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A methodology for the characterization of urban road safety through accident data analysis

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Abstract

As is known, road accidents essentially depend on four interrelated factors: human behaviour, vehicle efficiency, environmental conditions and the characteristics of the infrastructure. Although the vast majority of accidents is attributable to the first three factors, almost always attributable to improper user behaviour, it is of fundamental importance to try to reduce that part of the risk attributable to the infrastructure. In this research, the problem concerning the assessment of urban road safety in existing roads, in order to identify the dangerous sections on which to concentrate resources to make the functional adjustments deemed necessary, is addressed through the analysis of the accident rate found in operation. In particular, the research proposes a new model that characterizes the intrinsic risk of a urban road infrastructure through the assessment of accidents, disaggregated into different types, with a risk index that is a function of the two most significant variables that represent the accidents: the frequency with which they occur and the severity of the damages produced. The study also provides three aspects for achieving improved urban road safety. The first identifies the critical road sections (blackspots), through the application of the new model to the classic methods of accident assessment. The second defines the functional adjustments necessary to reduce the causes of accidents by comparing the risk of accidents, determined with the new methodology for each type of accident, and the technical characteristics of the road network in question. The third establishes the intervention priorities, based on an economic planning linked to the available budget, among the functional adjustments identified to reduce the risk of accident.

Keywords: Road accident analysis; road accident frequency; road accident severity.

1. Introduction

The high rate of motorization and the limited land area make Italy a country with a high density of vehicular traffic. A contribution that has increased the size of this phenomenon has been given by market strategies and political

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plans that have consolidated over time, such as that of focusing mainly on the transport of goods by road.

For these reasons, the efficiency and safety of the road and motorway network is a fundamental condition for the economic and social development of our country.

It is therefore clear that the problem of the safety of vehicular traffic is nowadays one of the most important aspects in the design and, above all, in the management of a road network. In particular, it is important to assess the risk of an accident that the user faces when traveling on a road infrastructure in operation.

If on the one hand, however, there has been an improvement in the standards of vehicles in order to improve their active and passive safety, on the other hand there has not been a correct adjustment of the services offered by the great existing road heritage.

Therefore, the objectives to be pursued to ensure road safety are: the improvement of the operating conditions of vehicular traffic and the reduction, as far as possible, of the conditions of accident risk.

In order to address both of the objectives mentioned, it is necessary to: have data, measure phenomena, evaluate causes, estimate effects, formulate hypotheses on the links and, finally, have suitable tools capable of providing adequate answers.

The occurrence of a road accident is an event that depends on the interaction of numerous causes that can be collected in the following four factors:

- user behavior (attitude, skills, experience, etc.)
- vehicle characteristics (performance, maintenance, etc.)
- road infrastructure (geometry, paving, signage, intensity and type of traffic, etc.)
- environmental conditions (climate, morphology, exposure, etc.).

As is known from statistical estimates conducted on very large samples, about 80% of road accidents are caused by human error (even if European statistics indicate that man is responsible or jointly responsible for accidents in 95% of cases); while those related to the characteristics of the vehicle are very low (about 2%) and the remainder are attributable, instead, to defects in the road infrastructure OCDE (2016), Shankar et al. (2008).

The most common methodologies, for the characterization of road safety, analyze the accident data found in operation. They are intended to identify road defects and anomalies, which lead drivers to drive errors.

The present research is placed in this area with the aim of evaluating, in quantitative terms, such as the geometric-functional and operational aspects of a road as well as the environmental and climatic ones, together with an in-depth and critical assessment of the accidents detected, can explain the situations with the greatest risk of accidents.

In particular, the report proposes a new method to estimate the intrinsic risk of a road infrastructure, through an assessment of accidents that takes into account their frequency and severity. The purpose is to highlight the events in which the infrastructure was involved in the cause of the harmful accidents.

The ultimate goal is to identify road sections with a high risk of accident on which to intervene with appropriate functional adjustments, to be carried out according to a scale of intervention priorities.

Accident analysis which takes into consideration all the factors involved in the occurrence of an accident are not frequent. This aspect depends above all on the partiality of the data provided by the various sources and on the difficulty of correlating the information obtained with each other.

In Italy, the collection of data concerning accidents is entrusted to ISTAT. This Institute has prepared a form, necessary for the statistical report of road accidents, supplied to all law of traffic Police. The latter are obliged to draw up a report whenever there are injuries and/or deaths in the accident, or when the people involved in the accident request it. The ISTAT model presents information regarding: the type of road, the geometry of the carriageway, the plano-altimetric trend, the state of the pavement, the weather conditions, the type and severity of the accident, the location as well as the time and date on which the accident occurred ISTAT (2016).

In this study, the mechanical reliability of the vehicle has not been investigated as the cause of the accidents because it is difficult to ascertain and above all because each user, aware of the performance of their vehicle, generally assumes an adequate form of driving. In addition, even on human behavior, it should be noted that any situation of maximum risk is in any case uncontrollable, whatever the attention to the design of a road works.

A correct study on the accidentality detected in an existing infrastructure must be conducted on the basis of knowledge of the following aspects concerning type and severity of road accidents:

- Type of accident: frontal collision, side collision, rear-end collision, off-road vehicle, pedestrian hit;
- Severity of the accident: damage to people (all unharmed, dead and injured number).

In addition, with regard to the technical characteristics of a road infrastructure, directly affected by the problems relating to accidents, the following aspects should be noted:

- Geometry: road axis, cross section, path losses;
- Pavement: surface regularity, adherence, dry or wet;
- Functional characteristics: conditions at the edges, intersections, signs;
- Circulation: amount of traffic, type of flow, percentage of heavy vehicles;
- Environmental context: landscape, exposure.

Much of this information can be drawn from existing archives or collected in the field Bonera and Maternini (2020), Barabino et al. (2021), Abay et al. (2013).

2. The techniques of accidents analysis

The study of the procedures adopted in the various civilian countries, where road safety has been tackled for some time, highlights that there is no single methodology for assessing accidents, but different criteria are used that make it possible to obtain different degrees of in-depth analysis Castro et al. (2013).

As is well known, road accident analysis techniques generally follow a direct method, when the number of accidents occurring along a road are simply evaluated; or an indirect method, when the number of accidents is assessed on the basis of the amount of traffic that affected the road itself.

The direct method (DM) provides an absolute accident hazard index which represents the degree of accident that can be associated with a road section.

$$DM = (N/yr) / L$$

Where N = number of accidents recorded in operation in the time (year); L= length of the reference road section taken as a unit (usually the km or hm).

The techniques mentioned, however, do not take into account the different exposure to risk represented by the traffic flows in the individual sections, a non-negligible condition when comparing different roads.

The indirect method that provides a relative hazard index and defines the Accident Frequency Rate (AFR), usually expressed in terms of the number of accidents in relation to 100 million vehicles per kilometer with respect to the reference section.

$$AFR = (N/yr * 10^8) / (365 * L * AADT)$$

Where: N = number of accident recorded in operation in the time (year); AADT = Average Annual Daily Traffic on the reference section; L = length of the section (homogeneous stretch or km).

The accident indicators, defined above, are usually compared with critical threshold values derived from statistical analyzes conducted on a large number of sampled sites. This way of operating, which is usually a quality control method, allows you to check if the detected accidentality is significantly higher than that calculated for roads with similar characteristics, assuming a Poisson distribution for accidents Ahmed et al. (2011).

3. New model for the assessment of accidents: frequency - severity risk index (FSRI)

In this research, a new model has been developed capable of synthesizing the two independent variables that characterize the accidents, the frequency of the events and the severity of the damage produced, in a single parameter called frequency-severity risk index Malyshkina and Mannering (2010). This index allows to weigh individual accidents, highlighting the most recurrent and serious ones, in order to carry out an analysis of accidents aimed at defining the risk of accidents along a road. The first fundamental step is to disaggregate the accidents into homogeneous classes on which to apply the developed technique. This allows to determine the risk of an accident for their different types. This aspect is useful for identifying the possible causes that generated them.

3.1. Frequency Level

A type of accident that is repeated in the same place with a high frequency cannot be considered as an isolated and

/ or fortuitous event, but predictable. Its repeatability can be considered as an indicator that ascertains the existence of a co-participation of the road system in the cause of that type of accident. In fact, when accidents are systematic, it is unlikely that they are only due to the psycho-physical state of the driver or to vehicle defects and breakdowns. They depend from identifiable technical - environmental factors and, therefore, eliminable or that, at least, can be contained.

For these reasons, it is considered appropriate to define the frequency level of accidents as a statistical processing that is able to discern accidental episodes from those potentially induced by the road. This operation takes place by comparing the number of accidents found, disaggregated into different types, with calculated reference thresholds.

Taking into consideration a generic type of accident (the j-th) and dividing the road into n reference sections, the average accident value Xj is defined as the ratio between the sum of all accidents of the j-th type and the total number of sections in which they were found.

With reference to the average value of accidents, three levels of frequency have been hypothesized on the basis of various applications and bibliographic investigations Xie et al. (2014), described in Table 1. Nij indicates the number of accidents of the j-th typology, which occurred in the i-th reference section, and with Xj the previously defined average. It should be noted that if the number of accidents, verified in a road section, exceeds the respective average value Xj by 50%, a systematic nature is recognized in the dynamics of that type of accident to be sought, as a cause, in the technical characteristics of the road infrastructure. On the contrary, if Nij does not reach 50% of Xj it means that there is no correlation between the accident and the infrastructure and it is an occasional event.

In conclusion, the level of frequency, assessed on the basis of the accidents recorded in operation, can be considered inversely proportional to the level of efficiency of a road infrastructure Lord and Mannering (2010).

Table 1. Frequency level classification of road accidents.

Frequency level	Description	Nij= n. accident Xj= Average
Frequent	The accident happens frequently	Nij > 1,5 * Xj
Possible	The accident is possible to happen	0,5 * Xj < Nij < 1,5 * Xj
Occasional	The accident happens occasionally	Nij < 0,50 * Xj

3.2. Severity Level

In this study, the assessment of the severity of an accident is based on the estimation of the severity of the consequences produced to the persons involved in the accident (neglecting damage to vehicles). This, in fact, is the only reliable information that can be extrapolated from the accident data (all unharmed, number of injuries and deaths).

In this regard, the level of severity reached by the single accident was defined by identifying four levels (Table 2) on the basis of the indications obtained from the traffic Police reports, which take into account the number of vehicles involved in the accident and the damage caused to people Zoi et al. (2010).

In Table 2 we distinguish cases that could seem analogous only in appearance. For example, the 2nd level characterizes an accident involving only one vehicle, while in the 3rd level, with equal injuries, more vehicles are involved. A single vehicle, with injuries, defines a marginal situation because the risks fall on a single subject. Several vehicles involved highlight a gravity caused by the infrastructure that causes critical and catastrophic damage.

In the 3rd level, the same severity was assigned for both a fatal accident, which occurred on a single vehicle, and for an accident with injuries on multiple vehicles. In this case, therefore, it has been assumed that the two situations produce comparable amounts of damage Ye and Lord (2014), Kim et al. (2013).

Table 2. Severity level classification of road accidents.

Severity level	Description
Insignificant	Without consequences for people
Marginal	Injuries to one vehicle only
Critic	Died in one vehicle or injured in multiple vehicles
Catastrophic	Deaths and injuries on multiple vehicles

3.3. Frequency-Severity Risk Index

It should be noted that the frequency and severity are independent variables and that both contain information on the risk of an accident. It is known that risk can be defined as the product of frequency and severity (R = F x S), for this reason a synthetic index was introduced that takes into account the combination of the two independent variables: the Frequency-Severity Risk Index (FSRI). This index is defined as a risk index because if applied (multiplied) to the generic accident Nij, the latter is weighted on the basis of the meaning of the two variables which are the frequency, with which that type of accident repeats itself, and the severity of the damage produced.

Accidents that are very frequent and very serious will have a higher FSRI index, the opposite for occasional ones with little consequences for people. The various combinations of frequency and severity levels were assigned indices (Table 3) capable of classifying the risk associated with each generic accident Zou et al. (2014).

The coefficients (or risk indices) have been calibrated both on the basis of the economic damage, produced by each category of accident, and taking into account the frequency of accidents (most likely caused by defects in the infrastructure and, therefore, potentially eliminable). It should be noted that an accident with fatal consequences, into a section with a high frequency of accidents, is rated 32 higher than one without consequences for users, which can be considered fortuitous. The first is referred to as a unit weight accident.

The FSRI, for what has been said, can be considered as a parameter capable of summarizing the variables that characterize an accident caused by deficiencies in the infrastructure in a single coefficient.

The model described does not define a rigid proposal but can be adapted to different circumstances or to different needs and assumptions.

Table 3. Risk classification matrix for determining the FSRI index.

	Severity level			
Frequency level	Insignificant	Marginal	Critic	Catastrophic
Frequent	1/8	1/4	1/2	1
Possible	1/16	1/8	1/4	1/2
Occasional	1/32	1/16	1/8	1/4

4. Quantitative analysis of accidents weighed with the risk index: application to direct and indirect methods

The purpose of this paragraph is to apply accidents weighed with the risk index (FSRI) to the two classic methods of accident assessment (direct and indirect).

The direct method of analysis is applied in the case of road sections: of limited length, subject to the same atmospheric and environmental conditions, used by vehicles of constant average composition and affected by homogeneous daily traffic volumes. The reference unit for this type of method is generally that of km or hm.

In this case, in the direct method, accidents are weighted with the risk index frequency – severity inferred on the basis of the level of frequency and the level of severity. We call NWj the number of accident of the j-th typology weighted with RIFS.

The accident analysis applied separately to the different types of accidents makes it possible to identify the most frequent and serious type from the comparison of NWj values. This is useful to define possible defects in the road system. The total number of accident weighted (NW), on the other hand, represents a global indicator that defines the road sections at the greatest risk of accidents. The reliability of the application obviously depends on the size of the reference sample. The complete parameter is DMW (Direct Method Weighted using NW in the formula).

As already seen, the indirect method of analysis allows you to study the relative danger of a road. It relates the annual number of accidents with the Average Annual Daily Traffic AADT and with the length of the road section (homogeneous both from the point of view of technical characteristics and traffic).

The unit of reference for this type of method is that of the homogeneous stretch or kilometer.

In this case, in the indirect method, the accident frequency rate (AFR) is determined by assigning to the number of accidents N the frequency – severity risk index which is a function of the level of frequency and the level of severity of each accident. We call AFRWj the number of AFR accident of the j-th typology weighted with RIFS index.

The accident analysis applied to the different types of accidents allows to identify, by comparing the AFRWj values, the most frequent and serious category to which the possible defects of the road system are associated.

The total number of AFRW, on the other hand, represents a global indicator that defines the road sections at greatest risk of accident.

The reliability of the application requires extremely precise data regarding the road category, the extent of the length considered, the number of accidents occurred (in a given period) and the relative source of origin. Obviously, it is desirable that the average reference values, with respect to which the frequency levels are defined, are deducted, for the individual categories of accidents, from the average of the rates assessed at a regional or national level on homogeneous infrastructures. This is in order to have a more reliable and generalized response.

5. The localization of blackspots through the application of the FSRI model

The purpose of any modernization project of an existing road infrastructure is to identify entire areas, narrow stretches or particular sections in which a large number of accidents have occurred or have increased over time.

The contribution given by the methodology developed in this study, and described in the previous paragraphs, is to enhance the situations in which a systematic repetition of serious accidents occurs.

This procedure is of general validity and can be applied, as already seen, both to the indirect method, which is aimed at identifying black areas or stretches, and to the direct method, which, instead, is used for the identification of black sections. This aspect, together with an in-depth analysis of the technical characteristics of the road infrastructure aimed at the type of accident at greatest risk of accident, is a valid support for the identification of any defects in the infrastructure. This allows to define the functional adjustments necessary to obtain the improvement of road safety.

The identification of blackspots (points with high accident rates) is then resolved with a subsequent steps analysis adopting the new accident risk assessment methodology in its various forms of application (indirect method, direct method).

Using the terminology of the OECD Committee for Road Research Flahaut et al. (2003), the first step identifies the black areas, ie entire areas of the route, characterized by homogeneous traffic and geometric characteristics, in which they occurred accidents with high frequency and serious consequences.

Within the black areas, with the second step, the black stretchs emerge, that is to say the kilometers with the greatest risk of systematic accidents with harmful consequences for users.

The third step locates, within the black stretchs, the black section (or even critical points or blackspots), i.e. the hectometers, with particular situations or certain characteristics of the infrastructure, to which the causes of accident are attributed.

However, it should be noted that for a correct assessment of the critical point identified, it is also necessary to examine the road sections that precede it because the causes of an accident always arise before the point of impact.

6. Identifying of the functional adjustments

The localization of accidents is a fundamental step in the study of road safety problems. However, it is not sufficient to define the causes of accidents, attributable to the infrastructure, and to determine the functional adjustments interventions necessary to reduce the risk of accident.

For the identification of potential road defects, it is useful to correlate information on accidents with the technical and functional characteristics of the infrastructure. This aspect has the purpose of defining the objective factors, that is intrinsic to the road and not related to the driver.

The examination of the types of accidents at greater risk and the evaluation of the maneuvers, trajectories and types of collisions associated with the same types of accidents, are important to define, in light of the technical characteristics of the infrastructure and any geometric-functional anomalies detected, the necessary interventions to eliminate potential defects in the road system.

More precisely, in this study it is proposed that the definition of functional adjustments derives from the comparison between the characteristics of the road system (evaluated through the analysis of the infrastructure, traffic and environment) and the risk of accidents assessed through the weighed accident rate with the FSRI risk index.

It is important to note that it has been observed that improvement interventions, carried out in the road sections classified as dangerous, can lead to an increase in accidents in adjacent sites and a significant reduction in the perception of risk by the user (favoring driving behavior less cautious).

The phenomenon, which takes the name of accident migration, must in any case be considered in the overall assessment of the effects produced by the proposed countermeasures. For this reason, the decisive intervention should not be thought of only in correspondence with the individual critical points (blackspots) identified, but must be implemented, in due form, taking into account the entire road section in question. More precisely, it is essential to analyze the geometric and functional characteristics of the road as a whole, not limiting itself to examining the individual specific negative characteristics.

Please note that there are various techniques in the literature for identifying the causes of accidents such as the Fuzzy analysis Barua et al. (2016a) or the methodology of Artificial Neural Networks Barua et al. (2016b). These techniques make it possible to relate the different roles that each variable, concerned and involved in the accidents, assumes in the causes of the accidents themselves.

7. Determination of intervention priorities

The choice of functional adjustment, for the improvement of road safety, must be dictated, as in any other field, by a compromise between the efficiency and economy of an intervention Eluru and Bhat (2007).

To take these aspects into account, the Intervention Priority Index (IPI) was introduced as follows:

$$IPI = NWij / CI$$

where is it:

NWij = number of accidents weighed with the FSRI risk index, recorded in the i-th critical point and belonging to the j-th type of accident.

CI = Cost of the functional adjustment intervention.

It is defined as the ratio between the number of NWij accidents and the cost of the intervention (CI - expressed in euro) which is assumed to be capable to eliminate the causes that caused the accidents in question.

The value of NWij can contain accidents of different types if the causes that produced them are removed with the same functional adjustment intervention.

The IPI index allows you to compare different intervention proposals and allows you to choose the one that combines high effectiveness with minimal cost. The higher the IPI, the better the solution proposed.

The definition of a functional adjustment, for one or more types of accident, is based on the exact discovery of the causes that produced the accidents and on the identification of intervention solutions capable of eliminating the deficiencies present in the infrastructure in question.

In the calculation of the IPI it is assumed that the adjustments are actually suitable for solving the problems of accidents in the involved sites, hypotheses that only future monitoring can validate Cameron and Trivedi (1986).

Conclusion

In this paper, the problem of road safety has been addressed by analyzing the accident data recorded in operation.

To assess the intrinsic risk present in a road infrastructure, a methodology was proposed that allows you to weigh accidents by attributing, to each, a Frequency-Severity Risk Index (FSRI). This index is defined on the basis of the frequency with which accidents are found and the severity of the damage resulting from them.

The developed methodology, if applied to the classic methods of accident analysis (direct and indirect method), allows to locate the critical points characterized by a repetitive and harmful accident. It also allows you to determine the priority of intervention through a cascade investigation performed on homogeneous sections, kilometers and hectometers. This allows the identification of black areas, black stretchs and black sections respectively.

The application of the methodology, to the individual types of accident, is of support for the determination of the functional adjustments necessary to remove the causes of accidents and for the definition of the most suitable interventions, according to a scale of priorities, according to the technical characteristics of the road network in question.

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