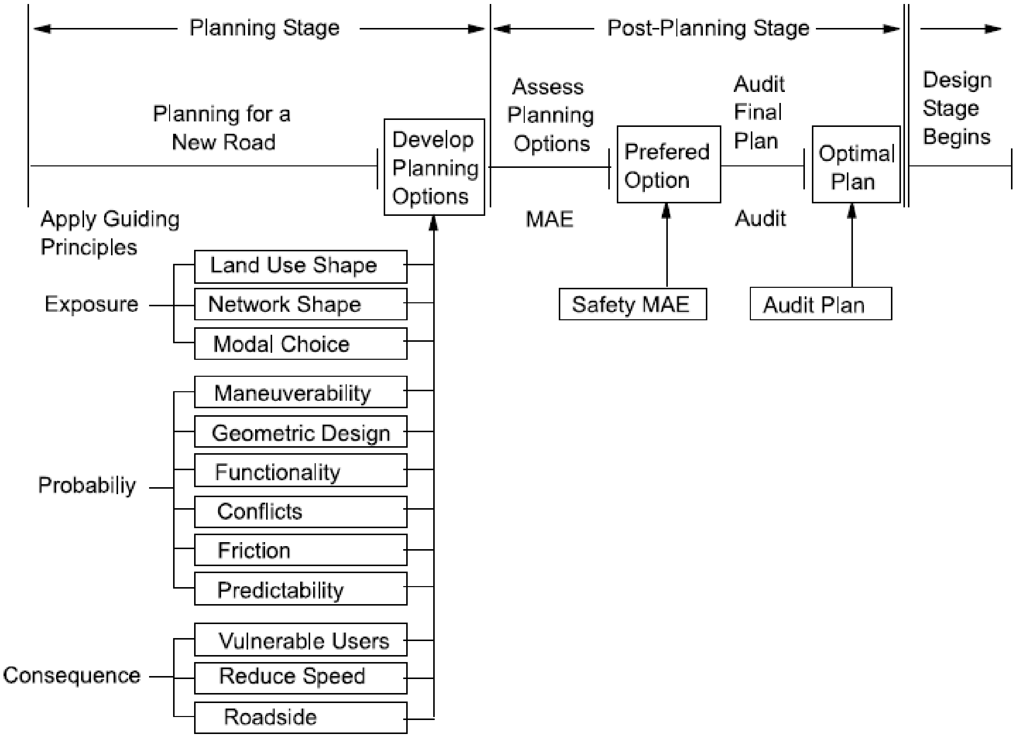
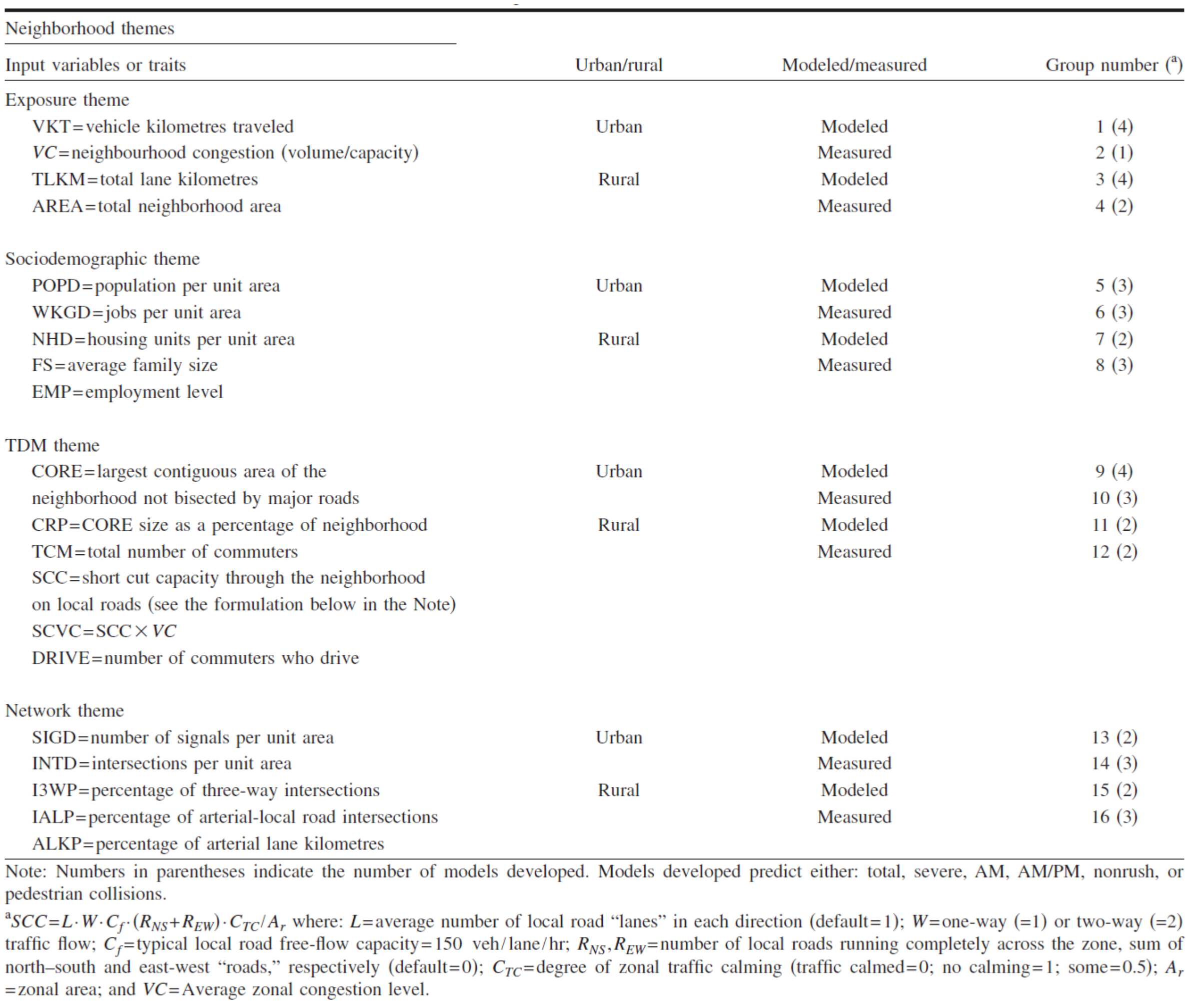


FIGURE 1: Proposed Framework for Proactive Road Safety Planning (de Leur and Sayed, 2003)

The uniqueness in the approach to developing macro-level CPMs for relatively large areas, such as neighborhoods, rather than for specific locations, such as intersections or mid-blocks, allows for the models to be applied at a larger scale that is more compatible with the planning process. These larger neighborhood areas are represented in the transportation planning process by what are traditionally known as traffic analysis zones (TAZs). Over 400 GVRD TAZs, each comprising an average of 350 ha in area, were used in the development of the CPMs. Data sets were assembled from five main sources: TransLink's regional transportation model AM peak hour travel patterns, in keeping with CPM development methodology , socio-demographic and commuter census data, GVRD land use data (GVRD 2004), the GVRD subset of the B.C. Provincial Digital Road Network, and GVRD collision claims data reported to the Insurance Corporation of British Columbia (ICBC). The TransLink regional transportation model is developed in the Emme/2 software platform and based on the four-step transportation demand modeling process.

Generalized linear regression modeling (GLM) techniques assuming negative binomial error distribution were used to develop these models. The goodness of fit of these models was checked using several statistical measures and met all standard tests - Lovegrove and Sayed (2006). A detailed discussion of these and all the other developed CPMs, including variable associations and summary statistics has been described previously by Lovegrove and Sayed (2006a). A key recommendation for quantifying safety in planning was the practice of systematically applying the tools. For example, any road safety evaluation of transportation plans should compare scenarios on a relative basis, which is consistent with the usual transportation planning practice of assessing the impact of different planning scenarios on a relative basis (versus absolute values), such that any systematic errors in the model cancel out. Therefore, Lovegrove and Sayed (2006b) developed guidelines for using macro-level CPMs, and tested them in two case studies at the neighborhood level.



Neighborhood themes Input variables or traits	Urban/rural	Modeled/measured	Group number (^{a})
Exposure theme			
VKT=vehicle kilometres traveled	Urban	Modeled	1 (4)
VC=neighbourhood congestion (volume/capacity)		Measured	2 (1)
TLKM=total lane kilometres	Rural	Modeled	3 (4)
AREA=total neighborhood area		Measured	4 (2)
Sociodemographic theme			
POPD=population per unit area	Urban	Modeled	5 (3)
WKGD=jobs per unit area		Measured	6 (3)
NHD=housing units per unit area	Rural	Modeled	7 (2)
FS=average family size		Measured	8 (3)
EMP=employment level			
TDM theme			
CORE=largest contiguous area of the	Urban	Modeled	9 (4)
neighborhood not bisected by major roads		Measured	10 (3)
CRP=CORE size as a percentage of neighborhood	Rural	Modeled	11 (2)
TCM=total number of commuters		Measured	12 (2)
SCC=short cut capacity through the neighborhood			
on local roads (see the formulation below in the Note)			
SCVC=SCC × VC			
DRIVE=number of commuters who drive			
Network theme			
SIGD=number of signals per unit area	Urban	Modeled	13 (2)
INTD=intersections per unit area		Measured	14 (3)
I3WP=percentage of three-way intersections	Rural	Modeled	15 (2)
IALP=percentage of arterial-local road intersections		Measured	16 (3)
ALKP=percentage of arterial lane kilometres			

Note: Numbers in parentheses indicate the number of models developed. Models developed predict either: total, severe, AM, AM/PM, nonrush, or pedestrian collisions.

[a] $SCC=L \cdot W \cdot C_f \cdot (R_{NS}+R_{EW}) \cdot C_{TC}/A_r$ where: L=average number of local road "lanes" in each direction (default=1); W=one-way (=1) or two-way (=2) traffic flow; C_f=typical local road free-flow capacity=150 veh/lane/hr; R_{NS}, R_{EW}=number of local roads running completely across the zone, sum of north–south and east-west "roads," respectively (default=0); C_{TC}=degree of zonal traffic calming (traffic calmed=0; no calming=1; some=0.5); A_r =zonal area; and VC=Average zonal congestion level.

TABLE 1: Vancouver - Macro-level Collision Prediction Model Categories

3.0 Explicit Safety Evaluation of Road Design

An important component of any design approach is the explicit evaluation of safety performance. An explicit safety evaluation facilitates the quantification of the safety impacts resulting from changes in highway design parameters and safety associated with the level of highway design consistency. Quantifying these safety impacts can support the design process by allowing decision makers the opportunity to analyze the safety benefits in relation to the cost of the highway improvement. This "trade-off" analysis allows for the justification and rationalization of highway infrastructure investment. Recent developments in the area of road safety engineering are emerging that can facilitate the explicit consideration and quantification of the safety impacts of highway design decisions. Technical guidance and engineering judgment will still be required in the highway design process, but it is believed that these new techniques will complement the traditional design approaches. Furthermore, the ability to quantify the safety impacts of design decisions is viewed as superior to the subjective nature of traditional approaches.

The ability to accurately quantify safety impacts is achieved by utilizing state of the art safety evaluation tools such as collision prediction models (CPMs), collision modification factors (CMFs), measures of design consistency, and reliability analysis. Although described and available in the highway safety engineering research literature for many years, these safety evaluation tools are now becoming widely accepted, since their use responds to the need to quantify safety performance. This is in sharp contrast to many traditional highway safety assessments that often rely solely on an “expert opinion” and thus have failed to adequately support difficult design decisions. The roadway geometry, traffic conditions, and roadside environment are the primary inputs to the driving task that determine the workload requirement on the driver. How quickly and how well these inputs are handled depends on driver expectancy and other human factors. Once these inputs are processed, they are translated into vehicle operations. When a roadway inconsistency exists that violates driver’s expectation, the driver may adopt an inappropriate speed or perform inappropriate maneuvers, potentially leading to collisions. In contrast, when design consistency is ensured and all abrupt changes in geometric features for contiguous highway elements are eliminated, hazardous driving maneuvers can be prevented, thereby minimizing collision risk. The following section provides an example that demonstrates how the explicit consideration of safety is becoming an essential part of the highway design process.

3.1 Explicit Safety Evaluation of the Sea to Sky Highway in British Columbia

The British Columbia Ministry of Transportation (MOT) undertook an upgrade Highway 99, the Sea-to-Sky Highway, between Horseshoe Bay and Whistler, as part of a long-term corridor improvement plan. The main goals of the upgrade were to improve the safety and reliability of the highway while enhancing the traffic service of the highway. MOT has chosen to utilize a design philosophy that emphasizes a collaborative, interdisciplinary effort to develop a transportation facility that not only addresses issues of safety, capacity and reliability, but is responsive to the constraints of the physical setting, to community needs, and to the preservation of aesthetic, cultural, environmental and historic resources.

Realizing the value that could be gained from a greater understanding of the quantification between specific design decisions and the corresponding impacts on safety performance, and understanding that the approach could be very helpful to support difficult design decisions, staff from British Columbia’s Ministry of Transportation (MOT) decided to test the approach on a new design on a section of the scenic Sea to Sky Highway. Due to difficult topography in the vicinity of the highway and a limited budget available for highway upgrading, MOT staff recognized that the explicit safety evaluation would assist in providing the justification for the required design decisions based on a sound cost-effectiveness rationale. Based on the success of the pilot project, MOT staff requested that the analysis be completed for all designs on the other portions of the Highway 99 North (Sea to Sky Highway) upgrade project from Horseshoe Bay to Whistler (Sayed and deLeur, 2005)

This analysis used state of the art highway safety evaluation techniques, including the application of collision prediction models, collision modification factors and several design consistency measures to quantify the expected safety performance on the Highway 99 North corridor. These analysis tools were used to estimate the safety performance associated with both the existing highway and the new designs in order to measure the benefits of the new design over the existing conditions. The process also allowed for the identification of locations that are currently problematic on the corridor and for locations that may become problematic after the design and construction of the new facility. Two major components are investigated in the explicit consideration of the road safety performance associated with the existing highway or the new design. The first is called “collision prediction”, which allows for the quantification of the road safety performance (measured in terms of the expected collision frequency) associated with typical highway design parameters. The second component in considering highway safety is called “design consistency,” which attempts to quantify and categorize the level of consistency: a factor known to impact road safety performance. The principle objectives of the project were as follows:

- To support the highway design process for the Highway 99 North by providing explicit and quantifiable safety and design consistency analysis.
- To systematically and objectively evaluate the existing highway and the new designs to determine the impact of design parameters on safety performance.
- To calculate the safety performance, measured in collision frequency, that is associated with highway design parameters and design consistency in an attempt to identify and rank locations that offer the greatest potential for safety improvement.

The results of the analysis showed that the new preliminary designs that have been developed for the Sea to Sky highway offer a considerable safety improvement over the existing highway as a result of the improved design parameters and improvements to design consistency. The results showed that the total number of accidents expected on the highway can be reduced by approximately 38%. The results were used to 1) determine the incremental safety benefits that are achieved by the new designs in relation to the existing highway conditions; 2) to identify specific locations on the new designs where the estimated safety performance may be less than desirable, or could be improved; and 3) to facilitate the investigation of the opportunities for design improvements, by providing insight into the nature of the safety performance problems.

4.0 A VISION-BASED SYSTEM FOR AUTOMATED ROAD SAFETY ANALYSIS

Despite the potential benefits of automated traffic safety analysis based on video sensors, limited computer vision research has been directly applied to road safety and even less so to the detection of traffic conflicts. Maurin et al. (2005) state that “despite significant advances in traffic sensors and algorithms, modern monitoring systems cannot effectively handle busy intersections”. Such a system requires a high level understanding of the scene and is traditionally composed of two levels of modules (see Figure 2): 1) a video processing module for road user detection and tracking, and 2) interpretation modules for traffic conflict detection. For road safety applications, Saunier and Sayed (2006) presented an automated road safety analysis approach that relies on the building of two databases: a trajectory database, where the results of the video processing module are stored, and an interaction database, where all interactions between road users within a given distance are considered, and for which various indicators, including collision probability and other severity indicators, are automatically computed. Identifying traffic conflicts and measuring other traffic parameters becomes the problem of mining these databases.

The road user detection and tracking module used in Saunier and Sayed 2006 system relies on a feature-based tracking method that extends to intersections the method described in Beymer et a. (1997). Feature-based tracking is used because it can handle partial occlusion. The tracking of features is done through the well known Kanade-Lucas-Tomasi feature tracker. Stationary features and features with unrealistic motion are filtered out, and new features are generated to track objects entering the field of view. Since a moving object can have multiple features, the next step is to group the features, i.e. deciding what set of features belongs to the same object, using cues like spatial proximity and common motion. A graph connecting features is constructed over time. A detailed description of the tracking algorithm is presented in Saunier and Sayed (2006). The tracking accuracy for motor vehicles has been measured between 84.7% and 94.4% on three different sets of sequences. This means that most trajectories are detected by the system, although overgrouping and oversegmentation still happens and may create some problems.

4.1 A Probabilistic Framework for the Automated Analysis of the Exposure to Road Collision

This application presents a comprehensive probabilistic framework for automated road safety analysis. Building upon traffic conflict techniques and the concept of the safety hierarchy, it provides computational definitions of the probability of collision for road users involved in an interaction. It proposes new definitions for individual road users and aggregated measures over time. This allows the interpretation of traffic from a safety perspective, studying all interactions and their relationship to safety. The formulas presented in this application are based on Hu et al. (2004). The collision probability for a given interaction between two road users can be computed at a given instant by summing the collision probability over all possible motions that lead to a collision, given the road users’ states. This requires the ability to generate for each road user at any instant a distribution over its possible future positions given its previous positions. A possible future motion, i.e. a temporal series of predicted positions, defines an extrapolation hypothesis. The collision probability computation is approximated by a discrete sum when taking into account a finite number of the most probable extrapolation hypotheses.

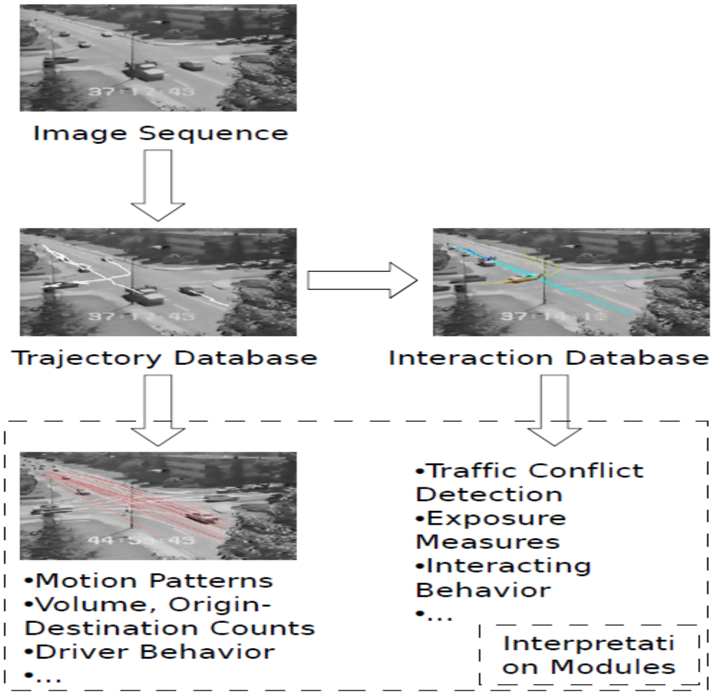


FIGURE 2: Overview of A Modular System for Vision-Based Automated Road Safety Analysis

First the collision probability at time t_0 for two road users A_1 and A_2 with respective observed trajectories $Q_{1,t\le t_0}$ and $Q_{2,t\le t_0}$ (before t_0) is defined when considering only one extrapolation hypothesis for each, respectively H_i and H_j. The predicted positions according to the hypotheses H_i and H_j are computed for a number of time steps: the predicted time of the collision $t_{i,j}$ is the first instant at which the road users would be in contact. The larger $\Delta_{i,j} = t_{i,j} - t_0$, the more likely the road users can react and avoid the collision. This time takes into account speed and distance and is directly measurable against the road users' reaction times. The formula of the probability of collision given hypotheses H_i and H_j is taken from Hu et al. (2004):

$$P(Collision(A_1, A_2) \mid H_i, H_j) = e^{-\frac{\Delta_{i,j}^2}{2\sigma^2}} \quad (1)$$

where σ is a normalizing constant. It is estimated in (*22*) that this probability should change when the elapsed time $\Delta_{i,j}$ is close to the road user reaction time. Therefore σ is chosen to be equal to an average user reaction time[1] . The number of predicted positions can be limited to 3σ, as the resulting probability is very close to zero when $\Delta_{i,j}$ reaches that value. The collision probability for two road users A_1 and A_2 at t_0 is

$$P(Collision(A_1, A_2) \mid Q_{1,t\le t_0}, Q_{2,t\le t_0}) = \sum_{i,j} P(H_i \mid Q_{1,t\le t_0}) P(H_j \mid Q_{2,t\le t_0}) e^{-\frac{\Delta_{i,j}^2}{2\sigma^2}} \quad (2)$$

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[1] A value of 1.5 seconds is chosen for the experiments described in this paper.

where $P(H_i | Q_{1,t \le t_0})$ is the probability of road user A_1 to move according to extrapolation hypothesis H_i (same for A_2 and H_j). The sum is done over a variety of extrapolation hypotheses, although this number must be limited to maintain reasonable computation times. This formula is illustrated in a simplified example in Figure 3. In a traditional TCT, one could choose a threshold on the collision probability and other indicators to define traffic conflicts. In this approach, road safety can be automatically analyzed in detail by computing continuously the collision probability of all interactions. When considering the collision probability for only one road user, the formulas have to be adapted. It is not possible to directly sum the collision probabilities of the interactions in which the road user is involved, as only one collision can happen for each extrapolation hypothesis. The predicted positions according to hypothesis H_i and all hypotheses that the other interacting road user may follow are computed for a number of time steps. If the road user follows the motion hypothesis H_i, the predicted time of the collision t_i is the first instant at which the road user following motion hypothesis H_i would be in contact with another road user ($\Delta_i = t_i - t_0$). Let $Q_{k(i)}$ be the observed trajectory of this road user and $H_{j(i)}$ the hypothesis that leads this road user to a collision. The collision probability of the road user A_1 with n other road users at t_0 is

$$P(Collision(A_1) | Q_{1,t \le t_0}, Q_{2,t \le t_0}, ..., Q_{n,t \le t_0}) = \sum_{i,j} P(H_i | Q_{1,t \le t_0}) P(H_{j(i)} | Q_{k(i),t \le t_0}) e^{-\frac{\Delta_i^2}{2\sigma^2}} \quad (3)$$

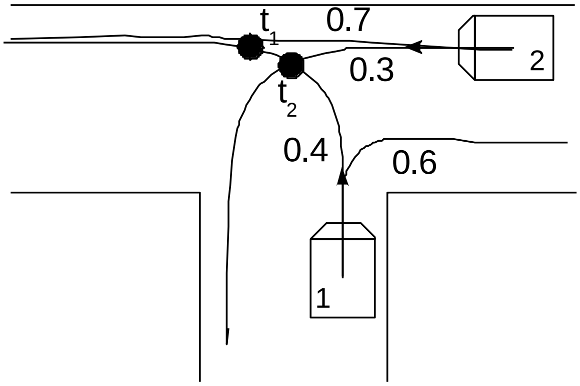

Figure 3: Two vehicles approach a T intersection at time t_0. Only two extrapolation hypotheses are considered for each vehicle. Vehicle 1 is expected to turn left or right, with respective probabilities 0.4 and 0.6. Vehicle 2 is expected to go straight or turn left, with respective probabilities 0.7 and 0.3. There are two potential collision points, that can happen at times t_1 and t_2. The collision probability at time t_0 is computed as

$$P(Collision) = 0.4 \times 0.7 \times e^{-\frac{(t_1 - t_0)^2}{2\sigma^2}} + 0.4 \times 0.3 \times e^{-\frac{(t_2 - t_0)^2}{2\sigma^2}}$$ **.**

The previous definitions deal only with one road user or one interaction between two road users at a given instant. The collision probability for two road users in interaction can be used for the detection of traffic events relevant to safety. However, to characterize a given period of time at a location, one needs a method to accumulate the indicators over all interactions that occurred in the monitored area during this period of time, or over all road users that went through the monitored area during this period of time. The first aggregation level is the interaction or the road user. This indicator should reflect the highest collision probability over time, but also the amount of time during which this collision probability was high. This should therefore be similar to an integral of the instantaneous collision probability over time. However, issues arise when dealing with real data, e.g. collected after automated road user tracking using video sensors: tracking errors and noise produce measures of collision probability over time which may be randomly truncated and noisy. Hu et al. (2004) report similar observations. This would make it difficult to compare fairly the interactions. Consequently, to improve robustness, it is preferred to use the average of a small number of largest values taken by the collision probability over time. Let *n* be that number. Let *SeverityIndex(A_1, A_2)* and *SeverityIndex(A_1)* be the averages of the *n* largest values taken respectively by the collision probability $P(Collision(A_1, A_2) \mid Q_{1,t \le t_0}, Q_{2,t \le t_0})$ over the time that the two road users A_1 and A_2 interacted in the monitored area, and by the collision probability $P(Collision(A_1) \mid Q_{1,t \le t_0}, Q_{2,t \le t_0}, \ldots, Q_{n,t \le t_0})$ over the time that the road user A_1 has spent in the monitored area. The values can subsequently be summed over time for all interactions or road users. The severity indices for the time interval [t_1 t_2] are

$$InteractionSeverityIndex([t_1\, t_2]) = \sum_{\substack{(i,j)\, such\, that\, A_i\, and\, A_j\, are\, observed \\ in\, Interaction\, during\, [t_1\, t_2]}} SeverityIndex(A_i, A_j) \qquad (4)$$

$$UserSeverityIndex([t_1\, t_2]) = \sum_{\substack{i\, such\, that\, A_i\, is\, observed \\ during\, [t_1\, t_2]}} SeverityIndex(A_i) \qquad (5)$$

Three sets of data are used. The first is a set of traffic sequences on the same location initially used for the training of traffic conflict observers in the 1980s in BC. The second dataset is composed of two long sequences, each close to one hour long, recorded at an intersection in the Twin Cities (United States), in Minnesota. The third dataset is composed of 6 sequences, each about 20 minutes long, recorded in Reggio di Calabria (south Italy).

First the motion patterns are learnt from the feature trajectories, which are smoothed using a Kalman filter beforehand. The learnt prototypes for the datasets are presented in Figure 3. The visual examination of the motion patterns suggests a plausible division of the trajectory space. Traffic patterns are well identified, and the traffic volumes are consistent with observation. Since only a few traffic conflict instances are available in the Conflict dataset, only preliminary results obtained for the three detectable traffic conflict instances are reported in this paper (these three traffic conflict instances belong to three sequences of the Conflict dataset). It appears that the prototype trajectories are well suited for the computation of the collision probability. An example of movement prediction is presented for one conflict in Figure 4. The curves of the collision probability as a function of time, computed using formula 2, are displayed for the three traffic conflicts in Figure 5. For each of these instances, one vehicle is over-segmented, resulting in two trajectories, and thus two traffic events (and two curves). It appears that the collision probability shows an expected evolution over time, starting with low values, increasing until the probability of collision reaches a maximum, to decrease afterward, often truncated due to tracking errors and disrupted trajectories. Using formula 5, the severity indices of all interactions are computed for the sequences of the Minnesota and Italy datasets, which are both more than one hour long. The distributions of the interaction according to their severity indices are represented individually for each sequence of the two datasets in Figure 6. As expected, the distributions exhibit the shape of the safety hierarchy, with the frequency of events decreasing as the severity increases. The different sequences in each dataset exhibit different distributions.

For example, more interactions for all level of severity are observed in the sequence 2 in the Minnesota dataset. This type of analysis could be performed to compare different situations, for example in before and after studies. It is also possible to study interactions by their locations, by building severity maps, and therefore analyze particular problems in the intersection. More results are presented in Saunier and Sayed (2008)

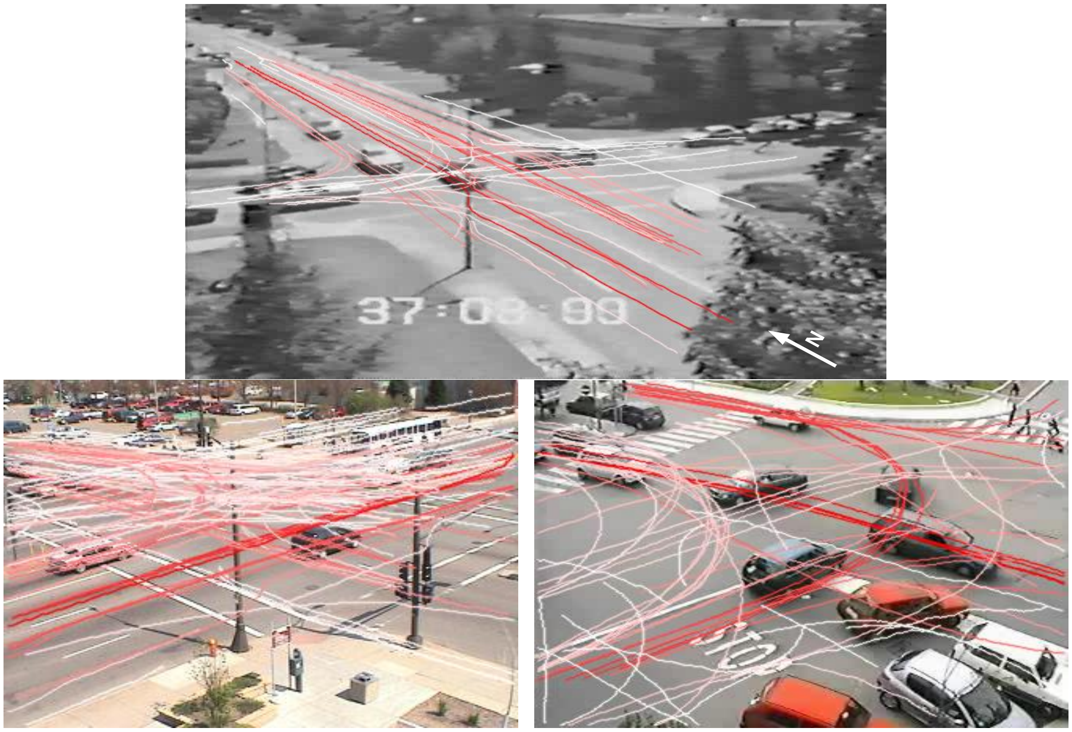

Figure 3: Motion patterns learnt on sequences of the Conflict dataset (top), the Minnesota dataset (bottom left) and the Italy dataset (bottom right).

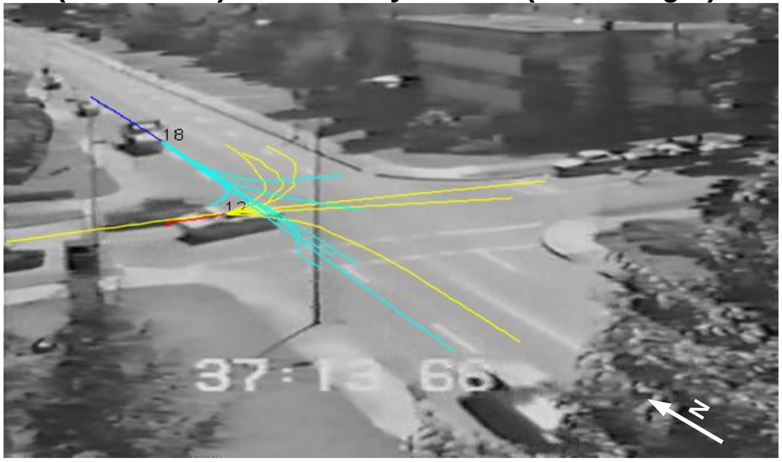

FIGURE 4: An example of movement prediction in a real traffic conflict situation. The vehicle trajectories are red and blue, with a dot marking their position, and the future positions are respectively cyan and yellow.

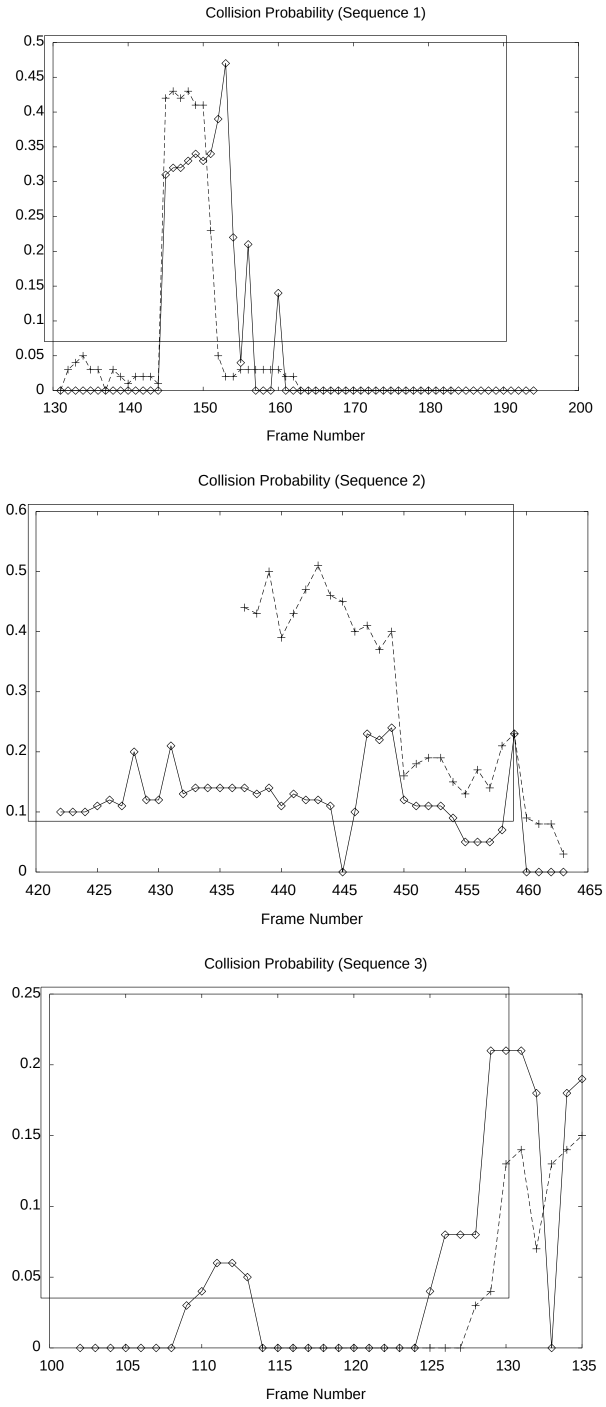

FIGURE 5: Graphs of the collision probability for the three traffic conflicts (collected in three separate sequences), as a function of time (counted in frame numbers). In all sequences, vehicle 1 travels south-bound through the intersection and vehicle 2 comes from an opposing approach. Vehicle 2 turns left in sequence 1 (top) (See Figure 4), right in sequence 2 (middle) and stops in sequence 3 (bottom).

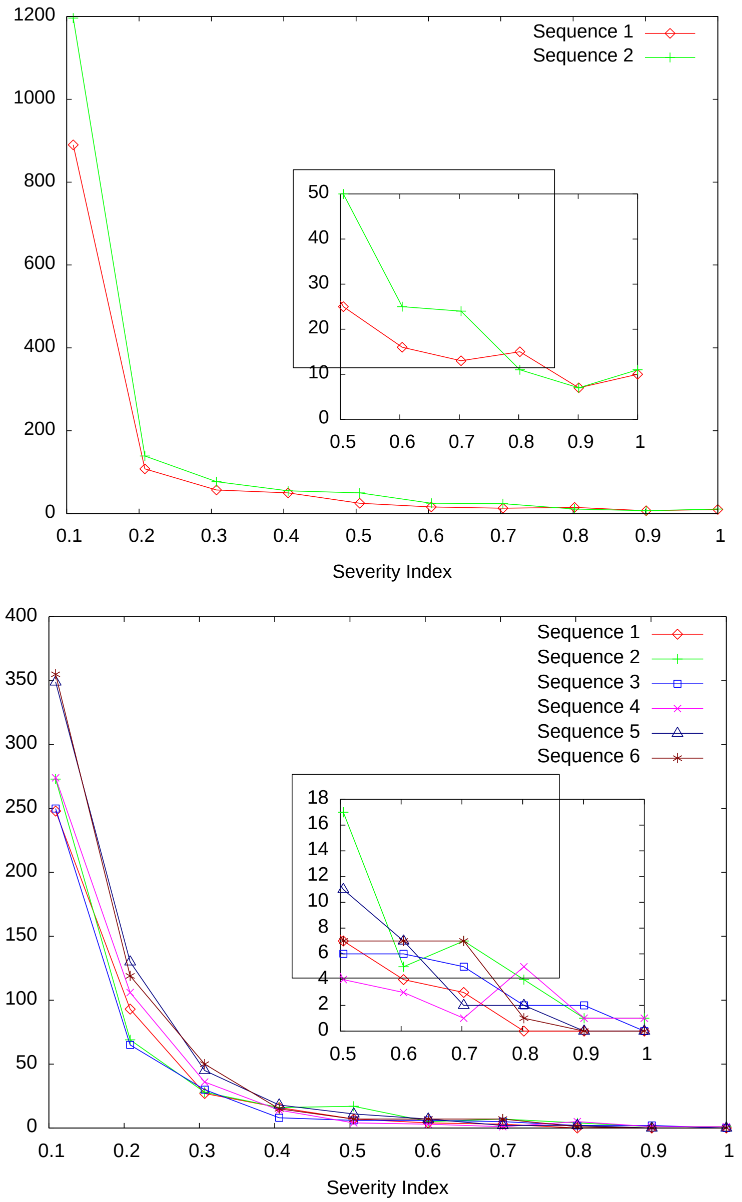

FIGURE 6: Distribution of the interactions according to their severity indices (with a zoom on the higher severities), quantified by 0.1 (the point at severity index *x* stands for the number of interactions with severity index between *x*-0.1 and *x*), for the sequences of the Minnesota dataset (top) and the Italy dataset (bottom).

5.0 CONCLUSION

All too often, engineering strategies aimed at improving road safety are reactions to existing problems that are brought to light by collisions which have occurred after the road has been designed and built. Targeting problem locations and developing plans to reduce collision potential is vital and has proven to be very successful. However, transportation professionals should also take a proactive approach that addresses road safety before problems are allowed to emerge. This paper presented three emerging trends in proactive road safety planning. These emerging trends included the use of safety conscious planning models, the explicit evaluation of safety in road design, and the automated safety analysis of video data.

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