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A Review of the use of traffic simulation for the evaluation of traffic safety levels: can we use simulation to predict crashes?

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Abstract

This paper presents a literature review on the application of traffic simulation for the evaluation of traffic safety levels. The main aim is to identify, through the implementation of a multi-step methodology current research-trends, main gaps in the literature and possible future challenges. First, a bibliometric analysis is carried out to obtain a broad overview of the topic of interest. Subsequently, the most influential contributions are analysed in-depth, with specific attention to specific issues.

Keywords: crash simulation; microsimulation; road safety; safety indicators; traffic conflicts, road crash, road incident.

1. Introduction

Traditionally, in transportation engineering, quantitative approaches have been applied to solve congestion problems with attempts to shift demand on transit systems (Marzano et al., 2018b) and to implement better road traffic control by adopting tools such as traffic simulation (Barceló et al., 2005; Martinez et al., 2011; Osorio and Punzo, 2019; Young et al., 2014), network dynamic equilibrium models (Cantarella et al., 2019; Cantarella and Watling, 2016; Gentile, 2018, 2016), and methodologies attempting to affect user route choice (Kucharski and Gentile, 2018; Marzano et al., 2018a; Papola, 2016; Papola et al., 2018; Trozzi et al., 2015).

Quantitative approaches involving Network modelling have seldom been applied to Traffic Safety evaluation. In this paper, a review of research attempts to use traffic simulation to assess safety levels and evaluate the risk of road crashes is presented. The traditional analysis of crashes is based on statistical methods that are applied, for the estimation of traffic safety, on data coming from databases (Abdel-Aty and Radwan, 2000; Caliendo et al., 2016,

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2007; Hauer, 1986, 1997; Jovanis and Chang, 1986; Miaou, 1994; Miaou and Lum, 1993; Shankar et al., 1995; Yan et al., 2005).

These classic methodologies, which are based on real crash data and have a solid background, usually do not consider explicitly the trajectories of vehicles at any given location. Classical statistical methods can extract from crash databases relevant information such as the probable causes of accidents. Moreover, it is possible to relate the road and traffic characteristics to potential effects (accidents) and outline better road planning solutions that consider safety issues.

This procedure cannot be applied to the planning of new roads or ahead to any change in the road network. For this reason, an alternative approach was proposed at the end of 1960: Perkins and Harris (1967) introduced the concept of traffic conflict for the first time.

The idea is to use traffic conflict data instead of crash data. Traffic conflicts are situations in which vehicles travel close in time and space in such a way that they could potentially end up in a crash. The several conflicts that can occur in traffic have been pictured in 1987 by Hyden (Hydén and Linderhonm, 2012) with a "safety performance pyramid" (see Fig. 1) which distinguishes the Swedish traffic conflicts approach.

Fig. 1. Hydén safety pyramid (from:Http://www.tft.lth.se/fileadmin/tft/video_in_traffic/Swedish_conflict_technique.pdf.).

Surrogate safety measures indicators evaluate the interactions among vehicles in traffic highlighting the occurrences of unsafe situations.

This methodological background appears to be solid enough to allow engineers in applying microsimulation or simulation in general in common planning activities with the aim of establishing safety levels of different planning layouts. Why procedures based on this methodological background have been applied only in the research field and have not successfully extended to the professional practice?

This paper intends to give an answer to this question or at least investigate the potential problems that have held back the application of these techniques in the common professional analysis of traffic scenarios.

2. Systematic bibliometric analysis

In this section, a methodologically developed literature review is presented.

2.1. Review Methodology

A systematic literature review about conflict-based indicators is presented in this research work. The adopted methodology has been based on a seven steps procedure showed in Fig. 2. This methodology is frequently used in literature (Kamble et al., 2018; Mishra et al., 2018).

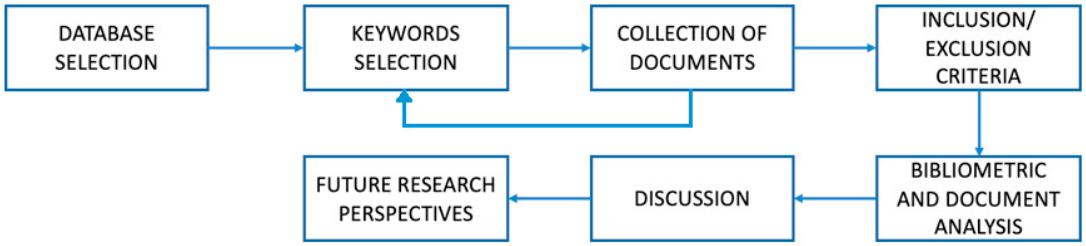

Fig. 2. Seven-steps procedure for systematic literature review.

2.2. Database Selection

In this paper, among the different citation databases, Scopus was selected. Scopus includes more than 25,000 peer-reviewed journals of the most important publishing houses. Scopus is somewhat more complete than Web of Science (WoS), which includes only ISI indexed journals with about 12,000 journal titles (Yong-Hak, 2013).

2.3. Keywords Selection

With the scope of building a thorough literature review in the indicated sector, the authors have identified the following four keywords groups: "road traffic conflict", "traffic surrogate safety measures", "microsimulation safety" and "traffic conflict simulation vehicle". The database has been then queried for every document that contains either in the title or in the abstract one of the three groups of keywords.

2.4. Collection of Documents and Filtering (Inclusion/Exclusion)

The first queries with attempted groups of keywords returned a considerable set of documents. It must be noted that some search attempts with alternative choices of keywords such as: "surrogate safety measures" or "traffic conflict" did bring a lot of documents not pertinent to the road traffic field. The iterative procedure applied has been represented by a backward-pointing arrow between the third and second step of the procedure in Fig. 2.

As an example the results of the search: "traffic conflict" brought 7219 documents with over 30% of documents not pertaining to the specific field of road traffic conflicts.

The results of the search: "road traffic conflict" brought 1477 documents. The results of the search: "traffic conflict simulation vehicle" brought 644 documents. The results of the search: "traffic surrogate safety measures" brought 317 documents. The results of the search: "traffic microsimulation safety" brought 277 documents.

With the above results and without manually excluding documents that are not pertinent to the field it was possible to elaborate the following preliminary temporal diagrams showed in the following Fig. 3 and 4.

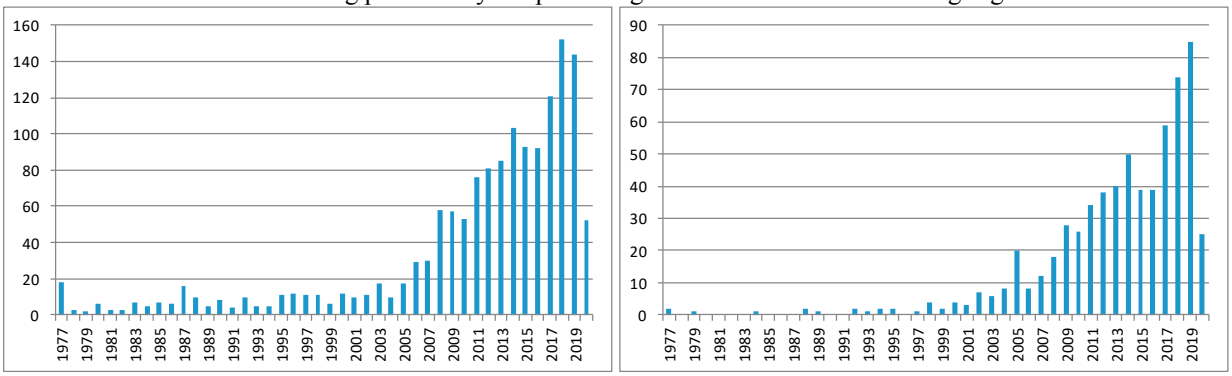

Fig. 3. Number of publications resulting from the search (a) "road traffic conflict" and (b) "traffic conflict simulation vehicle " over the years.

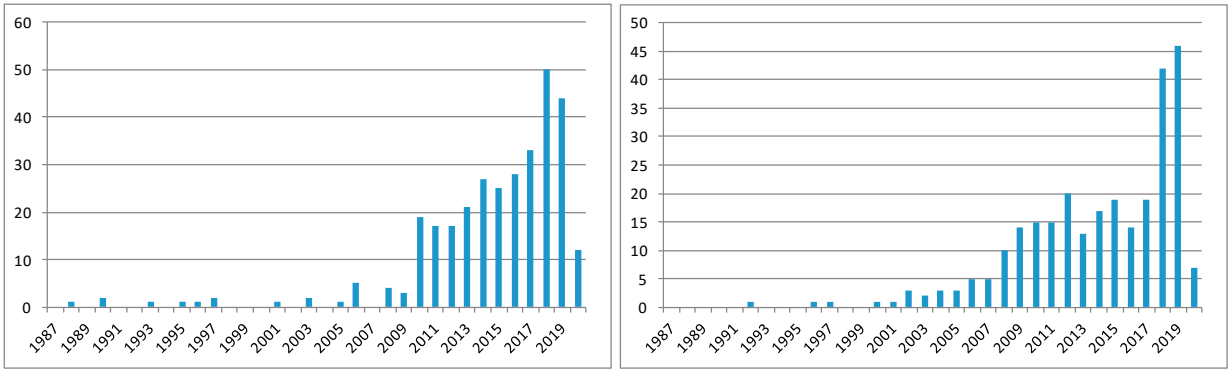

Fig. 4. Number of publications resulting from the search (a) "traffic surrogate safety measures" and (b) "traffic microsimulation safety".

Subsequently, all publications were combined into one common database excluding duplicates obtaining 2291 documents distributed by time as showed in the following Fig. 5. It must be noted that this preliminary and raw database of documents contains many documents that are outside the desired field of interest. At the same time, many works that might even be central to the field of traffic conflict might have been excluded according to a potential different word use in the abstracts and titles. Moreover, it is possible that some interesting and influential papers might not have been indexed by Scopus. Nevertheless, this preliminary database can be used to extract some useful information. According to this raw database the number of papers published each year has increased from under 100 in 2010 to over 250 in 2018 and 2019. In Fig. 5(b) it is possible to see the number of citations for year of the published documents. This graph again shows increased scientific attention with a special focus on papers published between 2010 and 2014.

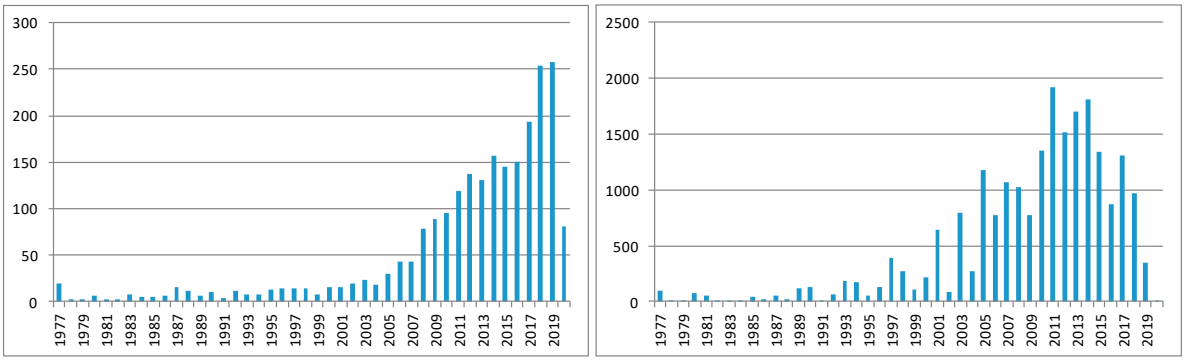

Fig. 5. (a) Number of total publications responding to the four performed queries over the years; (b) number of total citations for year of publication of documents responding to the four performed queries.

This paper is written in the hope to promote concepts that deserve to be studied, contributing to an increase in the volume of research on this topic. The target for researchers of this sector should be that of publishing new and interesting papers to such an extent that the citation peak of 2010-2014 can disappear in favor of more interesting and comprehensive articles.

The trend in the number of publications and citations over the years is one of the main reasons behind the present study, which aims to respond to the need of revealing important research gaps that might still present in the literature even given an enormous quantity of completed research. In any case the great number of works published in recent years motivates an interesting discussion on some important issues that might have been overlooked.

The obtained database of 2291 documents has been reduced to identify the most important contributions. The most influential documents and authors have been identified. The most prolific authors in the analyzed raw database of 2291 documents are presented in Fig. 6. By applying the software VOSviewer (1.6.13 version), which can be

used for conducting bibliometric analysis (van Eck and Waltman, 2010) we filtered the database for authors with at least 4 publications and 8 citations identifying 220 authors. Among these 220 authors the more influential authors were established according to the number of citations and total link strength of citation connections (data elaborated by using Vosviewer): the authors connected by citations are 209 and are graphically presented in the following Fig. 7 where the most influential in terms of citations have enlarged labels.

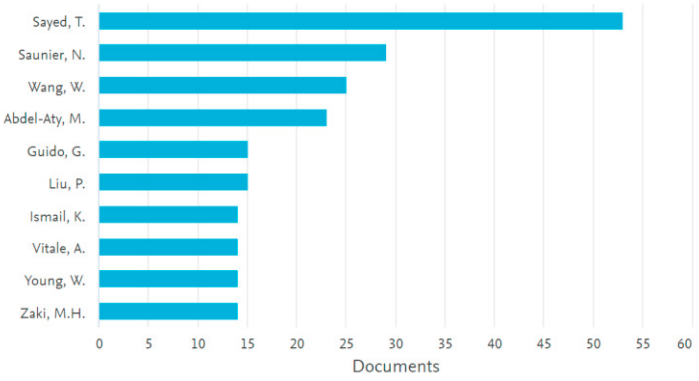

Fig. 6. The most prolific authors in the analyzed raw database of 2291 documents (source Scopus)

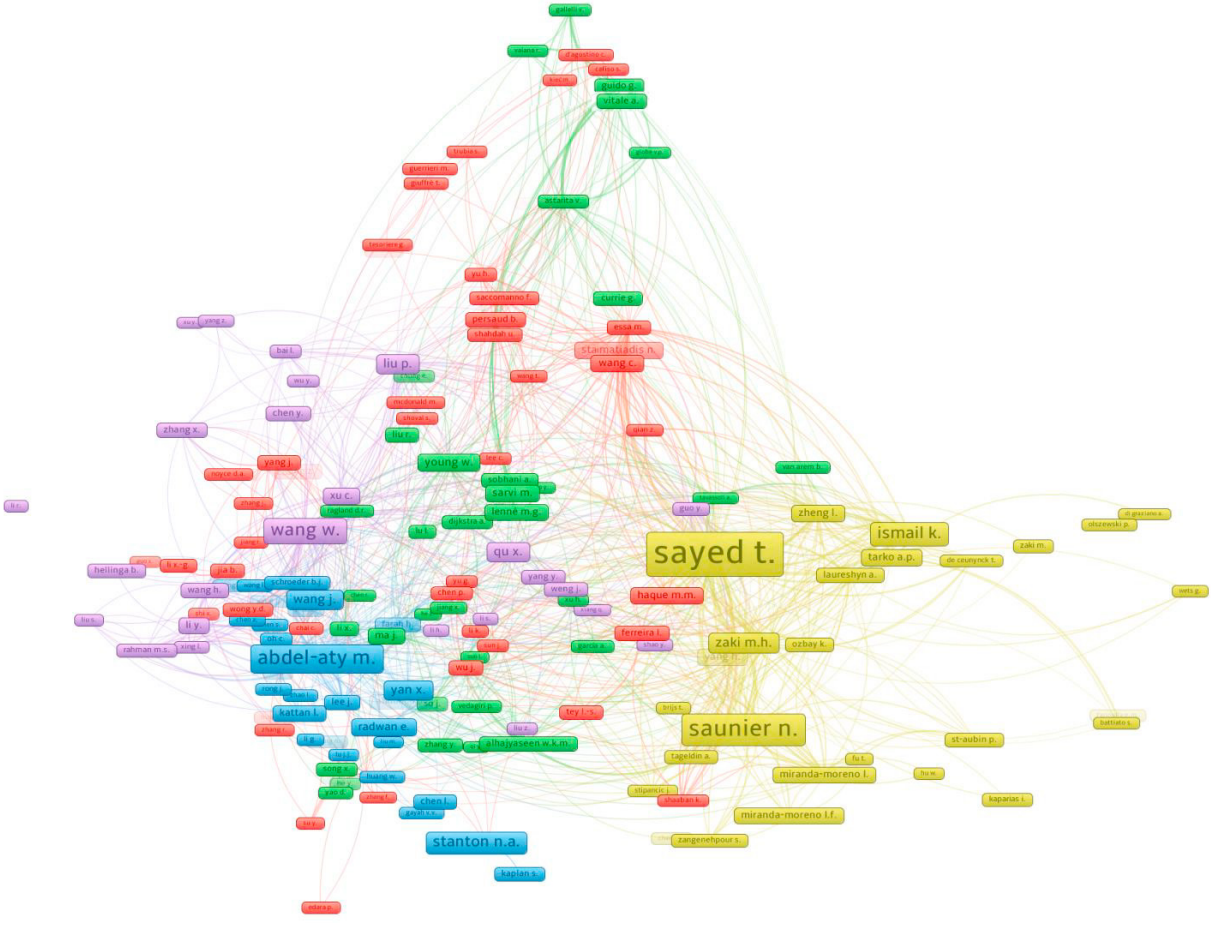

Fig. 7. The most influential authors according to citation connections (Elaborated with Vosviewer in 2020)

We want to excuse ourselves if some important authors have not been given the necessary importance in this analysis given our keyword choice (as an example the paper Laureshyn et al., 2010 has been excluded since it uses the term "encounter" instead of "conflict" in the abstract) or since some other important works (such as Hydén, 1987) are unfortunately not indexed by Scopus.

3. Discussion: can we use simulation to predict crashes?

Relying on the above indexed massive research efforts can we use traffic simulation to predict crashes? Given the mainstream current state of the art it is our opinion that the answer might be no for one simple reason: practically all the commonly used traffic indicators do not consider the existence of conflicts if road objects do not move on overlapping trajectories. This limitation does not allow considering the risks connected with many risky traffic scenarios such as those that would lead to single-vehicle crashes.

Single-vehicle crashes are the elephant in the room of traffic conflict techniques. Collisions with fixed objects in the United States (Holdridge et al., 2005) account for 19% of all reported crashes and they result in 44% of all fatal crashes. According to (Mannering and Lee, 1999): "single-vehicle run-off-roadway accidents result in a million highway crashes with roadside features every year".

Single-vehicle crashes inexplicability indicates that something is missing in the current state of the art of traffic conflict indicators. The problem is a well-known open problem as indicated in (Laureshyn et al., 2010): " However, the problem of integrating single road user events and encounters into one common severity hierarchy needs to be elaborated".

Recent research results (Alonso et al., 2020) based on the use of a new conflict indicator, that can consider conflicts between objects not moving on overlapping trajectories, are pointing to the fact that there is even another big chunk of risk which is lost by assuming that trajectories which do not overlap do not produce risks. In (Alonso et al., 2020) an urban network is studied where the area is divided into zones. For each zone, the number of crashes was known for an interval of time. All zones had at least one crash in the examined period of time. The analysis with traditional conflict indicators such as TimeTo Collision showed zero conflicts (according to SSAM elaborations) in many zones where unfortunately more than one crash (between vehicles) was present. Results of that work show even a situation where the number of crashes in a given area is higher than the number of simulated conflicts (see Fig. 8)!

According to the authors of this paper, the main problem in applying microsimulation to evaluate traffic safety risks relies on the choice of appropriate traffic conflict indicators. It is our opinion that the indicators that have been commonly used cannot be generally applied to every traffic situation and do not take full advantage of the quantity of information coming from microsimulation. The quantity of information and the details on simulated vehicle trajectories calls for new indicators that have not been extensively applied in the past since they are not easy to apply in visually-observed real traffic scenes. The latest version of software SSAM contains an indicator that could be used to overcome the overlapping trajectories limitation: Multiple TTC. Unfortunately, this indicator was never assessed nor used in scientific papers.

Fig. 8. A stretch of a road arterial with parallel lanes where more crashes happened than the number of conflicts generated with SSAM software applied to simulated trajectories.

Some attempts to overcome the overlapping trajectories limitation are present in the following works: (Astarita and Giofré, 2019; Mak et al., 2003; Mohamed and Saunier, 2013, 2018; Tarko, 2020, 2012). Multiple TTC and other

indicators that can solve this limitation are all based on extending the evaluation of conflicts to "deviated" trajectories. Once the "perturbation" of given trajectories is performed conflicts with road-side objects become possible and different methods can be used to define safety indicators and evaluate safety levels
Another limitation of current traffic conflict indicators is that of overlooking the severity of a potential crash. Some attempts to overcome this limitation can be found in (Laureshyn et al., 2017) and in (Astarita and Giofrè, 2020).

4. Conclusion

This paper presents a literature review on the application of traffic simulation for the evaluation of traffic safety levels. The paper helps to identify, with a scientometric analysis, current research-trends: a great number of papers are published every year in this field and some potential limitations of commonly used traffic conflict indicators are still to be resolved. For these reasons, the rhetorical question of the title has still to receive a definite answer.
Possibly the wide-spread on-going diffusion of big databases on both crash data and vehicle trajectories will help to solve limitations and prove the best methodologies after validation on the field.

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