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Trajectory Perturbation in Surrogate Safety Indicators

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Abstract

Traffic conflicts based surrogate safety indicators have been applied extensively on real trajectories and in simulation. Such indicators can be useful to assess the safety of a given scenario without the need to use real crash data (which in many cases may be unavailable). Unfortunately, all traffic conflict indicators that are commonly used have a structural limitation: they are not able to consider potential conflicts with roadside obstacles or barriers and conflicts between vehicles which are travelling on non-conflicting trajectories. This limitation is a serious limitation since crash data analysis shows that at least 40% of fatal crashes are originated by single vehicle accidents against a fixed object or by vehicles travelling in opposite directions. This paper is intended as a concept paper that presents an alternative view on conflict safety indicators showing that new indicators can be generated by the perturbation of vehicle trajectories overcoming the above indicated limitations.

Keywords: Traffic safety, Traffic theory; Accident analysis.

1. Introduction

Accident analysis is commonly applied to estimate road safety levels by use of inferential statistics (Hauer, 1986),(Jovanis and Chang, 1986),(Miaou and Lum, 1993),(Miaou, 1994),(Shankar et al., 1995), (Hauer, 1997),(Abdel-Aty and Radwan, 2000),(Yan et al., 2005). With this analysis it is possible to connect causes (infrastructural layouts) to effects (crashes) and improve road conditions. The limitation of this analysis is that crashes are random and rare events and that it is not possible to easily compare safety of different layouts in new infrastructures. For these reasons surrogate safety performance indicators based on the analysis of conflicts in vehicle trajectories have been proposed (Hayward, 1971),(Minderhoud and Bovy, 2001),(Huguenin et al., 2005),(Tarko et al., 2009). The main problem in the application of such measures is an objective definition of "high risk" situations or "near-misses". Amundsen and Hydén (Amundsen, F.H., and Hyden, 1977) provided the most

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accepted definition of traffic conflict as “an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged”. This definition unfortunately does not exactly define what a conflict is and while it states the importance of closeness in terms of space and time it does also not univocally clarify what would be the risk of collision. Even the statement "if their movements remain unchanged" can be interpreted in many ways.

The lack of a definitive and satisfactory definition of a conflict is aggravated by the current research practice (which is applied in most papers that compose the present state of the art), of considering conflicts only if the trajectories of road users intersect: according to the current state of the art in traffic conflict techniques if trajectories do not overlap there is no high risk and no observable conflict.

Common conflict indicators are expressed in terms of how close vehicles are in terms of spatial or temporal distance, other indicators are expressed in terms of the amount of evasive actions (for example such as braking) that is necessary to avoid a crash, in any case all used traffic safety indicators fail an obvious logical validation for some typologies of crashes in the sense that they are not able at all to identify potential conflicts that lead to the two very common crash typologies of events that happen on our roads every day:

-Collisions of isolated vehicles with roadside barriers and obstacles

-Collisions between vehicles that are travelling on non intersecting trajectories.

This paper is structured as a concept paper and it is a summary of issues that reflect the experience and expertise of the writers on the delicate matter of traffic safety analysis with microsimulation, it serves the purpose of providing an in-depth discussion of a topic which has been not discussed extensively in previous literature. In fact, despite the existence and application of several detailed traffic simulation models, the evaluation of safety risks considering also roadside barriers and obstacles was almost never performed and most simulation packages do not have any module built to evaluate safety levels as an output.

This paper does not provide detailed guidance for implementation of the methodology; it merely shows the uncomfortable truth that seldom there were attempts in literature to consider the two typologies of crashes above described with conflict based techniques (It must be noted that there are some exceptions such as for example in (Tarko, 2012)) and introduces a new viewpoint which possibly can motivate a great amount of scientific research in the near future since trajectory perturbation in surrogate safety studies can allow addressing also other important issues such as how autonomous vehicles and human drivers will have to interact on what we expect to be safer mixed traffic roads.

2. State of the art

The analysis of traffic conflicts dates back to Perkins and Harris in 1968 (Perkins et al., n.d.). It is important to note that in the early applications conflicts were determined by direct observation and registrations were performed manually. This means clearly that it was not possible to perform complicated calculations on vehicle trajectories since everything had to be done by human direct observation (see Fig. 1).

Figure 1: (a) The first researches on conflicts identified conflicts as events where an evasive maneuver was required to avoid a crash; (b and c) Conflicts were evaluated by direct human observation (images from (M.R. Parker, 1989)).

Nowadays conflicts are established on trajectories that can be identified with great accuracy (with video analysis) or obtained in simulation. The complete knowledge of vehicles trajectories, today, allows researchers to perform more complex calculations yet the original approach of considering conflicts as potentially leading to a crash only in the case of lack of evasive maneuvers has been maintained.

Amundsen and other researchers in 1977 (Amundsen, F.H., and Hyden, 1977) further developed the above introduced initial concepts. The conflicts that can occur, as vehicles interact on the roadway, have been symbolized in 1987 by Hyden (Hyden, 1987) with a "safety performance pyramid" which illustrates all potentially risky interactions, extending from more frequent and less severe events at the base of the pyramid to less frequent and more severe events near the top of the pyramid.

The use of traffic conflict surrogate techniques in traffic safety analysis has seen the definition of many different "surrogate safety measures" (indicators) such as: time to collision (TTC), post encroachment time (PET), initial deceleration rate (DR), maximum speed of two vehicles involved in the conflict event (MaxS), maximum relative speed of the two vehicles involved in the conflict event (DeltaS), deceleration rate to avoid the crash (DRAC), proportion of stopping distance (PSD) and Extended Delta-V (Laureshyn et al., 2017). All the above listed indicators do consider conflicts only between vehicle that are on conflicting trajectories. The only indicator that was presented in literature that considers the possibility of a collision with road-side objects is the Time to departure (TD) introduced in (Tarko, 2012).

The reason for this limitation could be that by performing manual observations of conflicts there was no way of applying methodologies that require more complex calculations (such as the one presented in this paper). Also common used conflict techniques originated at the intersection level and extended to car-following situation and they were not extended to consider these two typologies of crashes above described.

Unfortunately we cannot limitate safety studies to non conflicting trajectories. The following data tend to demonstrate this affirmation: in the work (Treese, 2017) around 3 millions of Florida crash records from 2006 to 2013 were accessed. Results show that 565,303 were single-vehicle accident with road side objects or barriers, among them 47,341 were tree-related accidents. Data also show that 12.5% of tree-related accidents turned into severe injuries or death. The paper (Holdridge et al., 2005) states that in the United States, collisions with fixed objects and non-collisions account for 19% of all reported crashes and they result in 44% of all fatal crashes. In the United States according to (Mannering and Lee, 1999): "single vehicle run-off-roadway accidents result in a million highway crashes with roadside features every year" and such accidents account for one third of all highway fatalities, with an estimated societal cost of over $80 billion in 1997 (Opiela and Mcginnis, 1998). From the report (National Highway Traffic Safety Administration, 2017) it is possible to find out that the increase in total fatalities from 2015 and 2016 in the United states amounts to 1976 fatalities and 1180, among them , are fatalities from single vehicle crashes. In (Board and Wigan, 2015) it is made known that fatal crashes involving isolated vehicles, in USA in 2015, are 18.683 while fatal crashes involving multiple vehicles are 13,483. There are some research papers that tend to demonstrates that roadside objects in urban environment tend to increase safety by reducing aggressive driver behaviour such as (Dumbaugh, 2005) and (Harvey and Aultman-Hall, 2015), yet the staggering statistics above are telling us that single vehicle crashes account for at least 40% of total fatal crashes.

Isolated vehicle conflicts with road side object are not the only conflicts which are left out by current conflict indicators. As stated above current conflict indicators do not consider also other conflicts between vehicles that are travelling on non-intersecting trajectories such as head on crashes on undivided highways and rural roads. In the paper (Gårder, 2006) it is asserted that more than two out of three of all fatal crashes in Maine occur on rural, two-lane collector or arterial roads and that head-on crashes on these roads are responsible for almost half of all fatalities on these roads. In 2004, in the USA according to (NCSA National Highway Traffic Safety Adminis., 2004), fatal accidents on undivided roads were 25,477, fatal accidents on divided roads were 11,702 and on one way street 317. By applying cross-sectional models for typical sections of two- and four-lane roadways in four different states in the USA, in (Council and Stewart, 1999), crash reductions for conversion from two- to four-lane divided sections was estimated ranging from 40 to 60 percent. The estimated reduction due to conversion to a four-lane undivided configuration, was instead from no effect to a maximum 20 percent reduction. According to (Persaud et al., 2004) the major safety problem on rural two-lane roads is caused by vehicles crossing the centerline and striking opposing vehicles and these opposing-direction crashes account for "about 20% all fatal crashes on rural two-lane roads and result in about 4500 fatalities annually in the US (U.S. Department of Transportation, 2003). These results clearly show, the intuitive result, that safety increases with the insertion of a median barrier, that transforms an undivided road into a divided roads.

The inconvenient truth is that more than 100 research paper have been published on conflict analysis using indicators that do not consider the above empirical and scientific evidences. Not only conflict indicators do not consider the presence or the absence of a median barrier, they also assume that in an undivided road there are no potential conflicts between opposing traffic flows since trajectories do not intersect. These doubts on the use of conflict indicators are common among practitioners, in fact most microsimulation packages do not directly provide measure of performances for traffic safety. Only recently road safety performances indexes have been considered inside microsimulation packages: (Guido et al., 2011),(Astarita et al., 2011),(Astarita et al., 2017), (Astarita et al., 2014), (Astarita et al., 2012).

This paper, which follows a detailed description of a specific implementation of the methodology presented in (Astarita and Giofré, 2019), is mainly focused specifically on the conceptual problems that the new general method of perturbation of trajectories solves generating new traffic safety indicators that are able to overcome the above described limitations. In the proposed perturbation of trajectories methodology the above cited definition of Amundsen and Hydén [15] of traffic conflict is interpreted in a different way: "unchanged movement" is interpreted as a vehicle that keeps going at the same speed for a given amount of time with an erroneous small deviated direction, making it possible a collision with road side barriers and obstacles and with vehicles that are travelling on otherwise non intersecting trajectories.

3. The perturbation of trajectories and similarities with existing traffic safety indicators

The objective of this paragraph is to present a new method to evaluate traffic conflicts that would consider not only rear-end and intersection conflicts but also conflicts between vehicles that are moving on non intersecting trajectories and conflicts between vehicles and roadside objects. In the traffic scenario of Figure 2(a) traditional conflict indicators would consider only conflicts between the two couples of vehicles A and C and B and C. A potential conflicts between vehicle A and B would not be considered.

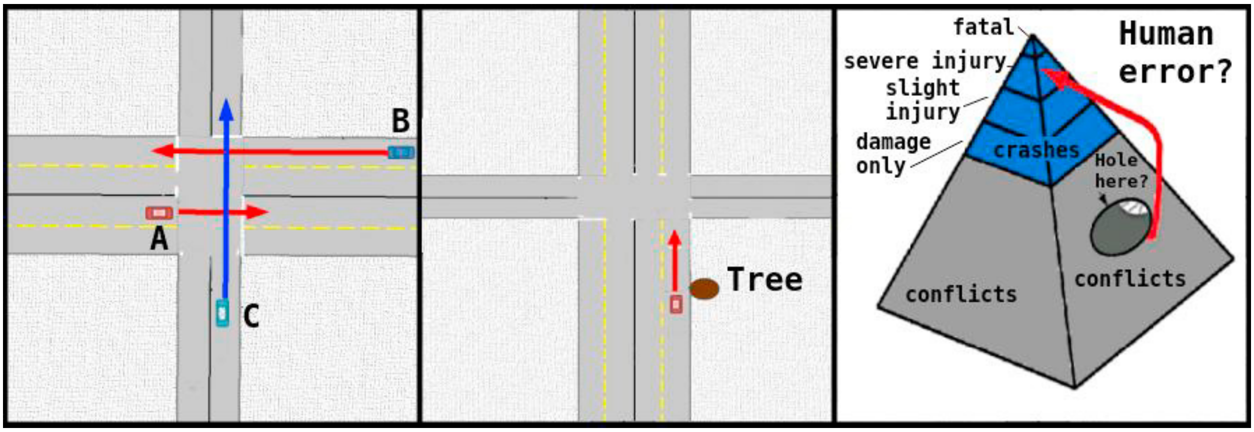


Figure 2: (a) Traffic scenario in which A and B do not generate a conflict according to SSAM software (Gettman et al., 2008); (b) Traffic scenario in which a car drives close to a roadside dangerous object and that is not considered as a conflict according to the Swedish conflict methodology; (c) Current traffic safety indicators may be missing a big portion of the Hyden pyramid since in their formulation they do not consider driver errors and consequent vehicle deviations from given correct trajectories.

Moreover with current traffic conflict indicators there is no way also of accounting the risk of the traffic scenario depicted in figure 2(b) in which a vehicle travels near a dangerous road-side obstacle. How it is possible that 40% of all road fatalities are vehicles that do crash into roadside objects? Obviously the cause of such an high number of fatalities lay in the human fallible capacities of drivers. Drivers commit mistakes often and those mistakes turn into a fatal crash only in some unlucky circumstances. When a traffic safety analysis is performed with SSAM software, trajectories of vehicles are taken and elaborated exactly in the form that the microsimulation package has produced. In reality drivers tend to make mistakes and deviate from the correct trajectories. Crashes are the obvious consequences of human errors, though human error is considered in traffic conflict theory only at the level of evasive actions. The lack of proper evasive action is considered as the cause of a crash in many conflict indicators. Those indicators obviously do not allow to observe conflicts that would lead to a crash with fixed objects (fixed object cannot perform evasive maneuvers).

By using traditional approach an important part of the Hyden Pyramid is left out: the part where human errors turn into deviations from normal trajectories causing potential crashes with other objects (such as fixed object or vehicle driving in the opposite direction) that cannot avoid the crash (see Fig. 2(c))

The only way to consider all these left out conflicts is to introduce new traffic safety indicators which are based on deviated trajectories. The concept of proximity in time and space can be retained and normal trajectories have to be perturbed to allow counting conflicts between vehicles and roadside objects (or conflicts among vehicles travelling on non-conflicting trajectories). This simple logical step generates the general method of perturbation of trajectories which was implicitly already partially adopted in some previous papers. In fact the approach followed by some previous papers can be considered as part of this general method. We believe that after the formalization and definition of the here presented perturbation of trajectories method new research efforts will be able to advance traffic safety science considerably.

The perturbation of trajectories is a method that introduces erroneous trajectories in an observed traffic scenario. Trajectories of vehicles driven by drivers which are commiting driving mistakes can be extrapolated and over imposed on the correct trajectories contained in a traffic scenario. This simple concept originates the method of perturbation of trajectories.

The method can be applied on a given traffic scenario (as it is done with other conflict indicators), with the following general steps:

1) Given the set of trajectories of vehicles in a traffic scenario. 2) A vehicle x in an instant t of the given traffic scenario is chosen according to some random or deterministic law (obviously in such a way that vehicles which are travelling for longer time in the traffic scenario have an higher probability of being chosen). 3) A deviated random trajectory is generated for vehicle x according to some probabilistic or deterministic law (a constant speed equal to the speed of vehicle x at time t and a constant angle can be assumed for the next DT seconds for the vehicle or any other alternatively defined deviated trajectory). 4) Starting at time t vehicle x is assumed moving on the generated trajectory for the next DT seconds. 5)Potential collisions between vehicle x and road side obstacles or other vehicles are evaluated in terms of severity according to a crash dynamic model. 6)The calculation process goes back to step 2 until a sufficient number of potential crashes have been evaluated or a sufficient number of random vehicles have been chosen.

The first research work that followed the proposed perturbation of trajectories method was the Roadside Safety Analysis Program (RSAP) developed in the National Cooperative Highway Research Program (NCHRP) and presented in report 492 (Mak et al., 2003). RSAP has the objective of helping roadside safety engineers to evaluate impacts of roadside safety improvements. The methodology used by RSAP is based on the perturbation of trajectories since vehicles are considered having a defined encroachment speed and angle with a consequent vehicle orientation on impact. RSAP (and other works such as (Mak et al., 1998),(Archer and Kosonen, 2000),(Erbsmehl, 2009)) unfortunately is not applied to car-to-car potential crashes and conflicts happening between different vehicles in different road scenarios.

We could say that also the approach proposed in (Tarko, 2012) for the definition of TD follows the steps of the proposed perturbation of trajectories method with a deterministic extraction of vehicles (all of them) and with a simplified evaluation of potential collisions. In the paper (Tarko, 2012) the risk of roadside obstacles collisions is evaluated with the introduction of Time to Departure indicator (TD). Unfortunately the TD indicator does not considers some important factors in the estimation of risk-road departure: the real positions and consistency of roadside obstacles and the actual speed of the considered vehicle. The outcome of a road departure event in terms of severity depends on the energy of the collision and how the energy is dissipated. Vehicle speed and detailed information on the position, shape and consistency of an obstacle are necessary information to establish the severity of a potential impact. Moreover it is not clear how TD could be integrated to assess the risk of traditional car-to-car conflicts. In this paper we omit for brevity sake the details relative to our specific implementation of the above presented method since the reader can find this in: (Astarita and Giofré, 2019).

4. Some preliminary results and discussion

The method of perturbation of trajectories above described can produce an easy measurable number of potential crashes and the severity of consequences of each crash. An estimation of number of injuries and/or death can also be obtained. In this paper a specific implementation of the above described method is presented and applied on a specific traffic scenario following the approach of (Astarita and Giofré, 2019). The scenario is a stretch of road on the 106 Jonica Italian state road between Sant'Anna (Kr) and Steccato di Cutro (Kr), and extends for about 12 km. Numerous investigations on the data collected by the Traffic Police have classified the Ionian state road 106 as a road with an high number of accidents with personal injuries: as many as 345 in 2014, which resulted in 14 deaths and 672 wounded. In Italy this road appears to have the highest mortality rate (8.5 deaths per 100 accidents).

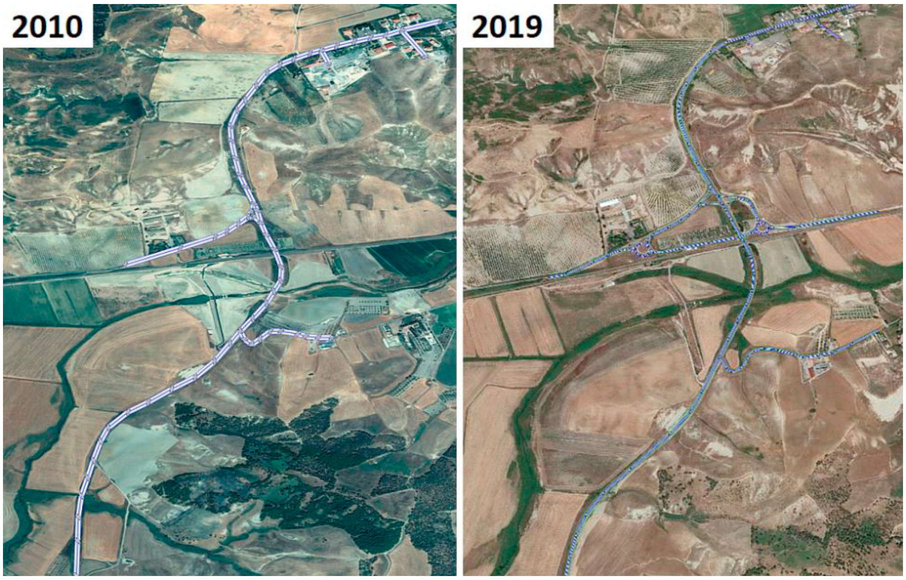
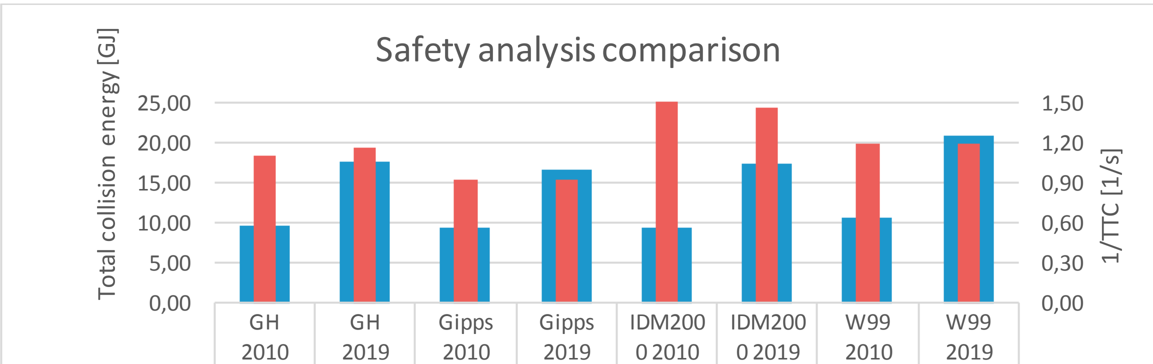


Figure 3: The simulated scenario.



	GH 2010	GH 2019	Gipps 2010	Gipps 2019	IDM2000 2010	IDM2000 2019	W99 2010	W99 2019
ZombieDriver	9,51	17,71	9,30	16,54	9,46	17,33	10,53	20,75
SSAM	1,106	1,168	0,927	0,919	1,553	1,458	1,195	1,199

Figure 4: Results of TTC analysis and the proposed methodology (the Zombiedriver indicator was introduced in (Astarita and Giofré, 2019)).

The road examined is composed of a single two-way carriageway with an almost regular altimetric course that develops alternating long straight stretch of road to wide-radius curves. The smooth running of the highway and in particular the long straight parts induce the users to maintain high speeds also at intersections with secondary roads. Another technical problems affecting the infrastructure is also the poor maintenance of the wear layer and of the restraint systems, in addition there is a reduced distance between vehicles and roadside objects. Two safety assessment were made in two different scenarios (see Fig.3), before intervention in the year 2010 and at the current state in 2019 in which a new access junction to the SS106 was created. Simulations were carried out using the TRITONE microsimulation software with four different Gazis-Herman (GH), Gipps, IDM 2000 and Wiedemann 99 (W99) car-following models. These models were calibrated using the GEH function, in order to obtain realistic simulations. The use of different car-following models was introduced to assess the sensibility of the proposed approach to different simulation environments. The analysis of the results was based on two main indicators (the Zombiedriver indicator that follows the proposed methodology and a traditional SSAM analysis based on TTC): the total impact energy for the proposed methodology, and 1/TTC obtained from for SSAM software. The Zombiedriver indicator is the total energy of all crashes that are generated by ap applying three perturbations to the trajectory of each vehicle, each second in the microsimulation. The perturbations are applied imposing a constant speed and angle to the chosen "Zombie" vehicle while other vehicles will keep the given trajectory without the possibility of performing an evasive maneuver.

Moreover, a road safety inspection was performed by professionals who concluded that the new scenario might be more risky than the previous one. The comparison of the simulation results confirmed that the introduction of the new access ramp has decreased road safety, but this results can clearly be determined only with the proposed methodology since the evaluation of TTC with SSAM does not bring consistent results with all models (see Fig.4).

5. Conclusion

This short paper introduces the calculation of traffic conflicts on deviated trajectories. The methodology originates automatically when conflicts with roadside obstacles (and between vehicles which are travelling on non-conflicting trajectories) need to be taken into consideration. Hazards from road-side objects can be considered in the traffic conflict approach by considering deviation from correct trajectories. This is an obvious fact which does not require a demonstration with experimental data. More research efforts will have to be devoted to demonstrate that this methodology can bring comparable or better results than classical traffic conflict indicator. This result is outside the scope of this concept paper. Trajectory perturbation in conflict theory is a new approach. At the moment a proved limitation is the temporary lack of confirmations based on real crash data. The potential of this approach is to suggest a new direction in the field of traffic conflict safety indicators.

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