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Original Research Paper

Safety ranking definition for infrastructures with high PTW flow

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HIGHLIGHTS

- PTW accidents are analyzed by suitable indicator, including the innovative safety potential (SAPO).
- SAPO determines critical road sections and the range of resources which could be saved.
- SAPO is usually applied to rural areas and was adapted to describe the phenomena in urban areas.
- In synergy with the accident rate, SAPO enables to improve the accuracy of road safety analyses.

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ABSTRACT

Powered two-wheelers (PTWs) provide a suitable mode for a large portion of population in many cities due to rider's personal convenience and the vehicle supposed easiness of manoeuvring. At the same time PTWs present serious safety issues compared to other motorized vehicles. This paper reports the main outcome of study carried out in Rome, where this mode is very popular and assesses the economic efforts to make infrastructure safer for PTWs. The methodology, extensively described in the paper, includes three steps: the accident analysis, the development of economic indicators of accidents costs, the maintenance priority. In the first step the location of the PTWs local accidents are identified, then the accidents are analyzed by means of the suitable indicators and, among these the safety potential (SAPO). Lastly, according to the results of the analyzed indicators the need of infrastructure maintenance will be defined. Usually SAPO is applied to rural areas, but here it has been adapted to describe the phenomena of the urban area in hand. As a result, the estimation of the saving potential to improve the infrastructure safety levels, thus reducing the amount of accidents, is presented, along with recommendations on how to upscale the SAPO at city level.

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1. Introduction

As a mode of urban transportation, powered two-wheelers (PTWs), i.e. motorcycles, mopeds, and scooters, encompass a great variety of vehicles and they are used for a wide range of purposes. Although stricter safety measures for riders have been progressively enforced through the years, PTWs accidents rates are still high worldwide.

According to the data of World Health Organization (WHO), 2015, the dominance of the mode and the poor compliance to safety requirements contribute in many cases to a high fatality rate. But high PTWs ownership rates, poor enforcement of regulations and controls are significant but not exhaustive explanations to that and for a long time in scientific and grey literature emphasis was also placed on low income levels as additional contributing factors: "road accidents disproportionately affect the poor, making road safety an economic development imperative. Most of the victims of road accidents aren't even in a motor vehicle. Pedestrians, cyclists and motorcycle riders are the most vulnerable road users and account for the majority of traffic deaths in low and middle income countries" (World Bank, 2009).

But in Europe, where PTWs are not the dominant mode, reasons for the accidents national rates must be searched elsewhere. ERSO statistics and others (European Commission, 2015a; Musso and Corazza, 2010) confirms that PTWs motorization rates are higher in the southern areas, as reported in Fig. 1, where Greece, with 128 mopeds and 142 motorcycles per 1000 inhabitants, is ranked first. But the very high ownership rates of motorcycles in Switzerland, Germany and Austria or of mopeds in Finland seem to debunk the myth of milder climate as a contributing factor to the PTWs usage.

Fig. 1 also highlights that the fatality rate generally decreased in the last decade; on the one hand, the progressive enforcement of stricter regulations and controls can be credited for this. But on the other hand, the 2011–2012 overall economic downturn has decreased the sale, and consequently, the fleet of PTW across Europe (International Transport Forum, 2015), thus contributing to reduce the role of the mode in the mobility patterns.

Nevertheless, road accidents still take a significant toll on lives every year in Europe. To this aim, it is worth reminding that, after the 1968 Vienna Convention on Road Traffic, road accidents are defined as such for any events involving at least one road vehicle and occurring on a road open to public circulation, and in which at least one person is injured or killed (in 30 days after the event).

PTW fatalities account for 18% of the total number of road deaths in the EU-28 countries in 2013 (European Commission, 2015b); among them, 15% come from motorcycles and 3% from mopeds fatal crashes. In the same year, if compared to passenger cars, per 100,000 registered vehicles, the fatalities consisted in respectively 11 deceased motorcyclists versus 5 deceased car occupants (European Commission, 2015b). To be noted that motorcycling is the mode of transport for which the number of fatalities decreased least between 2005 and 2014 (European Commission, 2016), as reported in Fig. 2.

Although between 2005 and 2015 a significant reduction occurred in the PTWs fatality rates in Italy (European Commission, 2016), the phenomenon is still far from being negligible (52,920 events in 2014). Highest occurrence are recorded in some of the most populated regions in northern and central Italy, Tuscany, Latium (where Rome is located),

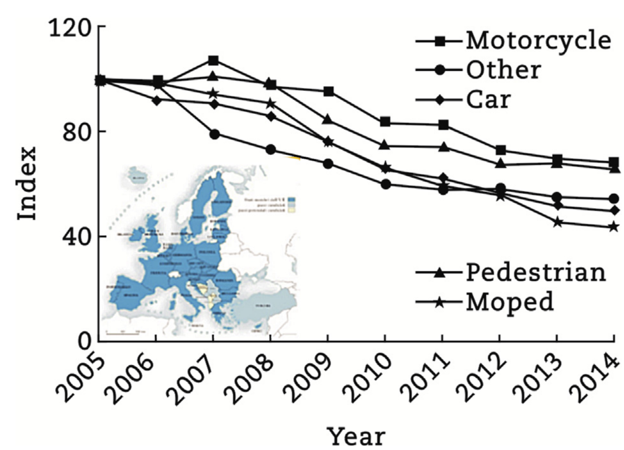


Fig. 2 – Index (100 in year 2005) of motorcycle and moped fatalities compared with other modes of transport in the EU member states, 2005–14 (European Commission, 2016).

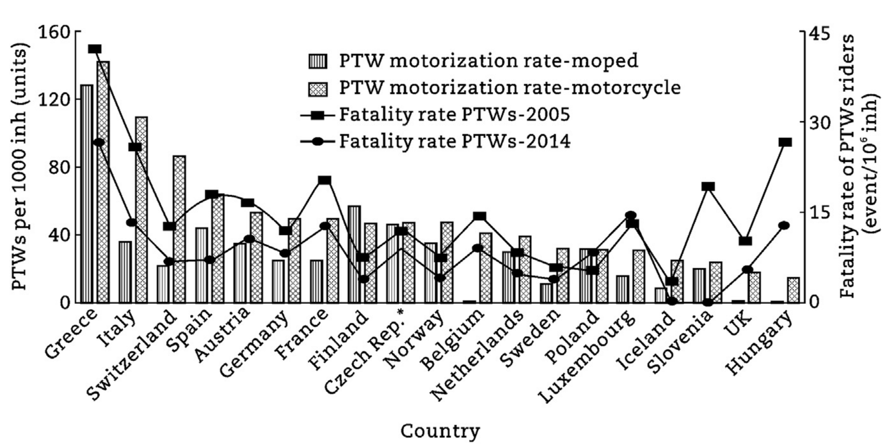


Fig. 1 – PTWs fatalities rates in selected European Countries, year 2015 (* is year 2013).

Lombardy and Liguria, but fatality rates in percentage are below the national threshold (29.9% of all events). On the contrary, higher fatality rates are equally recorded in northern (Piedmont, Veneto and Trentino Alto Adige, the latter with the highest record: 41% of all the events) and southern regions (Campania and Apulia) (Automobil Club Italia (ACI), 2014).

Scientific literature provides a wide array of methods and indicators to assess road safety (Choueiri et al., 1994; Compagne, 2008; Elvik and Vaa, 2009; Hakkert and Gitelman, 2007; Morsink et al., 2007) just to mention a few of the most cited references), but virtually all of them have been formulated with generic drivers' behaviour in mind, not PTW riders', or for general environments. Also grey literature (typically urban road safety plans enforced at local level, or research reports) usually describes the accident phenomena using general road safety indicators and/or stresses the need to develop more comprehensive indicators about PTWs (VicRoads, 2013; Transport for London (TFL), 2012, again just to mention some of the most cited references).

However, riders' behaviour, especially in terms of perception of safety differ from those of drivers' under many points of view, and not only because of the different driving conditions such as no separation between rider and his/her driving environment, vehicles' smaller size and the easier manoeuvrability (Yannis et al., 2007). Moreover, the supposed, easier manoeuvrability is behind the general underestimation of the skill required to ride a motorcycle. At the same time, riders are aware that motorcycles are more dangerous than cars and that they perform a potentially hazardous activity; their safety largely depends on their own behaviour (Avenoso and Beckmann, 2005), but they tend to marginalize the risk because they have a strong belief in their riding ability (Natalier, 2001). They even tend to develop their own concept of risk, very close to what has been described by the theory of risk homeostasis: indeed, most riders are convinced to have a kind of fixed level of acceptable risk, i.e. an own “decision making skill for risk reduction” (Wilde, 2005). This and the statement that “motorcyclists learn by observing and interacting with other motorcyclists” (Njå and Nesvåg, 2007) are maybe the key element to explain why risky or offensive behaviour are so common among the PTWs users, and why specific analysis patterns are required when dealing with riders' safety.

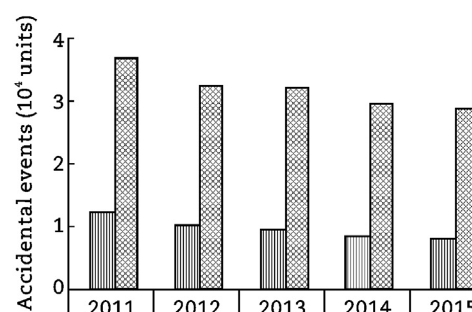
2. The Rome contemporary situation

In Italy, PTWs accidents take place mostly in urban areas and Rome is no exception. In this city, the estimated number of two-wheelers is about one for every five inhabitants (Rome Municipality, 2009). PTWs are part of the mobility of everyday life: more than half of the overall number of trips by motorized two-wheelers occurs in a distance range between 2 and 11 km (just as for passengers cars), and even for walking distances (0–1 km) the use of PTWs is still an option (ATAC, 2006). This, the high local PTWs number of accidents (Fig. 3) and the high fatality rate (Fig. 4), highlight the importance of appropriate strategies to achieve safer mobility patterns. A focus on accidents occurred between 2010 and 2012 highlighted that the amount of injured and deceased riders is virtually equal to that of drivers, respectively 42.2% and 43.8% and differences in the locations of accidents can be detected. The central areas and namely the 1st and the 2nd districts are those where the majority of PTWs accidents occur, as evidenced by the accident density referred to area (Fig. 5(a)) and population (Fig. 5(b)) of each district.

The two districts are rather different. The 1st district coincides with the city centre: a compact setting and unique historic built environment with world-wide famous landmarks and very mixed land use; the area is in part daytimes and nighttimes access-restricted to passenger cars (the so-called limited traffic zone – LTZ), but not to PTWs, and in part pedestrianized.

The 2nd district represents a typical Roman medium-to-high income, high density area, where residential and business activities prevail. The built environment is also high-quality, mostly with low-rise buildings (five stories in average), planted strips and plenty of vegetation, full provision of sidewalks, which make them ideal for walking.

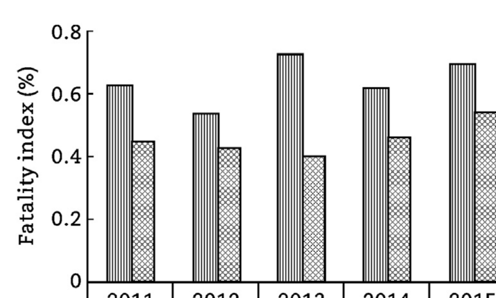
Both districts can be considered valid test fields to analyse PTWs accident trends. A preliminary study on PTWs accidents phenomena was focused on the 1st district (Corazza et al., 2016) but its built environment premium value and sensitive



Year	2011	2012	2013	2014	2015
Events involving PTWs	12382	10213	9484	8398	8203
Total events	37056	32612	32269	29667	28913

Year

Fig. 3 – Total number of accidents and the number of PTW's accidents occurred between 2011 and 2015 in Rome.



Year	2011	2012	2013	2014	2015
PTW fatality index	0.630	0.539	0.728	0.619	0.696
Total events fatality index	0.45	0.43	0.40	0.46	0.54

Year

Fig. 4 – Accidents fatality rate for PTW and the other vehicles.

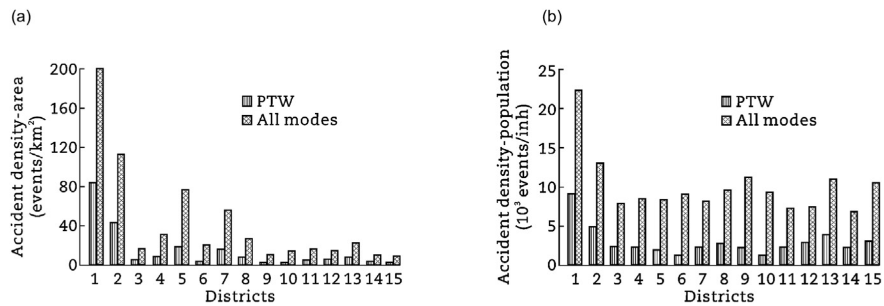


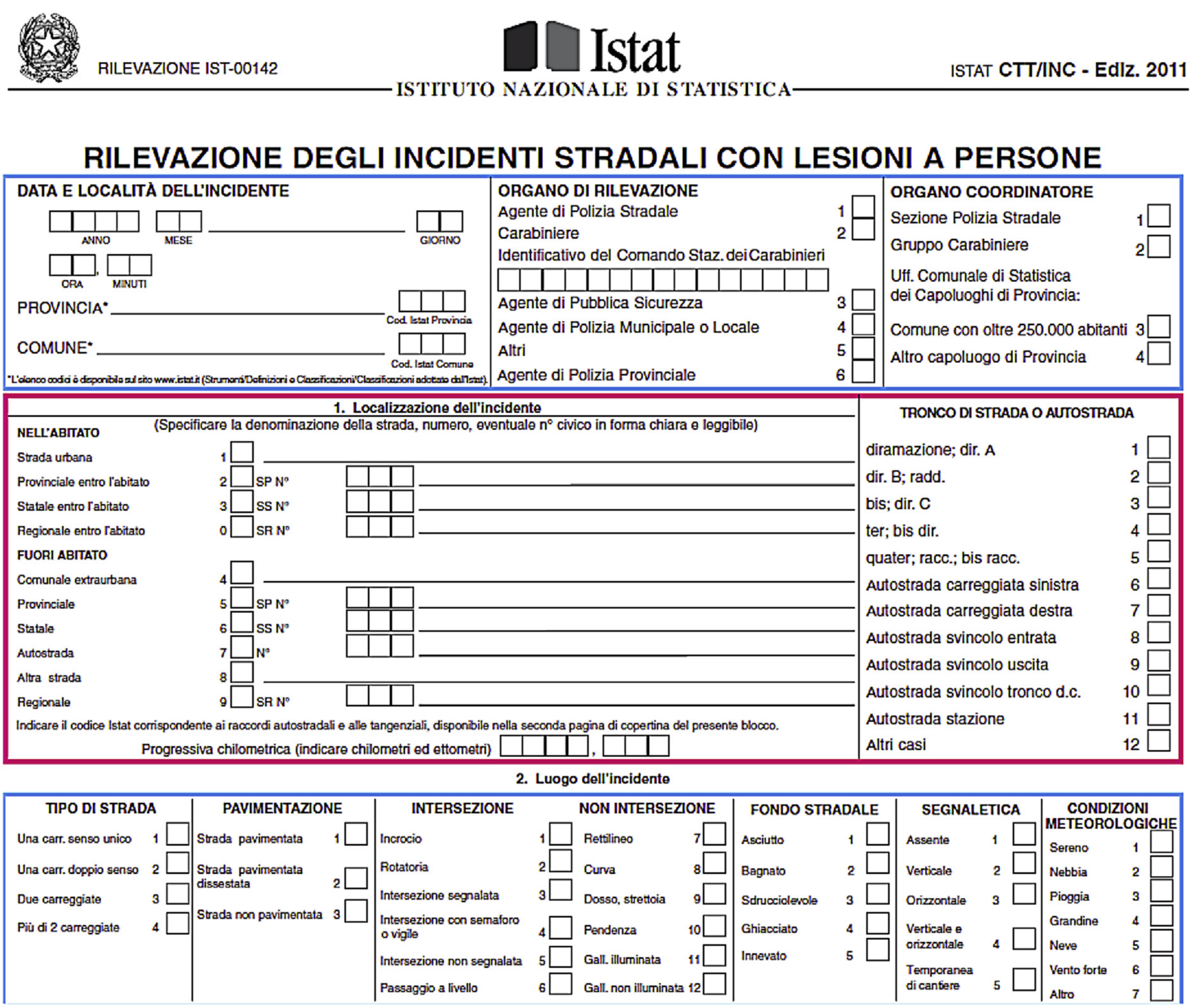
Fig. 5 – PTW accidents density per district in Rome (2015). (a) Area. (b) Population.

features and the extended LTZ regulation enforced for passenger cars only led to conclusions just partly transferable to the other areas of the city, and in general to other urban areas across Europe where the PTWs role is not negligible.

This is the reason why, the current study was focused on the 2nd district, more similar to many consolidated urban districts in Europe, and therefore more generally applicable for the analysis of the PTWs accidents phenomena. The study on a 2nd district main collector, Via Salaria, reported in the next sections serves, as a case in point for assessing recurring problems of main urban roads with large traffic flows, in spite of their modest capacity (usually due to restricted sections due to the built environment constraints).

3. Methodological approach

The methodological approach started by the consideration of the aggregated indexes, usually available in grey literature, i.e.


RILEVAZIONE IST-00142

Istat

ISTITUTO NAZIONALE DI STATISTICA

ISTAT CTT/INC - Ediz. 2011

RILEVAZIONE DEGLI INCIDENTI STRADALI CON LESIONI A PERSONE

DATA E LOCALITÀ DELL'INCIDENTE

ANNO MESE GIORNO

ORA MINUTI

PROVINCIA* Cod. Istat Provincia

COMUNE* Cod. Istat Comune

*L'elenco codici è disponibile sul sito www.istat.it (Strumenti/Definizioni e Classificazioni/Classificazioni adottate dall'Istat)

ORGANO DI RILEVAZIONE
Agente di Polizia Stradale 1
Carabiniere 2
Identificativo del Comando Staz. dei Carabinieri
Agente di Pubblica Sicurezza 3
Agente di Polizia Municipale o Locale 4
Altri 5
Agente di Polizia Provinciale 6

ORGANO COORDINATORE
Sezione Polizia Stradale 1
Gruppo Carabiniere 2
Uff. Comunale di Statistica dei Capoluoghi di Provincia:
Comune con oltre 250.000 abitanti 3
Altro capoluogo di Provincia 4

1. Localizzazione dell'incidente
(Specificare la denominazione della strada, numero, eventuale n° civico in forma chiara e leggibile)

NELL'ABITATO
Strada urbana 1
Provinciale entro l'abitato 2 SP N°
Statale entro l'abitato 3 SS N°
Regionale entro l'abitato 0 SR N°
FUORI ABITATO
Comunale extraurbana 4
Provinciale 5 SP N°
Statale 6 SS N°
Autostrada 7 N°
Altra strada 8
Regionale 9 SR N°

Indicare il codice Istat corrispondente ai raccordi autostradali e alle tangenziali, disponibile nella seconda pagina di copertina del presente blocco.

Progressiva chilometrica (indicare chilometri ed ettometri)

TRONCO DI STRADA O AUTOSTRADA
diramazione; dir. A 1
dir. B; radd. 2
bis; dir. C 3
ter; bis dir. 4
quater; racc.; bis racc. 5
Autostrada carreggiata sinistra 6
Autostrada carreggiata destra 7
Autostrada svincolo entrata 8
Autostrada svincolo uscita 9
Autostrada svincolo tronco d.c. 10
Autostrada stazione 11
Altri casi 12

2. Luogo dell'incidente

TIPO DI STRADA
Una carr. senso unico 1
Una carr. doppio senso 2
Due carreggiate 3
Più di 2 carreggiate 4

PAVIMENTAZIONE
Strada pavimentata 1
Strada pavimentata dissestata 2
Strada non pavimentata 3

INTERSEZIONE
Incrocio 1
Rotatoria 2
Intersezione segnalata 3
Intersezione con semaforo o vigile 4
Intersezione non segnalata 5
Passaggio a livello 6

NON INTERSEZIONE
Rettilineo 7
Curva 8
Dosso, strettoia 9
Pendenza 10
Gall. illuminata 11
Gall. non illuminata 12

FONDO STRADALE
Asciutto 1
Bagnato 2
Sdrucciolevole 3
Ghiacciato 4
Innevato 5

SEGNALETICA
Assente 1
Verticale 2
Orizzontale 3
Verticale e orizzontale 4
Temporanea di cantiere 5

CONDIZIONI METEOROLOGICHE
Sereno 1
Nebbia 2
Pioggia 3
Grandine 4
Neve 5
Vento forte 6
Altro 7

Fig. 6 – Italian official template to collect data on road accidents.

the total amounts of deceased and injured and the total amount of events, from which it was possible to calculated the injured (100 injured/events) and fatality (100 fatalities/events) rates and eventually the related severity rate (100 fatalities + injured/events); all were calculated from data supplied by the municipality official databank (Rome Municipality, 2016). These parameters allowed to identify the area with the highest accident levels in the city of Rome, and likewise, within this area, the road (or the links) with the lowest road safety level.

Then, more indicators were calculated, so to include in the safety analysis also the road geometric and operational features. More specifically, to comply with the Italian regulations (i.e. the Decree 11.3.2011 on road safety management) and national standards (CNR, 1995), the indicators A_r and SAPO (further elaborated) were introduced, to perform a local accidents analysis and identify priorities in the management of road safety interventions, respectively.

Recent studies for the Rome case (Corazza et al., 2016; Sgarra et al., 2014) introduced the possibility to "customize" the so-called safety potential or SAPO index, k€/km*year, to the PTWs events. As applied in some countries for general analysis on road safety and widely described in scientific literature (Cambon and Ganneau, 2005; Nguyen et al., 2013, 2016, Pukalskas et al., 2015); SAPO was also enforced by the Italian "guidelines on road safety management" (as reported in the National Decree 2.5.2012), as a key indicator within the Network Safety Management (NSM) assessment procedure (Ministero delle Infrastrutture e dei Trasporti (MIT), 2012). NSM provides a dedicated methodology to analyse existing road networks, with the aim to enable road administrations to determine road sections with a poor safety performance. In this frame, SAPO enables to draw a priority list of road links for which is of the utmost importance to intervene to improve safety, by assessing the consequent expected reduction of accidents and costs to these associated.

As previously mentioned, the Italian regulations also include the calculation of an additional indicator: the accident rate A_r (CNR, 1995), and consequently this study included both SAPO and A_r in the assessment of the safety levels along a 2nd district main collector: Via Salaria. This is a typical example of an urban road performing not according to capacity, and thus resulting into an unsafe link in the local network. The focus on Via Salaria enables to provide remarks on the applicability of the method and eventually draw conclusions on the upscaling of results.

The analysis was performed considering accident data from 2011 to 2015 involving PTWs available at the Rome Municipality open data project official databank (Rome Municipality, 2016), collected by the police and validated by the Italian Institute of Statistics. For each event (corresponding to accident as defined in the Vienna Convention previously mentioned), spatial location information and a set of standard alpha-numeric attributes are provided, in order to fully describe operational conditions and circumstances of each accident. More specifically typical alpha-numeric attributes are

- *Location*
- *Accident type*
- *Type of involved vehicles*
- *Accident circumstances*
- *Vehicles characteristics*
- *Type of involved consequences (persons and vehicles)*

As an example the official template including the alpha-numeric attributes above mentioned is reported in Fig. 6.

The availability of the spatial information for each accident (group of alpha-numeric attributes associated with location and accident type) enables to determine the position of each event along the road, which is represented by a graph, to highlight the relation between accident and road. The associated Geographic Information System (GIS) enabled to create a black spot map (Fig. 7), where PTWs accidents are identified (by the group of alpha-numeric attributes associated with type of involved vehicles and vehicles characteristics) and located and consequently road sections and links with high accident rates highlighted (by the group of alpha-numeric attributes associated with consequences).

GIS-referencing univocally interrelates the event to the closest topological elements of the road graph (links or nodes), by means of an algorithm based on the nearest distance criteria, considering a buffer area of 15 m from the road axis. The Via Salaria graph analyzed was divided into sections, with homogeneous characteristics in term of geometrics features (amount of lanes, types of carriageway, location and amount

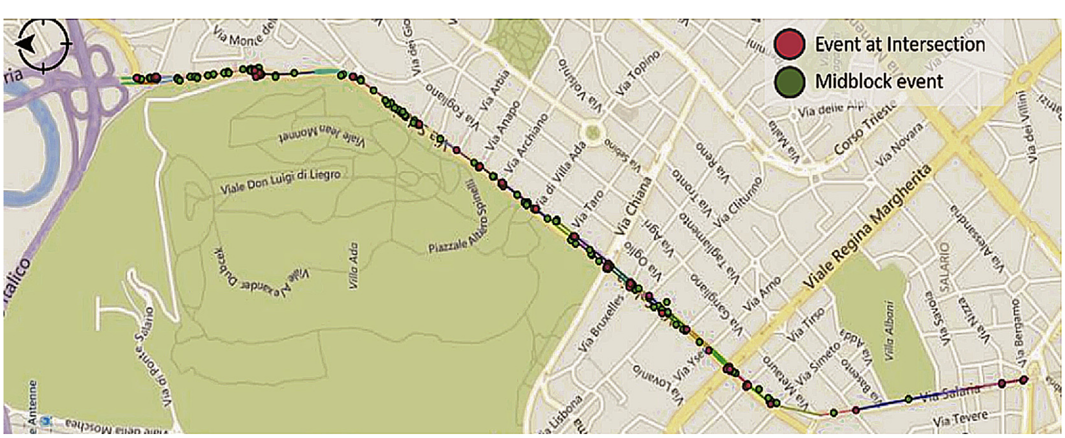


Fig. 7 – Via Salaria PTW black spot map.

of intersection) and traffic conditions (average daily traffic flows), as in Fig. 8.

In order to investigate the accident phenomena along Via Salaria, the above mentioned indicators, the accident rate A_r, and the SAPO index, were calculated for each section and node.

A_r (event/(veh·km)) is defined as the amount of events occurred on the road section i during a given period (in years) t, per the total traffic flow and the road section length. A_r can be calculated for each considered link as follows.

$$A_r = \frac{10^6 N_i}{365 l_i \sum_t \mathrm{ADT}_{i,t}} \tag{1}$$

where N_i is the amount of events (units), l_i is the road section length (km), $\mathrm{ADT}_{i,t}$ is the average daily traffic flow (CNR, 1995).

Similarly, the accident rate A_r at nodes, i.e. at intersections, can be calculated as

$$A_r = \frac{10^6 N_i}{365 \frac{1}{2} \sum_t \sum_j \mathrm{ADT}_{(i,j),t}} \tag{2}$$

In order to classify the road according to A_r, the Italian regulations (CNR, 1995) define two threshold values A_{up} and A_{low}, respectively for the upper and lower limits

$$A_{low} = A_a - K\sqrt{\frac{A_a}{M_i}} - \frac{1}{2M_i} \tag{3}$$

$$A_{up} = A_a + K\sqrt{\frac{A_a}{M_i}} + \frac{1}{2M_i} \tag{4}$$

$$A_a = \frac{10^6 \sum N_i}{365 \sum_i \sum_t l_i \mathrm{ADT}_{i,t}} \tag{5}$$

$$M_i = 365 l_i \sum_i \mathrm{ADT}_{i,t} (\mathrm{veh/24h}) \tag{6}$$

where A_a is the average accident rate, K is a constant of the Poisson distribution, $K = 1.645$ with an error probability of 10%.

Considering these thresholds, each link and each intersection can be classified as

- low accident rate if $A_r < A_{low}$
- medium accident rate if $A_{low} < A_r < A_{up}$
- high accident rate if $A_r > A_{up}$

In Fig. 9, the links and the intersections of Via Salaria with a low accident rate are highlighted in green, those with a medium accident rate in yellow and those with a high accident rate in red.

The SAPO index (Ministero delle Infrastrutture e dei Trasporti (MIT), 2012) is defined as the accident costs per kilometer of road length (cost density) that could be reduced if a road section would be (re)designed according to accident prevention best practise. The higher the SAPO, the more societal benefits can be expected due to the associated improvements on road safety (Ministero delle Infrastrutture e dei Trasporti (MIT), 2012).

SAPO can be calculated as

$$\mathrm{SAPO} = \mathrm{ACD} - \mathrm{BACD} \tag{7}$$

$$\mathrm{ACD} = \mathrm{AAC}/L \tag{8}$$

where ACD is the average density of accident cost related to the road section or intersection per length, L is the road section length in km, AAC is the average annual cost of accident, calculated as the product of number of injuries and fatalities occurred on the road section and the related cost, according to the Italian guidelines to assess social costs related to road accidents (Ministero delle Infrastrutture e dei Trasporti (MIT), 2011).

BACD is the basis accident cost density and represents the expected average annual amount of road accidents per kilometer and per severity levels. It is calculated as

$$\mathrm{BACD} = \frac{\mathrm{BACR} \cdot \mathrm{ADT} \cdot 365}{10^6} \tag{9}$$

where BACR is the basis accident cost rate which defines different costs for accidents occurred in different types of roads, and related to different types of road users, in this instance the riders in the Via Salaria case study.

Sections eligible for the SAPO calculation were those with at least the occurrence of one event per year. The calculation of SAPO required in this case an adaptation process, being this index designed for general assessment. For example, an initial

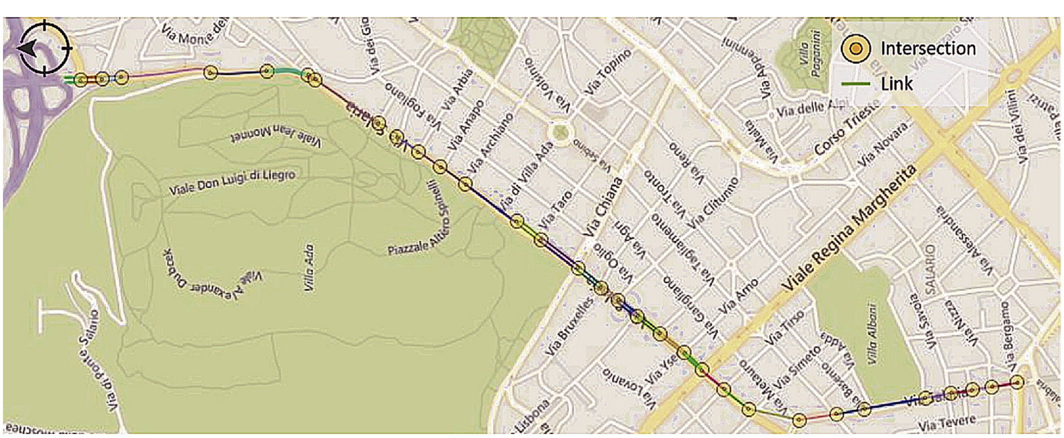


Fig. 8 – Via Salaria sections, with homogeneous characteristics.

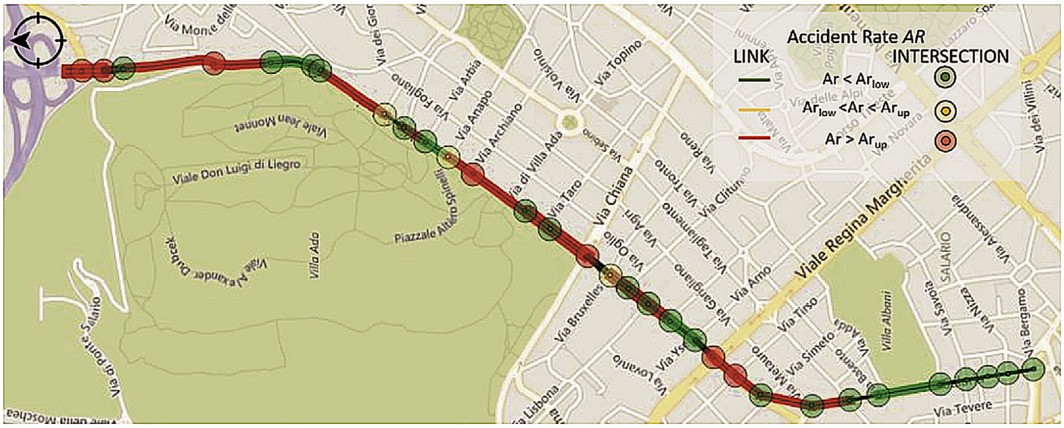


Fig. 9 — Classification of links and intersections on Via Salaria according to A_r.

difficulty in calculating SAPO was to adapt its parameters to the urban context, as SAPO was initially designed to be applied to the trans-European road network - TEN according to the European Directive 2008/96 EC, and further recommended for wider applications, including the urban network.

A typical example in translating the application to urban areas was the difficulty in assessing the appropriate length of road sections: the Italian guidelines recommend 100 m as a minimum, which is appropriate in non-urban environment, but hardly applicable in compact and consolidated city areas. To cope with such unsuitability, the Italian guidelines (Ministero delle Infrastrutture e dei Trasporti (MIT), 2012) enable road designers and analysts to be flexible in assessing the most suitable length according to the local geometric and operational features, especially when in case of consolidated urban areas. In this case the topographical features of the Via Salaria area suggested to set for this parameter a minimum value of 40 m. Similarly, an adaptation of the BACR parameter was necessary. The accident cost rates in the Italian scientific literature are defined mostly for passenger cars, motorways and rural roads, as reported in Table 1, therefore far from being applicable to Via Salaria. As a reference, a value provided for a comprehensive study on traffic external costs in the Flemish Region (Delhaye et al., 2010), reported in the second column of Table 1, has been considered. The values seemed the most suitable for the Via Salaria case and therefore used in this assessment. This study enabled to estimate a BACR equal to 400 Euro/1000 veh*km for every single accident occurred on urban roads and involving PTWs.

According to all of the above, SAPO was calculated for the identified sections, which were ranked using a quantile distribution according to a three-class criterion reported in Fig. 10. This proved to be the most suitable for a comparison with A_r, because it enabled to highlight an average value, comparable to A_a.

Intersections were assessed through the average annual cost of accident - AAC (in Euro/1000*year) calculated as the product of number of injuries and fatalities occurred on the road section and the related base cost, according to the Italian guidelines to assess social costs related to road accidents (Ministero delle Infrastrutture e dei Trasporti (MIT), 2011). Also in this case the accident phenomena were analyzed using a quantile distribution on three classes, in order to provide a priority ranking of interventions based on the expected cost/benefit ratio for each intersection considered.

4. Results

Considering the resulting distribution and the priority ranking of interventions based on the SAPO application, road segments characterized by the highest potential in terms of accident reduction are included in the third tercile.

Table 1 — BACR base accident cost rate adaptation.

Users	Roads	Ministero delle Infrastrutture e dei Trasporti (MIT), 2012 (Euro/1000 veh*km)	Delhaye et al., 2010 (Euro/1000 veh*km)
Passenger car	Urban roads		11.2
	Other non urban roads	24	10.0
	Motorways	7	3.1
Truck	Urban roads		38.5
	Other non urban roads		45.3
	Motorways		14.4
Motorcycle	Urban roads	400	169.5
	Other non urban roads		160.3
	Motorways		51.7

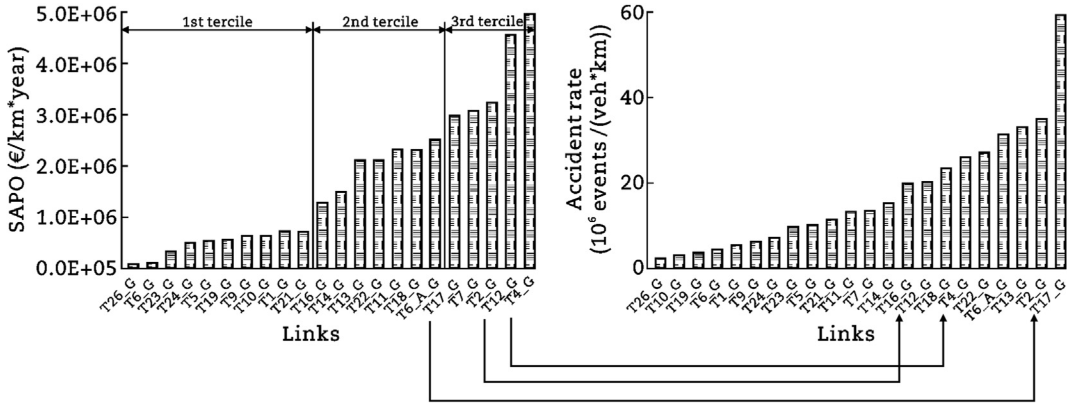


Fig. 10 – Classification of links on Via Salaria according to SAPO (left) and A_r (right).

The analysis shows that the SAPO is more sensitive to the amount of events occurred in the shorter segments. This is the reason why the selection of an appropriate range for the *L* parameter is of the utmost importance: in this study the reference value of 40 m proved to be highly suitable to correctly evaluate the accident phenomena in an urban, compact environment.

Fig. 10 shows respectively, on the left and on the right, the results of SAPO and A_r calculated in all the sections of Via Salaria. It is to be noted that the links with the highest SAPO values do not coincide with those with the highest A_r values. In fact, the two indexes, although complementing each other, provide two different information: A_r represents the actual accidental phenomena while SAPO represents the prospective benefits coming from a risk mitigation intervention. Fig. 11 shows the scenario resulting from the simultaneous overlap of SAPO and A_r assessment on Via Salaria, and finally Fig. 12 shows the scenario for Via Salaria also including the rates the intersections are provided with. To prioritize interventions, the combination of SAPO (or AAC) and A_r was thus considered, as reported in Fig. 13(a), by an Element Safety Ranking Matrix (ESRM). Highest importance is attached to SAPO outcomes because they provide information on the maximum achievable benefits. In the ESRM, elements with both indicators in the red field (Fig. 11) are rated as "high". Lower rates are considered when the SAPO codes are yellow or green. Within the same SAPO class, the intervention priority is set by A_r level.

Fig. 10 enables to assess similarities and differences at local level (but scalable at network size) between SAPO and A_r, for instance the segment T4 (Fig. 10) has the higher value of SAPO, corresponding to the maximum expected benefit, while in the A_r distribution it has an medium value referred to the accident rate thresholds.

The SAPO assessment also provides directions for the mitigation interventions. These should be chosen also considering the mutual connection and the influence between adjacent links and intersections. Therefore, in order to consider the conditions of the adjacent elements, the Network Safety Ranking Matrix - NSRM reported in Fig. 13(b) was built. The NSRM resumes the significant combinations of links and nodes rating on the road. For each row, links and intersections highlighted in red are those with the highest values of SAPO or AAC, and the combination of at least two red-coded elements qualifies as "high" the resulting sections

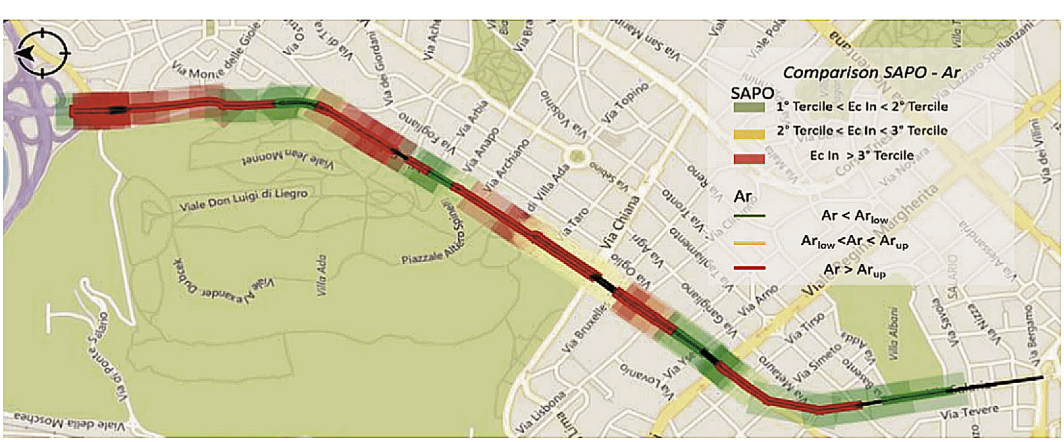


Fig. 11 – Comparison of SAPO and A_r calculated on Via Salaria.

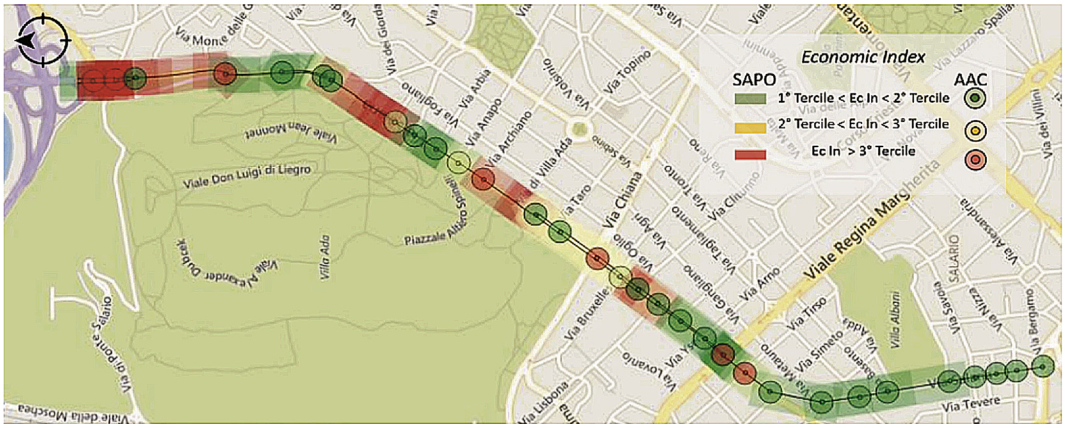


Fig. 12 – Rating of SAPO on Via Salaria links and AAC at intersections.

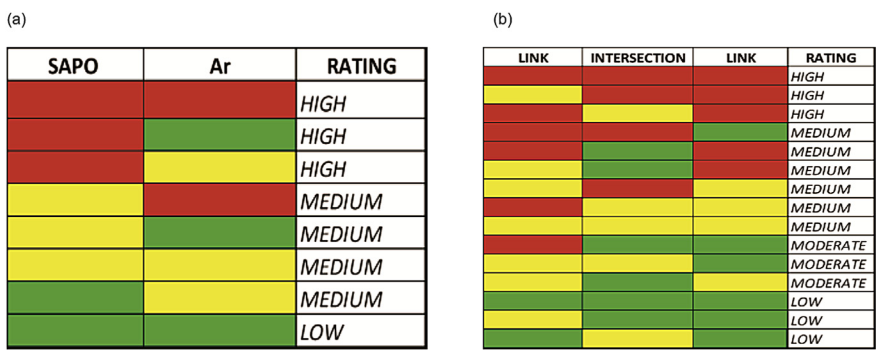


Fig. 13 – Safety ranking matrixes assembly phases. (a) Element safety ranking matrix. (b) Network safety ranking matrix.

of the road. Likewise, the links and intersections with the yellow codes are those where medium values of SAPO or AAC, and the combination of one or two red-coded elements results into assessing the rate "medium" to the composed sections of the road. The rate "moderate" is associated to sections with just one red element and the rate "low" for the sections with no red elements.

It is also to stress that SAPO can be considered more critical in this type of analysis as it provides an economic evaluation on expected benefits in the planning of the regular maintenance works by the municipality.

If the previous example is considered, the segment T4 has the SAPO in the third tercile, represented in red in the matrix ESRM, while the corresponding value of A_r, that is in the medium field, is represented in yellow. The result is a high rating.

5. Conclusions

SAPO enables to assess different road types, according to different traffic volumes at the same time and therefore contributes to improve accuracy in the analysis of black spots in general. More specifically, in this case it helped detect critical road sections and determine the range of how much could be saved thanks to appropriate interventions. In synergy with A_r on the links and AAC at the intersections, it improves correctness of analysis.

Furthermore, the case of Via Salaria also suggests the possibility to achieve a reliable assessment of safety costs and extension of mitigating interventions, even when regulatory references are not updated or not comprehensive of specific modes. The case of Via Salaria also stresses how parameters such as SAPO, if upscaled, might help understand the size of expenditure for the safety interventions at urban scale and where to intervene first. Further research will include this aspect and the related data analysis in this field is currently in progress. At the same time, the same methodology is under study in a different city area, to appraise variations in the indexes according to changed environmental features.

Moreover, should the results of the Via Salaria case be upscaled, consequences in terms for a whole reconsideration of PTWs in the city road safety policies will become unavoidable.

This lesson is also valid for all those communities where PTWs, although a dominant or relevant mode in the local modal share, are not properly involved in the local road safety agendas. Needless to say, additional efforts are required also to promote the research towards more specific studies in which parameters and procedures to evaluate PTWs safety conditions can be determined according to advanced analyses and tailored according to the riders' needs and not derived from general assessment procedures developed for passenger cars.

Conflicts of interest

The authors do not have any conflict of interest with other entities or researchers.

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