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Aims and scope
AdDrivens in Transportation Studies is a quarterly (four monthly) and refereed journal that contains theoretical and practical contributions to the most recent developments in studies and advanced research in the field of Road and Highways. Engineering, with a particular focus on the safety, effectiveness, efficiency and sustainability of transport. Topics discussed include design, standards and regulations, aspects of human factors in facilities design, geometry, flood resistance, standards, provision of facilities, fatigue life, traffic management (for Transportation Sciences and Research) and related aspects of transport infrastructure. The journal welcomes contributions on particular topics, such as policy analysis, formulation and evaluation of transport systems, management and coordination of transport policies, etc., published from time to time and provide a wide range of information for Administrators and Policy Analysts, etc. The journal contains abstracts, details of the papers on transport topics.

A selection of papers

- Khaled A. Abbas Egypt National Institute of Transport (Egypt)
- Zhongyin Guo Tongji University of Shanghai (China)
- Iouri Chkitsci State Technical University - MADI (Russia)
- Janusz Blaszczyk Academy of Physical Education (Poland)
- Carlo Benedetto University Roma Tre (Italy)
- Basil Psarianos Technical University of Athens (Greece)
- Jarkko Niittymäki LT-Konsultit Oy (Finland)
- Andrzej Michalski Nencki Institute (Poland)
- Yasser Hassan University of Carleton (Canada)
- Alfredo García García Politechnic University of Valencia (Spain)
- Maria Dabrowska-Loranc Motor Transport Institute Road Traffic Safety Center (Poland)
- Maria Rosaria De Blasiis University Roma Tre (Italy)
- Krzysztof Cichocki Technical University of Koszalin (Poland)
- Romuald Bauer Motor Transport Institute Road Traffic Safety Center (Poland)
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A computer vision system for traffic accident risk measurement
A case study

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Abstract
A reliable estimation of the safety level of the roads is a valuable tool for detecting critical points in the road infrastructure, planning and implement countermeasures, and evaluating their impact on the traffic. A method for the computation of the accident risk is proposed, which is based on microscopic traffic data collected automatically by a video-based monitoring system, i.e. class, speed, and trajectory of each single road-user. The benefit of the proposed method is twofold: the risk level is computed without statistics on past accidents, and its computation is fully automated, therefore it does not require a manual collection of traffic data. The paper presents the definition of the proposed risk index and describes its application to a real case: the evaluation of the accident risk at an urban intersection, before and after the reorganization of its geometry. The proposed risk index, although based only on some parameters that are automatically measurable, seems to reflect the expectation of traffic experts in evaluating the impact of intervention to improve the safety of the intersection.

Keywords - Road safety measurement, accident risk, traffic scene analysis, video analysis, traffic conflicts

1. Introduction
The ever-increasing number of injuries and deaths caused by road traffic accidents motivates a wide range of studies that have been conducted with the general goal of improving the safety of road users. A commonly accepted classification of the causes of accidents divides them into three categories: human behaviours; vehicle characteristics; external conditions (road, traffic, weather). Fig. 1 and Fig. 2 show two examples of dangerous behaviour. In order to mitigate the causes of accidents and to achieve a general reduction in their number and gravity, actions should be taken in all three categories. A crucial aspect in the definition of a plan of intervention is related to the selection of the sites where the danger is high.

The measure of the risk level, which describes the dangerousness of a road, is often based on the number and gravity of past accidents occurred in the area. Such a measurement has many drawbacks, the main of which is that a reliable estimate requires a large number of events. Secondly, it is a common feeling that it provides a risk underestimation because, for various reasons, minor accidents are often not reported. These drawbacks led groups of road safety experts to devise new techniques for the identification of dangerous road sections and the evaluation of the effects of the implemented risk-reducing actions.
A Computer Vision System for Traffic Accident Risk Measurement: A Case Study*

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Abstract
A reliable estimation of the safety level of the roads is a valuable tool for detecting critical points in the road infrastructure, planning and implement countermeasures, and evaluating their impact on the traffic. A method for the computation of the accident risk is proposed, which is based on microscopic traffic data collected automatically by a video-based monitoring system, i.e. class, speed, and trajectory of each single road-user. The benefit of the proposed method is twofold: the risk level is computed without statistics on past accidents, and its computation is fully automated, i.e. it does not require a manual collection of traffic data. The paper presents the definition of the proposed risk index and describes its application to a real case: the evaluation of the accident risk at an urban intersection, before and after the reorganization of its geometry. The proposed risk index, although based only on those parameters that are automatically measurable, seems to reflect the expectation of traffic experts in evaluating the impact of intervention to improve the safety level of the intersection.

Keywords: Road safety measurement; Accident risk; Traffic scene analysis; Video analysis; Traffic conflicts.

1 Introduction
The ever increasing number of injuries and deaths caused by road traffic accidents, motivates a wide range of studies that have been conducted with the
general goal of improving the safety of road users. A commonly accepted classification of the causes of accidents divides them into three categories: human behaviours, vehicle characteristics, and external conditions (road, traffic, weather). Figures 1 and 2 show two examples of dangerous behaviour. In order to mitigate the causes of accidents and to achieve a general reduction in their number and gravity, actions should be taken in all three categories. A crucial aspect in the definition of a plan of intervention is related to the selection of the sites where the danger is high. The measure of the risk level, which describes the danger-ness of a road, is often based on the number and gravity of past accidents occurred in the area. Such a measurement has many drawbacks, the main of which is that a reliable estimate requires a large number of events. Secondly, it is a common feeling that it provides a risk underestimation because, for various reasons, minor accidents are often not reported. These drawbacks led groups of road safety experts to devise new techniques for the identification of dangerous road sections and the evaluation of the effects of the implemented risk-reducing actions. Several methods have been proposed to measure the risk level in a given road section without using the accident frequency and to use it as a base.
for the selection of the appropriate strategy. Furthermore, it can be used to quantify the benefit of a new road geometry by computing the index variation before and after the work.

Recently, microsimulation models have been developed and used for safety assessment [1], but the most popular on-field technique is based on the detection and the description of specific traffic events, called traffic conflicts. They have been recognized as danger indicators that permit an indirect measurement of the road safety [2, 3]. A traffic conflict is an event involving the interaction of two or more road users where, at least, one of them takes evasive action to avoid a collision. The study of traffic conflicts has been recognized as an effective way to supplement crash studies in estimating the accident risk of various roads, and to provide measures of traffic safety when crash rates are not representative.

Furthermore, traffic conflict data can also be valuable in identifying the prevalent unsafe behaviours of the road users, and to select the most appropriate corrective actions.

Traditionally, the collection of traffic conflict data is performed by one or more trained observers stationed near the road. Each observer manually records number, nature and severity of each conflict. The nature of conflicts is categorized with respect to the involved elements (e.g. car-car, car-bus, car-bicycle) and to the type of conflict. Relevance of conflicts is judged by the observer and this represents one important limitation of the method. In order to make the judgment as objective as possible some measures have been proposed, among which are: Time To Collision (TTC), Post Encroachment Time (PET), and Time Headway (TH). TTC is the time required for two road users to collide if they remain on their path and speed [4]. PET is the time lapse between the moment the offending vehicle leaves the area of potential collision and the arrival time in the same area of the vehicle possessing the right way. TH is defined as the elapsed time between the front of the lead vehicle passing a point on the roadway and the front of the following vehicle passing the same point; it can be used as longitudinal risk indicator [5].

An advantage of the traffic conflict technique with respect to the accidents frequency analysis is that it requires a shorter observation period: in the same period the number of conflicts is much higher than the number of crashes. From the other side, the manual collection of traffic conflicts can be a very expensive task both in term of time and human resources. In fact, a typical traffic conflict study [2] is performed by one or more trained observers, placed in uncomfortable locations along the road, for a few-hour period. Data is collected for 20 to 25 minutes every 30 minutes, with a short break to regain concentration. Some attempts have been made to improve the data collection conditions by acquiring and recording traffic scenes with one or more cameras, so that the observers can detect conflicts in a more convenient environment and without strict time constraints.

The method proposed in this work follows the idea that some traffic parameters can be extracted automatically from recorded sequences by a video analysis system, or even directly in the field if a real-time working system is available. We developed a camera-based monitoring system capable of collecting traffic
parameters for statistical purposes. In particular, our system provides the following functionalities: counting of the vehicles (or pedestrian) crossing the field of view of the observing camera, classification of them into one of seven categories, average speed estimation, and compilation of the turning map, i.e. a map containing, for each pair enter/exit lanes in the field of view, the number of vehicles following that path. We propose a risk index based on the rich description of the traffic data provided by our monitoring system, along with other information about the paths which are allowed or prohibited for the different road user categories in the considered section. A first advantage is that the automatic data collection avoids the subjective judgment problem and ensures the repeatability and comparability of results. In order to establish a correspondence between the number output as risk index and the actual risk, the proposed method has been applied to a real case, namely a road intersection in the city of Trento, before and after the implementation of some risk reduction actions. The site has been selected for the relevant number of past accidents, and the improvements on the road geometry have been designed by traffic experts.

The paper is organized as follows. Session 2 provides a general introduction of the concept of accident risk, and describes the related traffic events and parameters to be measured for the risk index computation. Section 3 illustrates the architecture of the system we have developed for the collection of traffic parameters, the data collection strategy, along with a short description of the computer vision algorithms used for the basic traffic data extraction. The algorithm for the estimation of the risk level, starting from the computed parameters, is described in the Section 4. Finally, Section 5 reports the results of the traffic risk analysis before and after the road structure modifications and concludes with the comments about the study.

2 Risk definition

In common terms, the concept of risk is related to the concept of hazard, damage, or probability of an event with undesirable consequences. It is perceived as the negative power of an event. Formally, the risk is a function of the probability of the event and the consequences of its occurrence:

\[ R = f(P, D) \] (1)

where \( P \) is the event probability and \( D \) is a value that quantify the damage (economic or other form of loss) as a consequence of the event. \( D \) is also called intensity of the consequence. In risk management, an accident is any unanticipated or unpredictable event that interferes with the normal functions of a system and cause logical or physical damage. Usually, the accident risk is defined as follows:

\[ R = P \times D^k \text{ for some } k \] (2)

where the exponent \( k \) allows tuning the weight of the damaging consequences \( D \) with respect to the probability of accident occurrence \( P \), in a non-linear way.
Figure 3: Measurable sources of accident probability are the traffic situation, weather condition, time of day. The probability of an unsafe situation and conflict depends on the local traffic, usually described with parameters such as occupation, gaps, speeds, and paths, and weather, described with rain intensity, ice, visibility, and so on. The consequences D of a collision are mainly related to the involved categories and speeds.

In the domain of traffic, a reduction of the accident risk can be achieved by both reducing the number of collisions and the damage that they cause. The knowledge of the global risk alone is not sufficient to identify the most appropriate actions in order to reduce the risk itself. For example, if $P$ is the dominating factor in Equation 2, the goal will be accident prevention, differently, protection and mitigation actions are more appropriate.

In this predictional context, where experiments are not feasible, it is more convenient to use the De Finetti subjective conception of probability [6] instead of the definition as the limit of relative frequencies. In fact, subjective probability concept is adopted in risk management for the estimation of probability of rare events or events that have never occurred. Therefore, in the domain of traffic, we should estimate the probability of collision starting from the observation of several events, different from accidents, that can lead to accidents, i.e. we have to consider the concatenation of facts (Figure 3) that can transform the hazard situation into an accident. A precise identification of the factors that affect the accident probability is very complicated, if not almost impossible. Analogously, the consequences of an accident can vary from little car damage to loss of lives, making very difficult to determine a reliable value for the term $D$. To face these questions, according to the risk assessment methodology, the risk estimation procedure requires, as a preliminary step, the definition of the following three aspects: scenario, relevant events, and associated consequences.

Scenario In this context, the scenario is a formal description of the system under analysis, that is a model of the road section which includes all the relevant elements such as road geometry, road users, fixed element, local traffic rules. It provides an approximation of the system dynamics.
Relevant events The factors that contribute to the occurrence of the negative events, i.e. accidents, have to be identified and their frequencies estimated.

Associated consequences The damage produced by the occurrence of accidents has to be determined as a function of the involved road users and of the factors that caused the event.

2.1 Scenario

The scenario is represented by the road section that is observed either by a human or an artificial monitoring system. It is modeled as a zone containing regions where road users (vehicles and pedestrians) can move, and traffic inhibition areas, e.g. buildings. The model describes the different categories of road user that can enter, go through and leave the system, and the main restrictions on their motion. The motion is subject to the ground-plane constrain, i.e. all road user can move only on the road plane. Other restrictions are specific for the different categories, for example a pedestrian should pass on pedestrian crossing, or a vehicle should travel inside certain lanes. Often only certain types of vehicles may use reserved lanes or turn. These constraints are defined by the local traffic rules (oneway, turning movement, stop lines, speed limit). It is important that this knowledge is incorporated in the model because it enables to establish if road users are violating some rule, a situation that can have a great impact on the risk level. Within this model, the system is successful if objects enter and exit without to collide with fixed obstacles or other moving entities.

2.2 Relevant events

It is well known that the collision probability is mainly affected by traffic conditions, but several other factors are relevant, like vehicle status (power, age, breaks and tyre condition, presence of auxiliary devices,...), driver status (age, alcohol, fatigue, distraction, knowledge of the road), weather conditions (rain intensity, fog, sun position and so on), and road conditions, like geometry, visibility, pavement condition, signing legibility. We focus our attention on the following traffic parameters:

- density/occupancy: the accident probability is related to the number of road users moving in the scene;
- distances between vehicles (gap distribution): the collision probability increases if vehicles do not observe the safety distance;
- paths: the frequency of anomalous or illegal trajectories (overtaking, people passing outside the pedestrian crossing), but also the intersections of regular paths due to road geometry, are related to accident probability;
• speed: it is one of the main factors affecting accident probability in the urban environment. It is known, in fact, that at a higher speed the eyes focus on further points of the roadway, narrowing the functional field of view, and therefore decreasing the attention in near zone, with detriment of an early recognition of pedestrians, cross-traffic or parking activity typical of the urban environment. Furthermore, higher speed reduces the time available to actuate evasive actions and makes it harder to control the vehicle, especially in turns and curves.

Another factor to be considered is the time of exposure, i.e. the time spent by the object in a critical zone inside the considered road section. For example, a short pedestrian crossing is safer than a long one, because it brings about a reduction in the time in which pedestrians can be hit. By choosing appropriate measures that integrate values along the object trajectory, the exposure factor will be implicitly taken into consideration in our risk index.

2.3 Associated consequences

The severity of an accident is a key factor in the determination of the risk. A quantitative evaluation of it is critical mainly because it is not a well defined concept. The study reported in [7] measures the accident consequences from the economic point of view and provides a detailed evaluation of them in many different situations. In the present work we define an indicator of the accident seriousness which depends on the factors that, from the analysis of the existing studies, mostly affect the accident severity, i.e. speed and nature of the involved actors. This comes from the physical fact that in a collision the kinetic energy, which depends on the mass of the objects and their speed, transforms into some other form, mainly friction with the road surface and deformation of the object structures. The occupants of the involved vehicles can be injured at different degrees, depending on the type of crash, car structure, seat belt wearing, or activation of other protective devices. Although we cannot take into account all such specific factors, it is obvious that the deformation of the objects can lead to very different damage degrees, if a truck or a pedestrian are involved in the accident. This introduces the vulnerability concept, i.e. the propensity to be highly damaged in an accident. The road users with highest vulnerability are pedestrians, cyclists and motorcyclists.

Various statistical studies have been conducted on the consequences of crashes and they demonstrate that the seriousness increases disproportionately with speed [8]. For example, a pedestrian hit by a car traveling at 65 kilometers per hour has a 85% chance of being killed. At 50 km/h, the expectation of death is around 45%, while if the speed reduces to 30 km/h, then the expectation of a pedestrian death falls to 10%.

Therefore, in order to evaluate the consequences of an accident involving a vehicle of a given class traveling with a given velocity, we estimate the probability of the presence of other vehicles of each single class and their average speed.
3 Traffic data collection

The main goal of our work is to define a completely automatic method for the estimation of the accident risk. The most important requirement is the capability to extract, in an automatic way, valuable information from the observation of the road section under analysis. Nowadays computer vision technologies are diffusely used for this purpose [9]. Recently, we developed a system for traffic parameter estimation [10], named scoca, which analyses the images acquired from a pole-mounted camera. The system is able to automatically detect vehicles crossing the zone, to determine their categories, to estimate their speed and to track their trajectory. Data provided by scoca is called microscopic or atomic because they are relative to each single vehicle/pedestrian crossing the scene. Starting from the atomic data we aggregate them in a more general statistical description of the traffic conditions. Our purpose is to use this data to estimate the frequencies of the relevant events for the collision risk definition. The calibration of our index relies on the comparison of the risk value computed on the same road section before and after restructuring works aimed to improve the safety.

3.1 Site selection and acquisition strategy

On the basis of past accident reports, the department “Servizio Reti” of the Municipality of Trento gave priority to improve the safety level of four sites in the city. They were characterized by relatively high traffic volume and by heterogeneous traffic composition.

In order to collect a representative sample of the traffic conditions, we defined an acquisition plan covering five days in a week and four time intervals in a day:

- Monday: the first working day in the week;
- Wednesday/Thursday: working days;
- Saturday/Sunday: weekend days.
- time intervals: 6–9; 11–13; 16–20; 22–01.

We captured 60 hours of video for each site, before (May 2003) and after (May 2004) the restructuring of the road.

3.2 System architecture

We installed cameras to acquire traffic images from the sites selected for the experimentation. Cameras were mounted on poles or on building and connected to elaboration units placed in cabinets on the road sides (see Figure 4). The elaboration units were programmed to acquire image sequences, in the scheduled period, with a 25fps rate, compress and store them. The camera positions, orientations and field-of-views have been chosen accordingly to the events to be extracted automatically from the video sequences. This information along
with the camera intrinsic parameters (focal length, sensor resolution) have to be provided to SCOCA in order to permit its auto-configuration for the specific road section. In fact, SCOCA needs the parameters of the projective model to determine the position on the road of a three-dimensional object starting from a two-dimensional view. Usually, intrinsic camera parameters are known, the other parameters (view angle, camera height), if not available, can be estimated from the images by comparing the real dimensions of markers on the road pavement and their correspondent size in the image [11].

3.3 Traffic parameters extraction

In this section we provide an overview of SCOCA [10], the traffic monitoring system we used to extract traffic parameters from the image sequences stored during the acquisition phase. As already mentioned, it analyzes the traffic images and, for each vehicle/pedestrian crossing the scene, it provides the following data:

- category: one of pedestrian, bicycle, motorcycle, car, van, lorry, bus;
- instantaneous and average speed;
- trajectory defined by a set of points in the road coordinate system;
- entering and exit lanes.
The first step, performed before starting the video sequence analysis, is the configuration of the system. It comprises the system adaptation to the camera parameters and the operator intervention in order to specify, through a graphical tool, the portion of the image to be monitored (typically the region corresponding to the road) and the possible entering and exit lanes along the boundary of the selected region. In this phase the system pre-computes some view-dependent data in order to speed-up subsequent phases, in particular, the vehicle classification.

The core of the video analysis system comprises two main modules working in parallel, i.e. the Detector and Tracker and the Object Parameter Extractor. The first one analyzes the frames of the video sequence in order to locate objects passing through the field of view of the camera, and to track them until they leave the observed scene. The detection of the moving object is based on the well-known background subtraction paradigm: the system maintains a reference image depicting the scene without foreground objects, and detects them by analyzing the difference between the current frame and the reference image. We developed a novel algorithm [12] in order to deal with the numerous problems caused by the high variability of the lighting conditions in outdoor environment, e.g. gradual and sudden global illumination variations, pixel saturation. It relies on the use of the Kalman filtering method with the introduction of an estimation of the global illumination as an external control of the filter. To satisfy the real-time constraint, the tracking strategy follows two alternative branches at two different temporal resolutions: one is a region-based method that relies on the cited moving object detection method, and the other, much faster, is a feature-based tracking which updates the position of the objects in the images. Only a few small windows, characterized by the presence of horizontal and vertical edges, are selected to track the moving objects. They are searched for in the subsequent frame exploring a neighborhood of their expected position, estimated from the last object displacement. An overlap test between new and expected positions enables to trace correctly each object in case of multiple object tracking. The output of the Detector and Tracker is a list of passed objects which describes each object with data about its appearance and motion while crossing the scene.

The Object Parameter Extractor analyses each passed object, in order to estimate its real world path through the scene under analysis, in particular to determine the entering and exit lanes, and its speed. The object classification into one of the predetermined categories is the most important task, upon which the computation of the remaining parameters relies.

The classification process works in two consecutive steps: a model-based and a feature-based classification. The former is based on the comparison between the object shape and the projection on the image of a family of 3D models which roughly represent the various categories. These projections have been precomputed and stored in a map during the off-line configuration step. An efficient accessing method allows the system to directly select only the models which are closest to the object to be classified. The method is designed in order to detect objects also when only partial views of them are available. This is
particularly useful when the field-of-view is not very wide, as in our case. This method provides not only the best matching model for each object view, but also the best pose. Therefore it enables a reliable computation of the real trajectory, on the road, of the moving object and, consequently, of its speed.

The feature-based classification step is a refinement of the first one and is invoked when it is necessary to distinguish between classes represented by the same 3D model, like bicycles and motorcycles. Basically, it extracts some visual features from the object region and uses their values to assign the object to the appropriate category. In the case of bicycles and motorcycles, features are extracted from the region corresponding to the wheels of the vehicle, after splitting the problem into two sub-cases depending on the computed motion direction. The classification is performed by means of a non-linear Support Vector Machine [13]. The evaluation of the classification performance with respect to a manually labelled ground-truth provided a correct classification rate of 92.5%.

4 Risk computation

In this section we explain the procedure for the estimation of the accident risk, starting from the following atomic data associated to each $i$-th element (vehicle/pedestrian) that crossed the road section under analysis:

- belonging class: $k_i$;
- entering and exit lanes: $(G_{i}^{\text{in}}, G_{i}^{\text{out}})$;
- average speed through the scene: $\bar{v}_i$;
- trajectory defined as a sequence of real world coordinates at each quantized time: $T_i = \{(x_1, y_1), ..., (x_n, y_n)\}$;
- instantaneous speed computed as the derivative of the trajectory with respect to time: $v_i = \{v_1, ..., v_n\}$.

Cumulating the atomic data of all the vehicles/pedestrians, we compute the following maps which provide a global traffic description in the scene over the analyzed period:

- occupation map $O$: it associates to each point $(x, y)$ on the image the percentage $O(x, y)$ of time in which the point is occupied by an object;
- class occupation map $O^k$: the same as above, computed separately for each road user category $k$;
- lane occupation map $O^{\text{in}, \text{out}}$: the same as above, computed separately for vehicles/pedestrians entering the scene from lane $G^{\text{in}}$ and exiting from lane $G^{\text{out}}$.
safety distance $D_{in}$: for each entering lane $G_{in}$, contains the frequency of vehicles entering from $G_{in}$ which are not respecting the safety distance from the preceding vehicle. The safety distance is computed with the standard approximative formula: $v \times r + v^2/(2a)$, where $r$ is the average reaction time and $a$ is the average deceleration (typical values are $r = 0.7s$, $a = 9m/s^2$, but they can be set differently according to the weather conditions at the collection time);

- speed map $V$: for each point $(x, y)$ in the image it stores the average speed $V(x, y)$ of the vehicles passing through $(x, y)$;
- class speed map $V^k$: it is the speed map computed separately for the road users belonging to the class $k$.

Furthermore each trajectory $T_i$ is classified as legal or illegal on the basis of the points of $T_i$, the class $k_i$ and the traffic rules defined for the scenario at hand.

Our proposal for the computation of the risk index, starts from the two following considerations:

- the conflict severity indices used in literature (such as TTC, PET, TH) consider the relations among the trajectories of the road users, and therefore implicitly on their speed, since the trajectory is a function of space and time;
- in the manual conflict collection a key information is the class of the road users involved in the conflict, e.g. car-car or car-pedestrian, in order to provide a quantification of the damage based on their vulnerability.

As a consequence, a reasonable risk definition has to consider the class, trajectory and speed of each individual road user that moves in the scene. We propose to compute the risk associated to each vehicle/pedestrian and to define the global risk as the average of the individual risks.

**Computation of the individual risk.** Consider the road user $i$, belonging to class $k_i$, that enters in scene from the lane $G_{in}^i$, exits through $G_{out}^i$, following the trajectory $T_i = (x_1, y_1), ..., (x_n, y_n)$, with average speed $\bar{v}_i$, and instantaneous speeds $v_i = \{v_1, ..., v_n\}$. Its risk of accident $R_i$ is a function of its parameters and of the global maps describing the traffic condition in the observed road section. Some parameters are related to the collision probability, others to the damage:

$$R_i = P_i \times D_i = \Phi(k_i, \bar{v}_i, T_i, v_i, G_{in}^i, G_{out}^i, O, O^k, O^{in, out}, D_{in}, V, V^k)$$ (3)

We have therefore to define the individual probability of accident $P_i$ and the individual damage $D_i$.

Considering that an accident is a particular case of conflict, the probability $P_i$ that $i$ collides is:

$$P_i = P(C_i) \times P(I|C_i)$$ (4)
where $P(C_i)$ is the probability that $i$ is in a conflict situation, and $P(I|C_i)$ is the collision probability conditioned to the event \{i has a conflict\}. $P_i$ is estimated by distinguishing two cases: (1) $T_i$ is illegal; (2) $T_i$ is legal. Let us now examine the two cases.

1. $T_i$ is illegal. We assume that $P(C_i) = 1$, in fact $i$ is moving along a path not permitted to its class, therefore in a conflict area. The collision probability $P_i$ is therefore given by the probability to encounter another road user that cross $T_i$. It is computed as the path integral of the occupancy map $O$ along $T_i$, which, in the discrete case, is written as:

$$P_i = \frac{1}{n} \sum_{j=1}^{n} O(x_j, y_j), \ (x_j, y_j) \in T_i$$  \hspace{1cm} (5)

2. $T_i$ is legal. In this case we identify two potential conflict situations: (a) $i$ has a conflict with a road users following its same path; (b) $i$ has a conflict with a road users following a path that crosses $T_i$. For this reason we separate the probability $P(C_i)$ as the sum of the two terms $P_1(C_i)$ and $P_2(C_i)$.

In the first case the conflict probability is related to the traffic density along the trajectory $T_i$ (information stored in $O^{in, out}$) and the typical observance of the safety distance for road users that enter from the lane $G_i^{in}$:

$$P_1(C_i) = \frac{1}{n} \sum_{j=0}^{n} O^{in, out}(x_j, y_j) \times D(G_i^{in})$$  \hspace{1cm} (6)

In the second case the conflict probability depends on the traffic density along the trajectories different from that followed by $i$:

$$P_2(C_i) = \frac{1}{n} \sum_{j=0}^{n} (O(x_j, y_j) - O^{in, out}(x_j, y_j))$$  \hspace{1cm} (7)

The collision probability given a conflict situation $P(I|C_i)$ mainly depends on the speed $\bar{v}_i$. We define a projection function $\pi$ that maps a velocity into the interval $[0, 1]$. Summarizing, for the case $T_i$ legal, we have that:

$$P_i = (P_1(C_i) + P_2(C_i)) \times \pi(\bar{v}_i)$$  \hspace{1cm} (8)

The individual damage $D_i$ after a collision of $i$, is a function of the classes of the involved road users and of their speed $v_s$ at the collision time. Formally:

$$D_i = \sum_k P(k) \times \sigma_{k_i,k}(v_s)$$  \hspace{1cm} (9)

where the sum is extended to all the classes and $P(k)$ represents the probability that the other involved road user encountered along $T_i$ belongs to the class $k$. 


The set \( \{\sigma_{k,h}\} \) is a family of monotone curves used to associate a damage value to a collision between two users belonging to classes \( k \) and \( h \) as a function of the impact speed \( v_s \). The type of functions and their parameters have been estimated from data reported in various scientific publications (e.g. [8, 14]), reporting studies about accidents and related consequences. We have chosen a family of sigmoid-functions having different slopes depending on the involved classes. The dependence on the classes try to take into account the different mass and shape of the involved vehicles as well as the vulnerability of the users.

Using the global occupation map \( O \) and the class occupation map \( O^k \), we estimate \( P(k) \) as the probability to find a vehicle of class \( k \) on the trajectory \( T_i \):

\[
P(k) = \frac{\sum_{j=1}^{n} O^k(x_j, y_j)}{\sum_{j=1}^{n} O(x_j, y_j)}
\]

(10)

The impact speed \( v_s \) between \( i \) and a road user of class \( k \) is computed by considering, for each point of \( T_i \), the instantaneous speed \( v_i \) and the expected speed of the other road user, which can be estimated from the class speed map \( V^k \):

\[
v_s = \alpha \frac{1}{n} \sum_{j=1}^{n} \max(v_i(x_j, y_j), V^k(x_j, y_j))
\]

(11)

The impact speed is the average, along the trajectory, of the local expected speeds, modulated with a reduction factor \( \alpha \) that aims to describe a probable deceleration before the collision.

That concludes the computation of the individual damage and therefore of the individual risk of \( i \).

**Computation of the global risk.** The global risk is defined as the average of the individual risks computed for each entity \( i \) that moves through the scene in a certain time interval:

\[
R = \frac{1}{|U|} \sum_{i \in U} R_i
\]

(12)

where \( U \) is the set of actors entered in the scene.

## 5 Study Results

In order to assess the proposed index as a predictor of accident risk, we focused on its variation applying the method to one of the considered road sections, namely where the structural improvements are more relevant (Figure 5).

Starting from the consideration that traffic rules alone are not enough to ensure safety, some modifications have been introduced in the infrastructure that aim at correcting the road-user behaviour by some geometric constrains. The main road has been narrowed with the insertion of flower beds along the Sud-side that separate roadway and sidewalk. Other flower beds have been built on the corner to discourage pedestrians to cross outside the crossing-walk. The
lane visibility has been enhanced by the installation of cat’s eyes along the Sudside border. The *yield the right of way* from the lateral road has been substituted by the stop rule and the stop line put forward. A cross walk has been introduced in the West part of the intersection, while the parking lots along the North-side of main road have been removed. These modifications should make the crossing safer because pedestrian are constrained to go through on the marked zone, that requires a shorter time spent on the roadway; the driver coming from east have more visibility of the pedestrians approaching the cross in the direction NS due to the removing of parking along the border. Road narrowing discourage overtaking maneuvers, that are dangerous at intersections and near cross-walks.

![Image of before and after works](image)

Figure 5: Images acquired from the same camera, before and after the works (May 2003 and May 2004). The main road is narrower, a new zebra crossing has been marked off on the street, flower beds discourage pedestrians to cross outside the crossing-walk, stop sign substituted the give priority sign.

Traffic data has been collected from the recorded sequences of the selected road intersection, both before and after the restructuring works. This data has been used to compile the maps involved in our risk estimation method and, finally, the global accident risk has been computed.

To improve the comprehension of the analysis results, a graphical interface, named *Statistical Suite*, has been designed and implemented. It allows the operator to see various traffic statistics including traffic composition, velocities distribution, distances distribution with respect to the safety distance, trajectories, occupancy maps and flow map. Moreover, the interface is a useful tool for the operator to specify the legal trajectories in the selected road section. For example, Figure 6 reports the illegal trajectories of bicyclists detected in an hour of the 2004 sequence. Figures 7, 8 are other examples produced with the *Statistical Suite*.

Some aggregate traffic parameters extracted from the video sequences of the selected intersection are reported in Table 1. From the table we can observe that global traffic volume figures are comparable, while other parameters undergo significant variations. The new pedestrian crossing lets increase the pedestrian volume, while for the other categories the traffic composition remains similar (see Figure 7).

The main effect of the structural changes is to reduce the speed of the vehicles
Figure 6: A panel of the *Statistical Suite* relative to the analysis of the trajectories. Right: selection of the class to be considered (here: Bicycle); Middle: Illegal paths detected by the system; Right: selection of entering and exit lanes to be considered.

Figure 7: Traffic composition before and after the changes in the road structure. In 2004 pedestrian volume has increased.
Figure 8: The safety distance is the minimum distance that should be left by each driver between the own vehicle and the ahead one. Here are histogramed the ratios of the measured distances and the respective safety distances. In 2003 the vehicles that do not respect the safety distance, i.e. the ratio between actual distance and safety distance is less than 1, are 52%, in 2004 they are 46%.

Table 1: Some traffic data, computed before and after the changes in the infrastructure.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Volume vehicles</td>
<td>965 V/h</td>
<td>923 V/h</td>
</tr>
<tr>
<td>Volume pedestrians</td>
<td>20 p/h</td>
<td>52 p/h</td>
</tr>
<tr>
<td>Median speed vehicles</td>
<td>47 Km/h</td>
<td>37 Km/h</td>
</tr>
<tr>
<td>Vehicles exceeding the speed limit</td>
<td>38%</td>
<td>15%</td>
</tr>
<tr>
<td>Vehicle speed at 85th percentile</td>
<td>57 Km/h</td>
<td>50 Km/h</td>
</tr>
<tr>
<td>Violations of safety distance</td>
<td>52%</td>
<td>46%</td>
</tr>
<tr>
<td>Vehicles on illegal route</td>
<td>6.9%</td>
<td>8.7%</td>
</tr>
<tr>
<td>Pedestrians on illegal route</td>
<td>100%</td>
<td>32%</td>
</tr>
<tr>
<td>Estimated Risk Index</td>
<td>2.85%</td>
<td>1.91%</td>
</tr>
</tbody>
</table>
The percentage of vehicles exceeding the maximum speed legally permitted on the given stretch of road (50 Km/h) drops from 38% (2003) to 15% (2004) and more drivers respect the safety distance. This contributes to a reduction of the global risk index from 2.85 a 1.91, i.e. 32% lesser. The number of illegal routes of pedestrians decreases, mainly because to the construction of the new zebra crossing; however, we must observe a small increment of vehicles on illegal route in the left turning from the main to the secondary road, due to the different position of the stop-line. We notice that the traffic slows down on the main road due to cars turning left that cannot get passed now, but that increases safety of crossing pedestrians.

6 Conclusions and future work

In this paper we have presented a novel methodology for a quantitative evaluation of the accident risk associated to a road section. We developed and tested an automatic tool to evaluate the effectiveness of risk mitigation interventions not relying on statistical data about accidents. The basic idea is to exploit the availability of video analysis technologies for the automatic collection of data about the traffic. We have used the atomic events automatically collected by a camera-based traffic monitoring system developed recently in our research group. The system is able to determine for each entity moving in the observed road section, the entering and exit lane, the trajectory on the road-plane, the speed, the belonging class among pedestrian, bicycle, motorcycle, car, van, bus, lorry. The aggregation of this data permits the computation of several maps, which provide a statistical description of local traffic. Considering the factors
that are usually taken into account, in literature, to evaluate the dangerousness of a road, we have proposed a method for the computation of the individual accident risk for a road user which crosses the scene; it is based on the collision probability and the damage estimation. The global risk is computed as the average of the individual risks on a lapse time.

We have applied this methodology using data coming from two sequences of the same junction before and after changes in its structure. The traffic volume remains almost the same, but the estimated risk is lower. This is mainly due to the reduction of speed, a factor that weights in the computation of the collision probability and of the damage as well. We emphasize that the improved safety corresponds to the perception of people living in the zone.

With the technologies today available, the architecture of the monitoring system and its implementation, the index can be computed in real-time, with only the necessary delay to collect statistical information of the last time period. A real-time on-field risk computation is straightforward and it can be useful to analyse the risk trend during the day time, week day and season, and to implement appropriate risk reduction strategies.

In the future we plan to develop novel computer vision algorithms for the automatic detection of a larger set of traffic events in order to enrich the information upon which the risk index is computed. In particular, investigations are needed to deal with groups of pedestrians, whose presence is frequent in road intersections regulated by traffic lamps.

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References


