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The impact of road accidents on hospital admissions and the potential of ADAS in containing health expenditure: Evidence from Piedmont data

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ABSTRACT

On average, more than 3,600 people die every day on world's roads: road accidents result in over 1.3 million deaths and 50 million injuries annually, placing a significant burden on society and generating substantial economic costs for Governments and Regions, which are responsible for healthcare expenditures.

This study proposes and applies a novel methodology aimed at quantifying the effects obtainable from the use of the *Advanced Driver Assistance Systems* (ADAS) on the base of a real case, in economic terms as well.

The real case consists on the analysis of a very large dataset regarding public health and hospital admissions, made possible by the exceptional access to the internal database, available for this scope, of the Piedmont Region (IT).

Unlike the decades that have passed, it is now conceivable to identify transport related technological solutions that make it possible to prevent, sometimes even avoid, road accidents or at least reduce their severity. These solutions can be identified in ADAS. In a nutshell, their aim is to create a protective layer that mitigates the risk of accidents or reduces their severity. This concept is analogous to the "onion diagram" used in the railway sector, where multiple layers of protection prevent a single failure from leading to an accident.

In essence, ADAS aim to introduce the industrial concept of *fail-safe* into road transport, at least providing it with a pre-alert: safety has been so far delegated only to the driver's alertness, caution and dexterity.

Through the selective analysis of the health costs linked to road accidents, it is possible to quantify the elements considered important for the choices of public decision-makers on both subjects of health and sustainable mobility: in the Piedmont region, the average cost of a hospitalization following a road accident in 2013 was significantly higher than a hospitalization due to general trauma and values have remained similar in the following years. In the same period, road accidents accounted for 15% of the total number of injuries due to trauma, which implies this share can be affected by the adoption of ADAS, so as analysed within this paper for the years 2017–2019, i.e. before the COVID-19 pandemic.

The weight of road accidents on hospitalisation is quantified: on the base of a huge Italian database, the average costs of hospitalisation due to loss of control is quantified. The role of ADAS (Advanced Driver Assistance Systems) for reducing costs of hospitalisation emerges.

1. Introduction

The spread of motor cars around the world, which has largely taken place since the second half of the 1900 s – gradually in Europe, in the United States and in Japan from the 1910s to the end of the century, much more rapidly in areas such as China, India and South America over the last thirty years – has led to a huge revolution in the field of transport. At the same time, this spread has provoked negative repercussions that all nations, whether highly industrialised or developing, have to deal with today: pollution, deaths and social costs for both public health and social ones, to mention the main ones (Dalla Chiara, 2019).

The increase in the number of vehicles has, in fact, progressively caused the negative externalities resulting from road traffic, such as pollution, congestion, the enormous – by now – consumption of crude oil as well as the spread phenomenon of road accidents: their importance

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– the subject of this study – is by no means negligible in global mortality and public health.

More than 3,600 people die every day on the world's roads (elaboration from WHO, 2018), about half of them pedestrians and cyclists, with an annual total of at least 1.3 million deaths and 50 million injuries. Ninety per cent of fatal accidents occur in low- and middle-income countries (LICs and MICs), where less than half of all vehicles are on the road (WHO, 2018).

Notoriously, road accidents can be caused by many causes but, in most cases, the main reason is the human factor; therefore, it is nowadays necessary to implement those innovative technological solutions that can prevent accidents or at least reduce their extent and severity. Such solutions, not diffusely available until a decade ago and much more developed in the very last years, can be found in the so-called ADAS, i.e. *Advanced Driver Assistance Systems*. A number of them already exist, some others are expected in the coming years and even made compulsory in some areas of the world (e.g., a sequence of Regulations make them obligatory in EU automobiles from 2024, Table 1). "Road safety is a central issue" in assisted-driving, faced by the "evolution that ADAS are undergoing in recent years, now becoming compulsory equipment for automobiles to be registered after 2023" (Antoniou C. et al, 2020).

The term ADAS is used to refer to integrated systems or, sometimes, simple devices installed in vehicles which, by alerting the driver, or by intervening in on-board controls such as braking and steering, can help to avoid an accident (Dalla Chiara et al., 2009). Their function, however, does not end with emergency interventions, as they provide the driver with useful information that would otherwise not be available in a short time, thus improving advance knowledge about potential road hazards. Their specific description is provided in Section 5, concerning ADAS and their effects.

Their purpose is, in short, to create an intermediate layer between the condition of safety and that of accidental damage. This concept is analogous to the "onion diagram" used in the railway sector, where multiple layers of protection prevent a single failure from leading to an accident.

In essence, ADAS aim to introduce the concept of *fail-safe*, or at least a state of pre-alertness, into road transport as well, a condition that did not exist for decades, delegating safety only to the driver's alertness, caution and dexterity.

The aim of this study is therefore to evaluate the effects, in economic terms, that could be obtained from the use of innovative driver assistance technologies, ADAS in particular, through the analysis of health-related costs deriving from road accidents. This analysis has been carried out by using a huge amount of original data, normally not accessible to the public or in the literature, obtained thanks to the Health sector of the Piedmont Region (Italy) and the joint research made by the authors.

In 2019, with the Regulation (EU) 2019/2144, the European Parliament made the installation of a package of 30 advanced safety devices mandatory from 2022 for new models and from 2024 (2025) for existing models (Table 1). The assumption of a blanket deployment of the different systems will be more likely in the following years.

In order to identify the expected public benefit due to the installation of the different ADAS on vehicles, it was necessary to identify, for each technology, the percentage of deaths or injuries that could be avoided by hypothesizing a blanket diffusion, and this was done through the analysis of the state of the art of literature, enucleating the main results for the ADAS considered.

In the Piedmont region, the average cost of a hospitalization following a road accident in 2013 was approximately 6500 € compared to 4600 € for a hospitalization due to general trauma. In the same year, road accidents accounted for 15 % of the total number of injuries due to trauma, which implies this share can be affected by ADAS; in the following years these values remained quite similar. In Piedmont Region a specific policy addressed at containing road accidents, also based on ADAS, has been defined in the last years (Montaldo and Occelli, 2019; IRES Piemonte, 2019).

Fig. 1 synthesises the analysis process followed in this research as well as in the paper: from road accidents to hospitalizations, quantifying the role of ADAS for containing costs with an analysis on real data. The all picture is self-explained while reading the text.

Table 1
Mandatory safety equipment for passenger cars according to EU Regulation 2019/2144.

ADAS	Homologation	Registration of the vehicle	References
Lane Keeping Systems (LKS)	6.07.2022	7.07.2024	EU Commission Implementing Regulation 2021/646 of 19 April 2021
Autonomous Emergency Braking (AEB)	6.07.2022	7.07.2024	Regulation No 131 UN/ECE, 2014
Intelligent Speed Adaptation (ISA)	6.07.2022	7.07.2024	EU Commission Delegated Regulation 2021/1958 (ed. 2023)
Alcohol interlocks	6.07.2022	7.07.2024	EU standard, EN 50436:2016
Driver Drowsiness and Attention Warning systems (DDAW)	6.07.2022	7.07.2024	EU Commission Delegated Regulation 2021/1341
Event Data Recorder (EDR)	6.07.2022	7.07.2024	Regulation No 160 UN/ECE, 2021
Advanced Emergency Braking Systems for pedestrians and cyclists	7.07.2024	7.07.2026	UN/ECE (in evolution)
Advanced Driver Distraction Warning systems (ADDW)	7.07.2024	7.07.2026	EU Commission Delegated Regulation C(2023)4523 (ed. 2023)

2. State of the art of literature on road safety, technology and accidents as leading causes of deaths: An overview

2.1. State of the art of literature on road safety and technology

Before proceeding to examine the sources and methodology characterising the study, which considers the Piedmont Region (IT) as the area of investigation, it is appropriate to provide a targeted overview of the global and national scenarios as well as the technologies used within our research.

As well synthesised by Christie (2018), transport "poses a public health risk" and "the burden is greatest on the poorest in society. There is a strong relationship between social class and the likelihood of road traffic injury". Referring to various policies implemented in favour of public health, the author underlines that "Such polices will not succeed in improving public health if they are delivered in an environmental context in which people feel unsafe", referring thereafter to road accidents ("If we do not address the safety of the environment for everyone and especially the most vulnerable in society, then we will not address health inequalities and may inadvertently increase them").

It is clear that in our contemporary society, at a global level, road accidents and fatalities are a primary problem at all levels of the society, as detailed further in this paper and also quantified in economic terms, both in the balance sheet of States in general, and as a monetary impact on hospital admissions. However, it is the *purpose of technological evolution* to remedy the damage that progress sometimes generates: in this case, a widespread motorisation has generated a problem that was not so significant a century ago. What is lacking in the literature is an understanding of the role that on-board technologies may assume in the near future: this is the main purpose of this research, which is not reflected in existing publications, except in the specific contexts mentioned below.

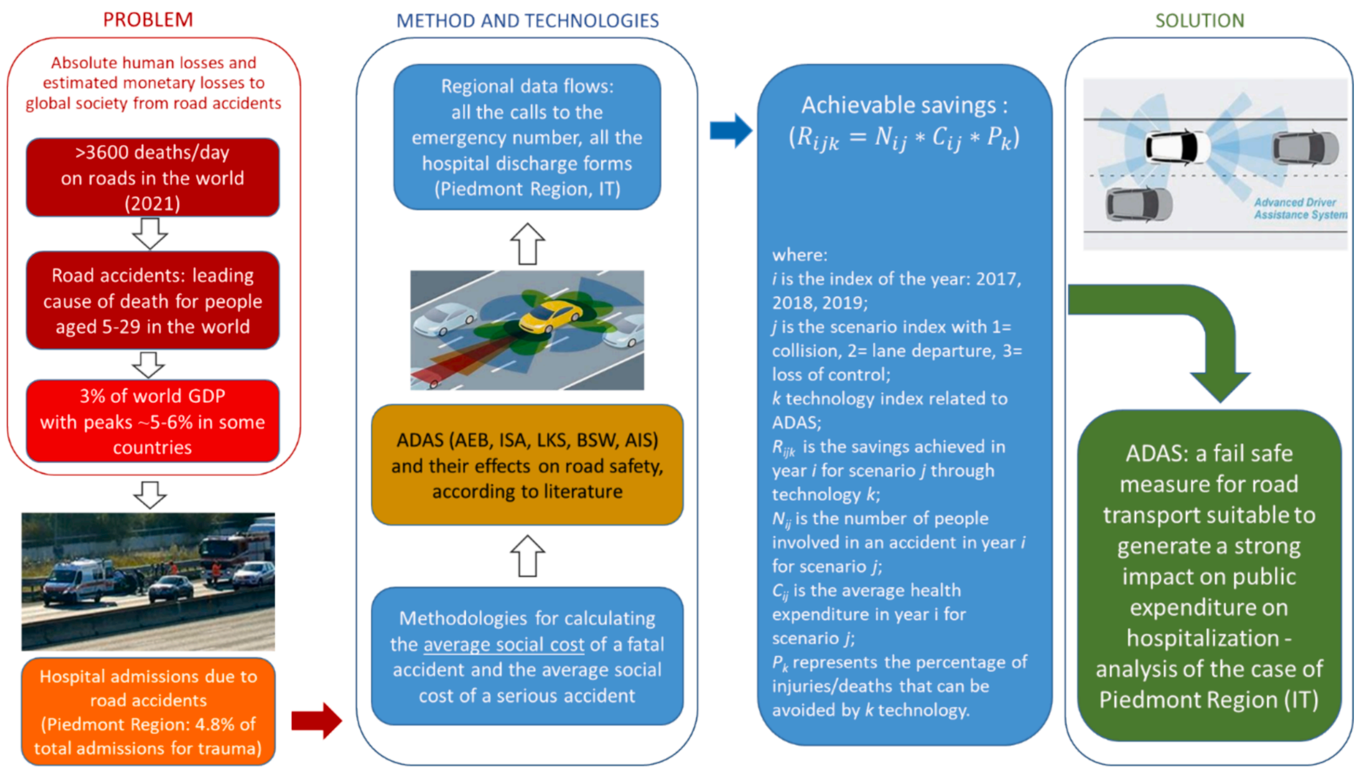

Fig. 1. The analysis process, from road accidents to hospitalizations: the role of ADAS for containing costs with a quantitative analysis on real data.

Devos et al. (2015) analyse the determinants of hospitalisation and hospital costs associated with road traffic accidents in Belgium, using an emergency and hospital care dataset. Such data will be recalled later in this paper, being important to understand the weight of road accidents within hospitalisation cases.

As regards *driving distractions*, they are one of the leading causes of traffic accidents (Wright and Dorilas, 2022) and road accidents are a major public health concern (Pascale et al., 2012; Giulietti et al., 2020). They are estimated as the ninth leading cause of death in all age groups globally (World Health Organization, 2015) and the major cause of death among teenagers (Karaca-Mandic and Ridgeway, 2010).

As a matter of fact, we need to recall that an *accident* occurs when the perception-reaction time of a driver plus the time necessary to actuate the braking, steering or other procedure of the vehicle he/she is driving is more than or equal to the time involved by the exogenous variation that occurs outside the vehicle. Such a perception-reaction time of the driver plus that of the vehicle is therefore the maximum time available for the driver to respond to an emergency condition on the road and avoid an accident (Dalla Chiara et al., 2009). Thereafter, being distracted while driving only increases the likelihood that the time left by the changing of a variable exogenous to the vehicle becomes excessive when compared to the driver's perception, reaction and actuation times.

Road traffic fatalities are indeed a complex global health issue that is strongly related to several factors, such as the levels of education and income in countries and the prevalence of motorisation. Some countries are affected harder than others, almost 90 % of all road accidents occur in low- and middle-income countries (LMICs) (Wegman, 2017), frequently because of both a lesser long-lasting maturation of car-related risks, and because perception-reaction and actuation times are sometimes made high by less well-maintained roads and older, even not always well-maintained, vehicles.

In any case, the problem of road accidents is not limited to LMICs and literature still lacks of preventive solutions, both for automobiles and weaker road users, namely passengers and users of bicycles and micromobility services.

Bicycle-related road accidents account for a considerable amount of the total number of road accidents in general (Utriainen et al., 2021): among cycling injuries, single-bicycle crashes (SBCs) represent a significant number of all injuries. The study of Utriainen et al. (2021) focuses on data mainly from the 2010s based on scientific publications, and explores the proportion and the characteristics of SBCs internationally.

Castro-Nuño M. and Arévalo-Quijada (2018) provides two multidimensional safety indicators for combining a set of criteria related to economics, demographics and sustainable urban transportation to assess urban road safety performance in 50 Spanish provinces. The indicators proposed in the mentioned paper could therefore provide a decision-making framework to support urban road safety management. In the Public Health and in Transportation fields, more specifically in the Road Safety policy context, decision makers need to make complex decisions regarding the use of public funds in a context that has to prioritise a limited number of options within a constrained budget. This aspect is quite related to the aims of our paper, as it will emerge in the following.

Incidentally, literature already found (Sang Chang Y., 2014) that when "the projected numbers of fatalities are compared with the target values on the future number of fatalities in 2030 by 10 analysed states, the results showed that the target values were significantly smaller than the projected numbers". In other words, nearly all the analysed states were predicting much more optimistic results. In this paper we provide a tool to better pursue such goals, on the base of new technologies suitable for pursuing the goal of reducing road accidents, with related social costs.

2.2. State of the art of literature on road accidents in terms of costs and leading causes of death

As a matter of fact, the *expenditure* that governments incur averages about *3 % of GDP* for most countries and *5 % for low- and LMICs* (Shadkam et al., 2019).

According to the World Health Organization's Global Road Safety Report, published in 2018 (World Health Organization, 2018), thus prior to the COVID period, 1.35 million deaths – as a result of road crashes – occurred in 2016: indicatively 3,700 deaths every day, on average, on the roads. In particular, road crashes are globally the ninth leading cause of death for all age groups and the leading cause of death for people aged 5–29.

Road traffic accidents are considered among the most common external *causes of injuries leading to hospitalisation* among young people in high-income countries worldwide (Hassani-Mahmooei et al, 2016), notwithstanding the fact that these countries are not the most impacting in the world in terms of number of accidents, as quoted above. Injury prevention is important to reduce the socio-economic burden of road crashes (Wijnen, Stipdonk, 2016).

As far as only European countries are concerned, road crashes are among the *top three leading causes of death* and the *first one considering European citizens under 50 years of age* (Segantini et al., 2020).

More than 40,000 people die on European roads every year (Commission of the European Communities, 2003 and for many years afterwards), and similar numbers can be found in the United States (Insurance Institute for Highway Safety, 2018).

The repercussions are economic as well as social: to the unquantifiable human tragedy the cost of accidents must be added, which is estimated to be close to *3 % of world GDP*, for a total of more than 500 billion USD a year (ACI, 2011, 2019 and 2020, on ONU Goals). Furthermore, some research shows that even considering European countries alone, government expenditure on road accidents is estimated to be around the same value of *3 % of GDP* (Gurzhii et al., 2021; Wijnen et al., 2019).

The high *socio-economic burden of road accidents* is often analysed in several documents of international organisations, including policy-oriented ones, such as the already-mentioned World Health Organisation (WHO, 2015), the World Bank (World Bank, 2013) and the European Commission (EC (2010). Their objective is to emphasise the need to improve road safety also from an economic point of view. The WHO has predicted that without sustained actions, road accidents will become the seventh leading cause of death by 2030 (Shadkam et al., 2017).

Since 2015, the United Nations have implemented several solutions to improve road safety proposing actions to address the global road safety crisis and considering it as one of the Sustainable Development Goals (SDGs) (Wegman, 2017). The goals of the United Nations 2030 Agenda for Sustainable Development include halving the global number of road accidents. According to Bertoli and Grembi (2021), governments can play a crucial role in promoting this challenging plan, which requires both effective traffic safety regulations and enforcement. In our paper we will also demonstrate the role of new available technologies.

Road safety has become a central issue on many policy agendas around the world. The scientific literature related to road injury prevention is extensive. However, shortcomings can be outlined in *assessing the economic side of these issues*; decision-makers seem to underestimate the relevance of public health costs for the recovery and rehabilitation of people involved in road accidents (Corazza et al., 2017). The present paper aims to fill this gap by investigating the economic aspects mentioned above and correlating them with new technologies.

Being able to compare the costs of road crashes with the costs of other areas of public expenditure can be useful as an input into setting priorities in various state policies. We will prove that investing in road vehicle technology (ADAS, as detailed below) can save a significant amount in public health costs – that we quantify as far as we can estimate – and, above all, in human losses.

As regards such economic aspects, cost-benefit analyses (CBAs) are important for assessing the social return on investment in infrastructure and road safety and to help prioritise road safety measures (Wijnen, Stipdonk, 2016). Moreover, several researches, in particular from the United States and Western Europe, dealt with the topic of road accidents at the international level, focusing specifically on the assessment of the economic impact of road mortality (Wijnen, Stipdonk, 2016; Trawén et al., 2002; Alfaro et al., 1994).

We already anticipated a few data related to the economic impact of road accidents but in order to outline the international scene more in detail, it is worthwhile to focus on some more extended recent research.

Fekete et al. (2012) point out that traffic accidents and subsequent medical care are important burden for Hungary with an annual expenditure of 17 billion HUF (97,7 million €).

Wijnen and Stipdonk (2016) present an international analysis including eight Asian countries, six European countries, Australia, New Zealand and the USA. Their research shows that the social costs of *road traffic injuries* in High-Income Countries (HIC) range from *0.5 % to 6.0 % of GDP, with an average of 2.7 %*; excluding countries that do not use the Willingness-To-Pay (WTP) method, which average *3.3 % of GDP*. For Low Middle-Income Countries (LMICs) the share of GDP varies from 1.1 % to 2.9 %; however, none of the LMICs included in the research apply the WTP method of human costs. Injury costs are on average 50 % for both HICs and LMICs, while the average share of deaths is 23 % and 30 % respectively. Furthermore, Wijnen and Stipdonk (2016) point out that there are substantial differences in the methods used to estimate specific cost components. Less developed countries do not use the internationally recommended WTP approach, resulting in substantial underestimation of road accident costs. In this approach, costs are estimated based on the amount that individuals are willing to pay for a reduction in risk and it is generally recommended as the most appropriate method for estimating human costs (Wijnen et al., 2019; Boardman et al., 2017; Freeman et al., 2014; Alfaro et al., 1994). Indeed, the Willingness-To-Pay approach has replaced the Human Capital (HC) approach as the preferred method for calculating accident costs in many developed countries (Silcock, 2003). These least come out as a useful comparison in our research, since ADAS – hereafter analysed – are gradually being introduced primarily in developed countries.

In any case, even if the cost classification recommended by the international guidelines is applied by all countries, there are differences with regard to unpaid production loss, property damage other than vehicle damage (especially infrastructure damage), human costs of minor injuries, congestion costs and vehicle unavailability costs (Wijnen, Stipdonk, 2016).

Wijnen et al. (2019) provide a European overview of official monetary evaluations of road accident prevention in 31 countries. To estimate the cost components, the authors applied several valuation methods:

1) "The restitution costs approach", which includes estimates of the costs of the resources needed to return road victims as far as possible to the situation before the road accident;
2) "Human Capital" (HC), which estimates the value to society of the loss of productive capacity of road victims;

"Willingness-To-Pay" (WTP), which – as introduced above – estimates how much individuals would be willing to make an effort (Mouloud Haddak, 2016) for a reduction in risk (Dalla Chiara et al., 2012).

The framework introduced by Wijnen et al. (2019) includes several main cost components, such as:

- medical costs (cost of hospitalisation, rehabilitation and other medical treatment);
- loss of production or productive capacity of road victims;
- human costs related to the intangible cost of grief, bereavement, loss of quality of life and years of life lost;
- damage to property, such as vehicles and infrastructure;
- administrative costs related to the police, the fire service, insurance and legal costs.

It is important to underline that the estimates of most European countries are based on the WTP approach, which provides higher evaluations than other methods. Total expenditure on *road accidents in European countries is estimated on average at 0.4–4.1 % of GDP including the* *extreme values of different sources*.

The relatively recent study by Gurzhii et al. (2021) also focuses on modern methods for calculating economic losses caused by road accidents. The authors show that in many European countries (in particular, Italy, Norway, France, Sweden) the approach for assessing accidents is fundamentally different from that in the United States and other countries around the world. Gurzhii et al. (2021) conclude their study by arguing that the magnitude of this impact far exceeds the effects of international terrorism, natural disasters or military conflicts and it is comparable to the most dangerous diseases, such as cardiovascular disease, AIDS, pneumonia.

Wijnen (2021) focuses on the socio-economic costs of road traffic accidents and their entity in Kazakhstan, again applying a hybrid methodological approach including: 1) "The restitution costs approach"; 2) "Human Capital" (HC); 3) "Willingness-To-Pay" (WTP) and considering five main cost components: medical costs, production losses, human costs, vehicle damage and administrative costs. In this case, administrative and medical costs are in any case relatively very small cost components. Wijnen (2021) highlights that the *socio-economic costs of road accidents in the country analysed average 3.3 % of GDP*, that is compliant with our previous comparisons on results obtained from literature.

In 1994, La Vecchia et al. (1994) already analysed the trends in age-specific and age-standardized death certification rates of motor vehicle accidents over the period 1950–1990, including in the research 48 countries from four continents. The authors outlined that there were a few countries with exceedingly high rates of motor vehicle accidents, therefore comprehensive interventions on this important cause of death are *a public health priority*.

Hasselberg and Laflamme (2008) examine the relationship between country of birth, socioeconomic position, and the risk of being injured as a young car driver. As outlined in GBD (2015), *transport injuries are ranked as one of the leading causes of death, disability, and property loss worldwide*; the authors provided an overview of the burden of transport injuries in the Eastern Mediterranean Region by age and sex from 1990 to 2015.

Hassani-Mahmooei et al. (2016) investigate the role of pre-existing health conditions in the cost of recovery from road traffic injury using records of health service over a 1-year period before and after the injury.

Shin et al. (2017) outline how in South Korea people injured in road traffic accidents receive compensation for medical costs through their automobile insurance. Their study aimed to investigate the factors associated with the Length of Hospital Stay (LOS), which was used as an indicator of healthcare utilisation, for inpatients covered by automobile insurance and undergoing invasive cervical discectomy. The authors suggest that policymakers and healthcare professionals should consider improved strategies for efficient management of automobile insurance. As authors, we underline that *insurance can vary in case of on-board equipment that can reduce accident classes* or, anyway, a risk index.

Nevertheless, only very recent literature (Tafidis, 2022) started investigating new technologies and assisted driving besides automated vehicles (AVs) as promising to improve road safety, reduce traffic congestion and emissions, and enhance mobility. Tafidis (2022) outline that, however, evidence regarding safety benefits has not been systematically investigated and documented. In the mentioned study, the author proposes a literature review related to higher levels safety implications of AV.

The synthesis reported in this Section has resumed and compared the economic methods and the different impacts of costs of road accidents on public health around the world: to the unquantifiable human tragedy, the cost of accidents is estimated to be close to 3 % of world GDP, with peaks around 5–6 % in some countries, placing this burden among the first ones on the national budgets, evidently associated to hospitalisations. As a matter of fact, a loss of working capability or loss of capital goods might be as high or even higher than hospitalization costs, though this loss is not considered in the abovementioned estimations, being not a direct cost for the States.

This analysis allows – after having compared the methodological differences in cost estimates in the following paragraph and having outlined the role of a data-driven international cooperation – to quantify the potential role of emerging on-board technologies for reducing road injuries and deaths, that is the issue addressed by this paper.

3. Theory: Approaches for assessing the state of road safety

Road safety is already recognised by the world's leading authorities as a major policy priority, indispensable for the dynamic development of the economy and for guaranteeing human rights relating to the protection of life and health (Global Status Report on Road Safety, 2015).

In order to assess the state of road traffic safety, the countries of Western Europe, North America and the Asia-Pacific region mostly use comprehensive information and analytical systems capable of ensuring continuous monitoring of road accidents. They are based on modern, progressive methods integrated into a national statistical accounting network.

In any case, it is important to note that there are still many countries, including European ones, which use outdated methods and are still far from implementing an advanced system (Gurzhii et al., 2021).

The methodologies used differ from one country to another, and the most debated issue is whether or not the internationally recommended willingness-to-pay (WTP) method should be applied.

Analyzing willingness to pay (WTP) related to road safety is crucial for understanding how individuals value safety measures and how they perceive the trade-offs between safety and other considerations, such as convenience, cost and time. There are some critical points to consider while analyzing WTP method:

a. perceived value of safety; individuals might express varying degrees of WTP based on their experiences, attitudes, and socio-economic backgrounds;
b. stated vs. revealed preferences; willingness to pay can be assessed using stated preference (surveys, questionnaires) or revealed preference (actual behavior);
c. income disparities and equity: affluent individuals might be more willing to pay for safety enhancements, while economically disadvantaged populations may have limited resources to allocate to safety;
d. behavioral factors; people might underestimate their personal risk, leading to lower WTP.

As authors, we deem that policymakers should use different insights to implement effective road safety measures that align with public preferences and promote a safer and more equitable transportation system.

Information on the costs of road accidents is a valuable input for road safety policymaking and is essential for conducting cost-benefit analysis (Wijnen, 2021; Wijnen et al., 2019). This type of analysis enables the assessment of whether investments in road safety are economically viable and what priority to give to road safety investments based on socio-economic returns (Boardman et al., 2017; Jones et al., 2014).

Thus, it becomes of primary importance to improve international guidelines and ensure in all countries the application of modern methods, possibly standardised internationally, in order to improve the reliability of cost estimates in individual countries (Wijnen and Stipdonk, 2016).

Methodological differences in cost estimates are a serious obstacle when decisions on countermeasures have to be made at supranational level or when international comparisons and benchmarking are needed (Wijnen et al., 2019).

Corazza et al. (2017) insist on the urgency to harmonise data collection procedures, include more items, standardise parameters and apply standard review processes, at least at European level, in order to be able to have reliable and unambiguous assessments of expenditure costs and comparable results across contexts.

National and regional road safety development programmes should be developed as far as possible, including specific indicators such as: a) estimation of direct economic losses (property damage, medical costs, legal costs, insurance payments, environmental damage, etc.); b) estimation of lost benefits (wages of victims, GDP per capita); c) cost of moral and physical suffering; d) estimation of "Willingness to pay", Gurzhii et al. (2021).

Wegman (2017) highlights that strong leadership and an active public sector are crucial in order to implement high security systems and achieve substantial results.

Similarly, the private sector and development banks could play a key role. Car manufacturers should strive to ensure minimum standards for all vehicles produced. Development banks, which finance large infrastructure projects, should verify that regulations are strictly adhered to in order to ensure a safer mobility system (Todt, 2016).

This is not the case for many low- and middle-income countries (LMICs) due to their many inherent difficulties such as lack of leadership, political priority, funding and expertise. LDCs should invest in local capacity building and create effective road safety communities involving all actors: the public sector, universities, NGOs and the private sector (Wegman, 2017). To improve the situation also in these countries a positive signal came with the Brasilia Declaration from the international community, willing to support LDCs towards improving road safety (WHO, 2015).

To improve road safety, stakeholders can collaborate on various initiatives and strategies. They can share relevant road safety data and collaborate on its analysis. This includes sharing accident data, traffic flow information, and data on risky behaviors. Analyzing this data collectively can help identifying high-risk areas and prioritize interventions such as public awareness campaigns, education programs, regulatory and policy development and technology integration

The global scenario therefore shows significant differences at continental and regional level.

In Europe, the numerous objectives set at EU and national level, legislative initiatives, and experimental programmes on new technologies – which are multiplied by the various institutions at both EU and local level – have led to a reduction in the number of road deaths between 2001 and 2010 of around 43 % (European Commission, 2019). However, the years following 2013 showed a slowdown in the progress made, up to the COVID period, during which the constraints on free movement also limited the effects on road accidents, which, moreover, picked up again in the post-pandemic phase as a result of the greater propensity to use private vehicles, for reasons of fear of contagion.

In 2019, the year considered as the most significant as it preceded the COVID-19 pandemic, fatal accidents in the EU totalled around 22,800, about 7,000 fewer than in 2010 (–23 %) and a fall of 2 % compared with 2018.

In 2019, road deaths were found to be on the increase in eleven countries, including some of the countries that have more recently joined the European Union, such as Slovenia (+12.1 %) and Slovakia (+7.0 %), but also those with an established road safety tradition, such as Denmark (+17.1 %) and the United Kingdom (+4.7 %).

In conclusion of this section, road safety is a critical global policy priority recognized by leading authorities. Improvements require collaboration among various stakeholders and the use of WTP methods is essential to accurately estimate the costs of road accidents. Standardising methodologies and data collection would improve cost estimates as well as enable meaningful comparisons and benchmarking among Countries. It results evident that road safety is a complex and multifaceted issue that requires collaboration, data-driven approaches, and international cooperation to achieve meaningful improvements and reduce road accidents worldwide.

4. The Italian scenario

Over the years, the Italian scenario has been similar to the European one in terms of trend, with a reduction in the number of road deaths of 42 % in the decade from 2001 to 2010 (ACI-ISTAT, 2019). However, the number of victims in 2019 (3,173), before the reduction in mobility due to the COVID pandemic, was still high and close to *a dozen deaths a day on* national *roads*.

The road mortality rate in relation to the population (deaths per million inhabitants) stood at 48.1 in the EU28 and 52.6 in Italy in 2019 (62.8 and 69.4 respectively in 2010).

Since the 1950s road accidents in Italy had been increasing very rapidly, as analysed by ACI-ISTAT (2011), which outlines, in the trend from 1950 to 2010, a peak for road fatalities in 1972 (11,078) and with more and more people injured in 2002, then declining thereafter.

The situation has much improved compared to the past: prevention has yielded considerable results in the last fifteen years, a part from the COVID period, when the constrictions to mobility had effects also on the reduction of accidents and of victims on the roads (Fig. 2.).

An analysis of the figures for the last ten most significant years before the COVID pandemic (2010 to 2019) reveals savings in economic terms of more than 9 billion € relating to road victims. Between 2011 and 2019, 6,035 lives were saved, while in economic terms over 9 billion € were saved on victims alone and 31.2 billion in total (Ministry of Infrastructure and Transport, 2020).

In 2010 there were 211,404 road accidents with personal injury, 4,090 fatalities and 302,735 injuries in Italy (ACI-ISTAT, 2011), while in 2019 there were 172,183 road accidents with personal injury in Italy, with 3,173 fatalities and 241,384 injuries (ACI-ISTAT, 2020).

The Ministry of Infrastructure and Transport (2012, 2020) assessed the social cost of road accidents in Italy. The social costs of road accidents are an estimate of the economic damage suffered by society as a result of such events, quantifying economically the burdens placed on society as a result of the consequences caused by a road accident.

The mentioned Ministry (2012) defined the methodology for calculating the average social cost of a fatal accident and the average social cost of a serious accident. According to this study, the cost of a fatality is about 1.5 million € and the average cost of a fatal accident is about 1.6 million € (Table 2). The same study also estimated the total national cost of road accidents in 2010 at around 28.5 billion €.

The social cost of accidents resulting in personal injury is gradually and almost constantly decreasing: from EUR 21.4 billion in 2010 to EUR 16.9 billion in 2019 (−21 %).

For the year 2019 the Ministry of Infrastructure and Transport (2020) estimated on the basis of the same methodology, that in fact the social costs with injuries for the year 2019 have decreased to 16,854,753,804 € (about 1 % of the national GDP) (Table 3).

The estimate of the social costs of accidents in Italy for 2019, adding to the cost of accidents involving personal injury (EUR 16.9 billion) the costs associated with accidents involving property damage only (EUR 6.57 billion), amounts to approximately EUR 23.42 billion.

The *road accident data in the Piedmont Region*, which is the subject of interest in this study, have followed the national trend, recording a decrease in the number of accidents from a high of 16,953 in 2001 to a low of *10,646 in 2019* (Piedmont Region, 2020).

5. Advanced driver Assistance systems (ADAS): Their expected effects on safety

Having grasped the economic effects, concerning road safety, that various actions taken over the decades – on drivers' behaviour, on infrastructures, on vehicles, with related technologies and retention systems for active and passive safety – have come to generate, the question is whether the new frontier of on-board technologies can procure benefits in terms of hospital admissions and, consequently, of burdens on public health. For the purposes of this paper, we will focus on the

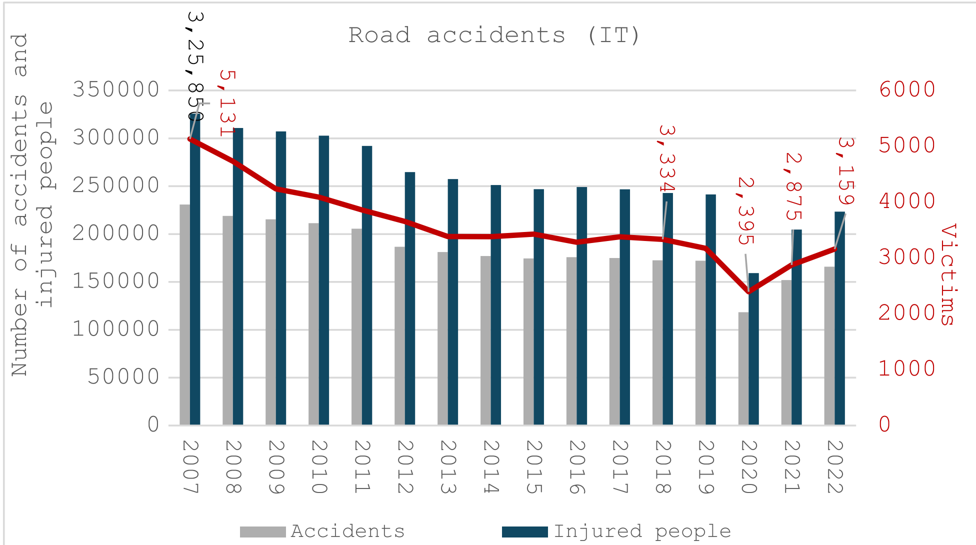

Fig. 2. Road traffic accidents resulting in personal injury from 2007 to 2022 (absolute values) on the whole Italian territory [Source: ACI-ISTAT-IT (2024)]

Table 2
Cost per level of severity [Source: Ministry of Infrastructure and Transport (2012)].

Severity	Average cost according to severity of injuries [k€]	Average cost according to severity of the accident [k€]
Fatal	1,503	1,642
With severe injuries	0.197	0.309
With slight injuries	0.017	0.032
With injuries (no distinction)	0.042	–

Source: Ministry of Infrastructure and Transport (2012)

Table 3
Total social cost of accidents involving personal injury (Year 2019) [Sources: ACI-ISTAT (2019); Ministry of Infrastructure and Transport (2020)].

Total social cost of personal injury accidents (2019)	
Average cost for death	1,503,990.00 €
Number of deaths	3,173
Total cost of deaths	**4,772,160,270.00 €**
Average cost for injured	42,219.00 €
Number of injured	241,384
Total social cost of injury accidents	**10,190,991,096.00 €**
Average general costs for accidents	10,986.00 €
Number of accidents	172,183
Total general costs	**1,891,602,438.00 €**
Social cost of injury accidents	**16,854,753,804.00 €**

frontier represented by ADAS.

These systems with related devices have become increasingly widespread on the market, especially starting from the second decade of the current century. Despite the inconsistent terminology in the market, we will use consistent terms throughout the paper for clarity. The diffusion of ADAS is expected to become even higher in the years to come following the European Parliament's decision to extend the compulsory use of additional safety systems on new vehicles from 2022/23.

They are included in the taxonomy proposed by the Society of Automobile Engineers (SAE), the aim of which is to classify available assistance technologies according to various levels of automation, from level 0 to level 5 (full automation of the car).

This research has analysed the main ADAS, reporting – wherever possible – the results of studies aimed at understanding the effect, in terms of percentage reduction in the number of injuries and accidents, and consequently in health costs, that their adoption can bring.

5.1. State of the art analysis concerning ADAS

Before moving on to a detailed analysis of the elements that allowed the identification of the economic benefits that can be introduced by the adoption of ADAS, it is necessary to summarise the results achieved and reported in literature.

Within the state of the art of literature, no evaluations result currently available to make it possible the link between benefits of road safety – in terms of accidents and lives saved attributable to a technological innovation at that of ADAS – and the economic benefits that could be obtained in terms of health. Sources present in literature have in fact usually focused on one of the two aspects: economic (economic-business and economic-health literature) or safety (technical-engineering literature).

In past and recent years, the economic aspect has been the subject of specific evaluations made by the health authorities of the Italian regions. More specifically, this was evaluated by the so-called supra-zonal epidemiology service ASL TO3 (ASL stands for the health local public institution and TO stands for Turin) of the Piedmont Region (IRES, 2014) which, by analysing the health costs associated with road accidents, made it possible to understand the evolution of the burden of care on the Region's hospitals.

The cost for rescuing and hospitalising a person injured in a road traffic accident has been increasing over the decade 2001 to 2011; in 2001 the average cost of hospitalisation for a road traffic accident resulted to weight 3,624 € and has almost doubled 11 years later. The most recent analytical data show that the average cost of a road traffic accident hospitalisation is 6,476 €. This cost is higher than the cost of hospitalisation due to other injuries (4,973 €) and is more than double the cost of non-trauma-related hospitalisation (3,184 €).

These costs have been estimated, albeit using a different method, for the Lombardy Region; the latter reports an average value of the unit health cost per hospitalisation in 2019, following a road accident, which is slightly lower than that calculated for the Piedmont Region and is equal to 5,290 € (Polis Lombardia, 2021).

The values reported above differ significantly from those reported in the study carried out by the aforementioned Ministry of Infrastructure and Transport (MIT), for some time (2020–2022) renamed as Ministry of Infrastructure and Sustainable Mobility (MIMS), "Study to evaluate the

Social Costs of Road Accidents", which forecast an average health cost per road accident victim (dead or injured) of 1,965 € in 2019.

The benefits that can be obtained from the various technologies, in terms of reducing the number of accidents, cannot of course be determined with certainty or in an absolute manner. However, the state of the art presents numerous studies that have tried to understand what results can be obtained through the systematic adoption of new technologies, leading to different results, also because of the adopted method of analysis.

The following is a summary of the results of international studies on each type of system with related devices.

What is undoubtedly true is that Intelligent Transport Systems (ITS), ADAS in particular, own some prerogatives suitable to lead to a reduction in the number of accidents occurring on the roads and, consequently, to reduce the impact that such events have on society.

5.2. Effects detected by individual ADAS according to literature

5.2.1. Intelligent speed Adaptation (ISA)

Intelligent Speed Adaptation or ISA is a device that informs, warns or discourages the driver from exceeding the speed limit or any other value set as a maximum limit. The value can be set automatically based on the speed limit posted on the road being travelled and can subsequently be updated using an automatic localisation system (e.g., GPS or GALILEO[1], the EU's satellite navigation system completed in 2022).

There are three types of *Intelligent Speed Adaptation* – Advisory ISA, Warning ISA, Mandatory ISA – depending on the degree of intervention.

The effectiveness of this ADAS in preventing road accidents was analysed in the study by Lai et al. (2012) in which a long-term prediction of the effects of this in-vehicle technological innovation was made for different scenarios. The first scenario envisages the voluntary adoption of the device, while the second one considers a regulated introduction; for both scenarios an estimate of the percentage reduction in accidents was then given depending on the degree of intervention of the system.

Among the different types of system, the one which has demonstrated the greatest benefits is the Mandatory ISA, which achieves strong reductions especially in an urban scenario; in fact, since it is not possible to exceed the speed limit, the speed distribution undergoes a change so that the frequency peak moves in correspondence with the limit itself. The first consequence is a reduction in speed variability, which allows for increased road safety and traffic fluidity. Under the assumption that its introduction is regulated, a reduction of 30 % in fatal accidents and 25 % in serious accidents is estimated, while for the Market Driven scenario they are 13 % and 8 % respectively (Lai et al., 2012).

5.2.2. Autonomous emergency braking (AEB) systems

The automatic (some literature calls it this way) or autonomous emergency braking system is a device that, thanks to the presence of sensors such as cameras, radars or lidars placed on the front of the vehicle, allows it to detect vehicles, obstacles or other road users: if the driver has not acted in time in an imminent collision situation, the ADAS automatically applies braking in such a way as to avoid the accident or reduce the speed of impact.

In order to assess the effectiveness of the *low-speed* system, the study carried out by Doyle et al. in 2015 compared the claims submitted to insurance companies by owners of vehicles equipped with City AEB with those submitted by owners of vehicles without the technology. This showed that vehicles equipped with the device are less frequently involved in accidents requiring the aid of the technology. Specifically, there was a 21 % reduction in claims for SUVs in the same category and a 45 % decrease in claims for other family vehicles.

According to the state of the art provided by Deflorio, Carboni (2022) a 100 % diffusion of the AEB system on board of all vehicles in Europe could result in a drop of 7 % for the number of deaths and 7.3 % for the injured personnel.

The quantification of the benefits has been estimated, within the study, through the calculation of the accident rate, carried out for different categories of vehicles equipped and not equipped with this system. For the A and B segments, the average reduction in the claims rate resulted to be the 20 %, while for the C and SUV segments the percentage reduction was almost double (−38 %).

In particular, by analysing the information on mileage data collected by the black boxes, the adoption of the AEB system in vehicles less than three years old reduces the number of rear-end collision accidents with injuries by 45 %, while the total number of accidents, regardless of their dynamics, decreases by 35 %.

5.2.3. Lane Keeping systems (LKS)

Lane-keeping support systems are devices that can, depending on their level of autonomy, warn the driver or bring the vehicle back into its lane whenever the vehicle unintentionally deviates from it (Pöllänen and Liimatainen, 2020).

They are divided into two main categories: devices that warn the driver of unintended lane departure and devices that act directly on the steering.

In order to estimate the benefit provided by these devices, we report the results of the study by Cicchino et al. in 2018. In particular, in order to understand the correlation between the number of accidents and the presence or absence of LKS and *Blind Spot Detection*, a regression analysis was conducted on different vehicle models for which information about the vehicle's equipment was available: thanks to the sensor that detects the presence of other vehicle within the blind spot, it is possible to avoid collisions that occur when, following an overtaking manoeuvre, the driver of the vehicle that has overtaken is preparing to re-enter his or her lane, with the presence of a LKS. It can be estimated a 20 % lower involvement in vehicles equipped with LKS and *blind spot warning* than in vehicles without them; this figure was calculated without making a distinction on the severity of the accident (Utriainen R. et al., 2020).

5.2.4. Blind spot detection devices (BSD)

The term "blind spot detection devices" covers a range of technological solutions referred to as *blind spot detection, blind spot warning, side blind zone alert*, or *side-view assist*. These systems warn the driver, by means of a visual signal, when a vehicle is detected in the adjacent lane that is within the driver's blind spot; the warning may also be accompanied by an audible signal if the driver activates the turn signal.

To estimate the benefit provided by this technology, the results of the study carried out by Cicchino et al. in 2018 are reported. In particular, in order to understand the correlation between the number of accidents and the presence or absence of *Blind spot detection*, a regression analysis was carried out on different vehicle models for which information about the equipment of the vehicle itself was available. It was estimated a 20 % lower involvement in vehicles equipped with BSD than in vehicles without them; this figure was calculated without making a distinction on the severity of the accident.

5.2.5. Alcohol Interlock system (AIS)

Alcohol-related road accidents have always been a recurring theme in road safety but, despite their high media impact, they are all too often regarded as tragic events and inevitable consequences of increased motorisation.

Although their importance is therefore not negligible, in Italy so as in other countries, there are still difficulties in obtaining data and information on the real extent of the phenomenon. The role of alcohol is clear in the definition provided above (§ 2) as it can extend the perception and

[1] GALILEO, the European Union Global Navigation Satellite System (GNSS), has begun the delivery of its High Accuracy Service (HAS) in January 2023: it is the first GNSS providing high accuracy Precise Point Positioning (PPP) corrections worldwide both through the Galileo signal in space (E6-B) and via the internet.

reaction times of the driver increasing thereafter the probability that their sum results higher that the time generated by the varying element outside the vehicle (the time used by and animal to cross the road, that of a stone to fall on the pavement from a bridge, a change of the geometry of the road at a given speed, the stopping time of a preceding vehicle, etc.).

Estimates made by Carabinieri (Military Police) and Traffic Police in Italy put the percentage of accidents related to the use of substances such as alcohol and drugs at 8.7 % and 3.4 % (Fondazione ANIA, Guidoni, 2014) of all accidents. These figures are undoubtedly underestimated, given that the WHO assesses that alcohol and drug abuse are responsible for 30 % of road accidents (WHO, 2016; 2018).

Levitt and Porter (2001) research estimates that drivers with alcohol in their blood are seven times more likely to cause a fatal crash and legally drunk drivers are thirteen times more likely to cause a fatal crash than drivers under normal conditions. Regarding this theme, most of the literature on alcohol abuse during driving analyses the influence of public policy (Green et al., 2014).

Control and enforcement activities are necessary to reduce the frequency of such incidents, as the greatest deterrent for offenders is the knowledge that they are more likely to be caught committing a traffic violation.

For these reasons, the introduction of innovative ADAS devices such as the AIS results to be important. This is a device that prevents drink-driving by requiring the driver to blow into an on-board breathalyser before starting the engine. The device can be set with different limits and, if the set limit is exceeded, it does not allow the vehicle to be started.

According to research carried out by the Perelman School of Medicine at the University of Pennsylvania, the use of this device has led to an extremely positive result, with a 15 % reduction in alcohol-related road accidents. However, this reduction does not continue over time, since most studies on the effects of this device show that once it is deactivated, the frequency of such behaviour increases.

However, although there are only temporary positive effects, given the possibility of these devices being switched off by the vehicle owner, the benefit/cost ratio remains high (European Road Safety Observatory, 2018).

Fig. 3 represents a schematic representation of main possible ADAS, putting in evidence those considered within this analysis.

6. Sources and data used for the analysis

This analysis has been based on the processing of a huge amount of health data made available by the Piedmont Region, Health and Welfare Directorate, Department of Health, Essential Levels of Care and Health Building (CSI, 2022).

As for the choice of the period of analysis, a base of three years has been considered satisfactory: 2017–2019. Despite the possibility of extending the analysis of data to 2020 and 2021, these two years were considered to be completely staggered and offsetting our research, since:

a. regulatory prohibitions on free mobility during the COVID period have drastically reduced both road traffic (Caballini et al., 2021) and road accidents in many parts of the world, not only in Italy;
b. the clogging up of hospital wards for COVID-related admissions has generated major shifts of staff towards areas more involved by the pandemic, actually conditioning interventions and expenditure for hospitalisations derived from road accidents to the real capacity of the structure, in any case in a situation of much reduced low road accidents with respect to 2019. These have then only much increased in 2023, with very intense traffic flows again, similar to the pre-pandemic, but without the three-year continuity and homogeneity that 2017–2019 allowed.

The originality of the approach that has characterised this work is

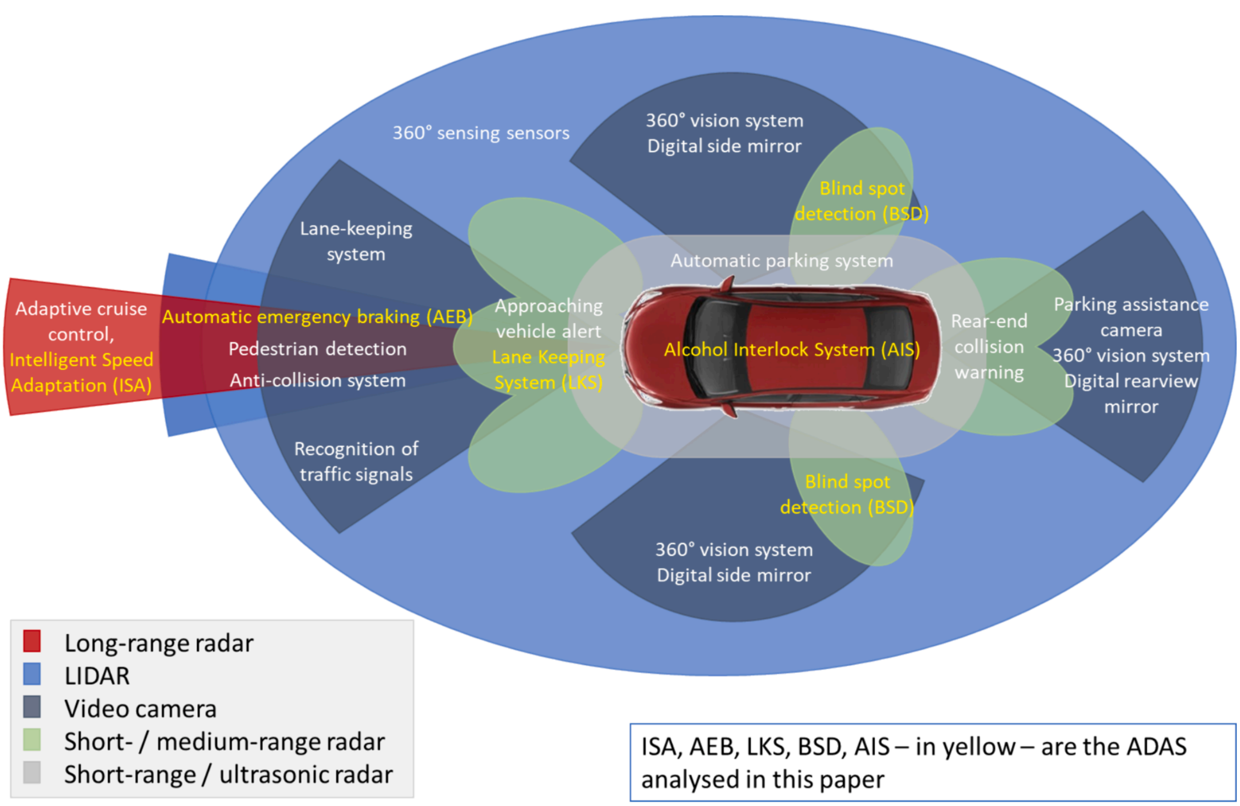

Fig. 3. Schematic representation of possible ADAS and evidence of those considered within this paper outlined in yellow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

based on the choice of having elaborated a database, starting from a series of data flows (all the calls to the emergency number 118, arriving at the emergency room, all the hospital discharge forms identified as SDO or “Schede di Dimissione Ospedaliera”), structured through the use of a special coding (“E”) present in the SDO according to the international classification of diseases, as detailed hereafter. In particular, the coding E includes all the external causes of injury, some of which concern road accidents.

The specific coding “E” allowed, for the three-year period under analysis (2017–2019), not only the classification of external causes of traumatism (e.g., types of motor vehicle accidents), but – above all – the reconstruction of the entire pathway (118 intervention, passage to the emergency room, hospitalisation) of each individual case examined.

The purpose-built database, initially consisting of 5032 observations, contains information on:

a. patient’s biographical information i.e., anonymous identification code, year, gender, age group and nationality;
b. A&E (Attendances and Emergency Admissions) data;
c. hospitalisation data contained in the hospital discharge forms or SDO, which constitute a concise and faithful representation of the medical record, suitably anonymised, in order to allow the collection of the main information.

For the purposes of this work, among the many pieces of information contained in the SDO flow, the following were extracted:

A. date of admission;
B. reasons for admission;
C. ICD-9-CM code[2] assigned to the diagnosis and description. This is an international system for classifying diseases and injuries into groups based on well-defined criteria, derived from the World Health Organisation’s ICD-9 classification. This classification comprises 17 chapters, 10 of which are devoted to specific anatomical organs or systems, while the remaining 7 describe specific types of conditions affecting the entire organism;
D. Additional classification of external causes of traumatism and poisoning. This is an important alphanumeric coding that allows the description of the events, circumstances or conditions that caused the traumatism (the subject of evaluation in this work), poisoning or other adverse factors. The ’E’ codes extracted were those identifying a road traffic accident, namely:
   - ’Motor vehicle traffic accident’ (E810-E819),
   - ’Other road vehicle accident’ (E826-E829),
   - ’Accidental traumatic injuries’ (E929);
E. date of discharge and number of days spent in hospital;
F. order of discharge diagnosis for which a distinction is made between principal and secondary diagnoses. The former is defined as the morbid condition, identified at the end of hospitalisation, that is the main cause of the need for treatment or diagnostic investigations, while the latter is a condition that may be present either at the time of hospitalisation or develop at a later time and that influences the treatment received or the length of stay. The latter must therefore be understood as a condition which is different from the principal diagnosis but which influences the care provided to the patient in a more or less important way;
G. mode of discharge;
H. the cost of a hospital stay is calculated using the DRG (*Diagnosis Related Group*) system. DRG is an international system to classify hospital cases into one of originally 467 groups, with the last group being “Ungroupable”; the system is also referred to as ”the DRGs“. The original objective of DRG was to develop a classification system that identified the ”products“ that the patient received. Since the introduction of DRGs in the early 1980s, the healthcare industry has evolved and developed an increased demand for a patient classification system that can serve its original objective at a higher level of sophistication and precision. These characteristics make the DRG classification system particularly suitable for use as a reference for the remuneration of hospital activity, to specify the in-patient services to which specific predetermined tariffs are to be attributed. The classification makes it possible to express the resources allocated to a patient on the basis of the clinical care provided, on the assumption that similar illnesses, treated in similar hospital departments, involve approximately the same consumption of human and material resources.

7. Methodology used: A novel approach

The elaboration of a special database, built starting from the “E” codes as mentioned above, that is from the classification of the external causes of traumatism, allowed to reconstruct the entire health or hospitalisation pathway, starting from the 118 interventions up to the eventual admission to the hospital, of every single case examined. This accuracy has allowed a detailed interpretation and classification of the examined cases that was more adequate and consistent with the objectives of the study than a generalist assessment.

Therefore, all patients who, in the analysed three years, presented an additional code belonging to one of the following categories were collected (Table 4): “Motor vehicle traffic accident” (E810-E819), “Other road vehicle accidents” (E826-E829), “Accidental traumatic injuries” (E929).

Subsequently, from the available descriptions associated with each “E” code, reported in the Table 4 and that can be consulted in the systematic list of illnesses and traumatisms on the Ministry of Health’s website – in Italy so as in other countries which adopt the same classification – it was possible to identify the dynamics or cause that

Table 4
Hospital admissions, classification of external causes of trauma due to the use of means of transport and mobility: codes “E”.

Code	Description
E810	Motor vehicle traffic accident involving collision with train
E811	Motor vehicle traffic accident involving re-entrant collision with another motor vehicle
E812	Other motor vehicle traffic accident involving a collision with a motor vehicle
E813	Motor vehicle traffic accident involving a collision with another motor vehicle
E814	Motor vehicle traffic accident involving collision with pedestrian
E815	Other motor vehicle traffic accident involving a collision on a public road
E816	Motor vehicle traffic accident due to loss of control without collision on public road
E817	Non-collision traffic motor vehicle accident while boarding or alighting
E818	Other non-collision traffic motor vehicle accident
E819	Traffic motor vehicle accident of unspecified nature
E826	Pedal cycle accident
E827	Animal-drawn vehicle accident
E828	Accident involving ridden animals
E829	Other road vehicle accidents
E929	Accidental traumatic injuries

[2] The International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) is based on the World Health Organization’s Ninth Revision, International Classification of Diseases (ICD-9). ICD-9-CM is the official system of assigning codes to diagnoses and procedures associated with hospital utilization. The ICD-9-CM consists of:

- a tabular list containing a numerical list of the disease code numbers in tabular form;
- an alphabetical index to the disease entries;
- a classification system for surgical, diagnostic, and therapeutic procedures (alphabetic index and tabular list).

characterised the accident according to the descriptive methods present in the ICD-9-CM classification.

The identification of the dynamics associated with the various accidents made it possible to define a number of scenarios – associated to the single road accidents – in which the installation and intervention of an ADAS device, so as described above, could have brought a benefit, making it possible to reduce the probability or even avoid the occurrence of the accident itself. The number of scenarios identified is three, divided into “Collision accidents”, “Lane departure accidents” and “Loss of control accidents”.

Accidents belonging to codes E810, E812, E813, E814 and E815 describing motor vehicle traffic accidents involving collisions with trains, with other motor vehicles, with other non-motor vehicles, with pedestrians and on public roads respectively, were grouped together in a single classification called ’Collision accidents’. The number of patients with one of the following codes has been reported in Table 5.

Claims characterised by code E811(from 0 to 9; Table 6), with the description ’Traffic accident involving a motor vehicle re-entering and

Table 5
Road accidents which belong to the class of “Collision accidents” along the years 2017 – 2018 – 2019.

Type	Description	Code	2017		2018		2019	
			Number	%	Number	%	Number	%
E810	Motor vehicle traffic accident concerning collision with train	E8100	9	32.14	21	32.31	13	41.94
		E8101	3	10.71	16	24.62	1	3.23
		E8102	8	28.57	11	16.92	13	41.94
		E8103	0	0	2	3.08	0	0
		E8104	0	0	0	0	0	0
		E8105	0	0	0	0	0	0
		E8106	1	3.57	6	9.23	2	6.45
		E8107	6	21.43	7	10.77	2	6.45
		E8108	1	3.57	1	1.54	0	0
		E8109	0	0	1	1.54	0	0
		Total	28	100	65	100	31	100
E812	Other motor vehicle traffic accident involving motor vehicle collision	E8120	27	20.9	35	31	30	28.6
		E8121	15	11.6	15	13.3	15	14.3
		E8122	35	27.1	29	25.7	28	26.7
		E8123	6	4.7	6	5.3	0	0
		E8124	1	0.8	0	0	0	0
		E8125	0	0	0	0	1	1
		E8126	5	3.9	5	4.4	13	12.4
		E8127	24	18.6	17	15	11	10.5
		E8128	7	5.4	2	1.8	4	3.8
		E8129	9	7	4	3.5	3	2.9
		Total	129	100	113	100	105	100
E813	Motor vehicle traffic accident involving a collision with another motor vehicle	E8130	21	28.77	23	27.06	35	32.11
		E8131	5	6.85	12	14.12	17	15.6
		E8132	17	23.29	20	23.53	19	17.43
		E8133	2	2.74	1	1.18	2	1.83
		E8134	1	1.37	0	0	0	0
		E8135	0	0	2	2.35	0	0
		E8136	21	28.77	19	22.35	20	18.35
		E8137	5	6.85	6	7.06	7	6.42
		E8138	0	0	1	1.18	6	5.5
		E8139	1	1.37	1	1.18	3	2.75
		Total	73	100	85	100	109	100
E814	Motor vehicle traffic accidents involving collision with pedestrian	E8140	9	11.11	1	1.64	3	3.33
		E8141	1	1.23	2	3.28	4	4.44
		E8142	0	0	0	0	2	2.22
		E8143	0	0	0	0	0	0
		E8144	0	0	1	1.64	0	0
		E8145	0	0	0	0	0	0
		E8146	3	3.7	0	0	4	4.44
		E8147	68	83.95	56	91.8	76	84.44
		E8148	0	0	0	0	0	0
		E8149	0	0	1	1.64	1	1.11
		Total	81	100	61	100	90	100
E815	Other motor vehicle traffic accident involving a collision on a public road	E8150	40	22.73	38	24.68	35	22.58
		E8151	16	9.09	16	10.39	25	16.13
		E8152	53	30.11	36	23.38	37	23.87
		E8153	3	1.7	3	1.95	4	2.58
		E8154	2	1.14	0	0	0	0
		E8155	0	0	0	0	0	0
		E8156	21	11.93	18	11.69	16	10.32
		E8157	26	14.77	30	19.48	28	18.06
		E8158	4	2.27	5	3.25	9	5.81
		E8159	11	6.25	8	5.19	1	0.65
		Total	176	100	154	100	155	100

Table 6
Road accidents that are classified as "Lane departure accidents" along the years 2017 – 2018 − 2019.

Type	Description	Code	2017		2018		2019	
			Number	%	Number	%	Number	%
E811	Motor vehicle traffic accident involving re-entrant collision with another motor vehicle	E8110	22	27	29	33	26	20
		E8111	15	18	6	7	22	17
		E8112	27	33	35	40	51	39
		E8113	6	7	2	2	10	8
		E8114	1	1	1	1	0	0
		E8115	0	0	0	0	0	0
		E8116	5	6	4	5	4	3
		E8117	2	2	6	7	7	5
		E8118	1	1	0	0	9	7
		E8119	4	5	4	5	2	1
		Total	83	100	87	100	131	100

colliding with another motor vehicle', have been renamed as 'Lane departure accidents' because they include collisions between a motor vehicle that accidentally or voluntarily leaves its lane of travel and re-enters the same lane, or the opposite lane on a separate public road, and another motor vehicle.

Finally, accidents falling under code E816 (from 0 to 9; Table 7), which describe motor vehicle accidents due to loss of control, without a collision on a public road (error in taking a bend, vehicle overturning, etc.), have been categorised under the title 'Accidents due to loss of control'.

The remaining types of accidents, although they fell into the more general category of road traffic accidents covered by the 'E' classification, were excluded from the subsequent analysis because it was not possible to identify for them a particular type of driving aid technology belonging to ADAS useful in preventing the accident from occurring. This meant that from the initial 5032 inpatients, taken together for the three years, only information from 2120 patients could be analysed.

The three indicated scenarios were then analysed according to different criteria in order to investigate a particular aspect or recurring phenomenon of the scenario considered, namely:

a) gender, aimed at determining whether there is a gender predominance in a specific incident scenario;
b) age, divided into age groups, designed to show whether in the scenarios considered there is a greater vulnerability of certain groups or a greater severity of traumas, with their outcomes;
c) nationality; this parameter was analysed in order to understand which nationalities (EU and non-EU area) were involved in the type of accidents under investigation;
d) type of person injured; this information was obtained by analysing the last digit of the 'E' code identifying the person injured in an accident;
e) in order to identify the geographical distribution of the case histories on the regional territory, an analysis was carried out by Health Authority/Hospital inpatient unit; this analysis has above all the objective of assessing a greater or lesser accuracy in the compilation of the SDOs, with regard to the coding of the external causes of traumatism ("E" code), by the hospital and the possible impact of this factor on the identification of certain areas with a higher frequency of road accidents characterised by a particular dynamic;
f) mode of discharge; identifying and analysing the mode of discharge specific to each case makes it possible to make an initial estimate of the severity of the outcomes, allowing to identify the percentage of patients who died or were transferred to other facilities for further treatment compared to patients discharged home. The first two methods of discharge indicate a greater severity of the injuries sustained by the patient than those who are discharged normally at home.

This analysis was carried out by subdividing the case histories according to the body district involved by the traumas. This was done using the Eurocost classification, which allows the classification of injuries according to diagnostic groups with different probability of permanent invalidity. In particular, this classification associates with each ICD-9-CM code belonging to a principal diagnosis the corresponding anatomical district to which it belongs, therefore, the use of this model appears useful also for calculating the costs relating to hospitalisation following a road accident.

Two parameters were then calculated for each body district within the Eurocost classification:

- Average hospitalisation;
- Average cost.

The two parameters indicate respectively the days of hospitalisation that on average are associated with a person admitted to hospital following a road accident and the economic resources spent on this hospitalisation. Through this last parameter it was possible to calculate, by means of a weighted average between the various body districts, the average cost of a hospitalisation for a particular type of accident.

Table 7
Road accidents that are classified as "Accidents due to loss of control" along the years 2017 – 2018 − 2019.

Type	Description	Code	2017		2018		2019	
			Number	%	Number	%	Number	%
E816	Motor vehicle traffic accident due to loss of control without collision on public road	E8160	37	27	48	36	29	30
		E8161	18	13	16	12	10	11
		E8162	58	43	47	35	43	45
		E8163	3	2	1	1	3	3
		E8164	0	0	0	0	0	0
		E8165	0	0	0	0	0	0
		E8166	15	11	14	11	8	8
		E8167	1	1	3	2	2	2
		E8168	1	1	1	1	1	1
		E8169	2	2	3	2	0	0
		Total	135	100	133	100	96	100

Each accident scenario has therefore been associated with one or more driver-assistance technologies which, in the scenario considered, reduce the probability of an accident occurring.

Automatic emergency braking (AEB) ADAS technology has been associated with accidents falling within the category 'Collision accidents' and therefore involving a collision with another motor vehicle, a cyclist, a pedestrian or another non-motor vehicle. According to the study carried out by the Caracciolo Foundation in cooperation with the Politecnico di Torino (Deflorio et al., 2022), the presence of this technology would lead to a 35 % reduction in collisions. Another technology that can act in this type of accident is the Intelligent Speed Adaptation (ISA) system, since the probability of not being able to avoid a collision increases with the speed at which the vehicle is moving, so at lower speeds the driver would have more time to apply corrective actions. The reduction in accidents as a result of the presence of the ISA was considered to be 25 % (Lai et al., 2012).

Lane departure incidents were associated with the following ADAS devices:

- *Lane Keeping System*; this device, having the function of avoiding an involuntary change of lane, would reduce the number of collisions that occur as a result of this type of manoeuvre. The presence of this technology would reduce the number of accidents by 28 % (Utriainen et al.).
- Blind spot detection devices: thanks to the sensor that detects the presence of another vehicle within the blind spot, it is possible to avoid a percentage of collisions of 20 % (Cicchino, 2018) that occur when, following an overtaking manoeuvre, the driver of the vehicle that has overtaken is preparing to re-enter his lane.

Finally, "Accidents due to loss of control" was associated with the ADAS for *Intelligent Speed Adaptation*, which acts on the speed factor, that is one of the main causes of accidents, by adjusting it according to the limits imposed on the road section.

The effect of the *Alcohol Interlock System* (CENELEC, 2016) was considered to be cross-sectional, i.e., its effectiveness in reducing road traffic accidents was considered to be positive regardless of the scenario since, as noted above, the risk of road traffic accidents increases exponentially with increasing blood alcohol levels, besides extending the perception-reaction overall time. The estimated percentage reduction was 15 % (Perelman School of Medicine at the University of Pennsylvania). These percentage reductions were then applied to the individual scenarios to determine the economic resources that could be saved, as detailed below.

8. Results

For each criterion defined in the previous paragraph concerning the methodology and used data, the results obtained were subsequently compared with the analyses on road accidents provided in the Italian ACI-ISTAT statistics, in order to verify any deviations. In this paper, however, only the results of the analysis obtained by data of the body district involved by the trauma are presented since it is through the use of this classification that it is possible to identify the cost associated with each scenario. In *collision accidents*, the most affected body districts result to be the lower extremities, the abdomen and the head. Analysing the two parameters of average stay (hospitalisation period) and average cost it can be seen that the most severe injuries, and therefore those with a higher value for these two indicators, are primarily head injuries, followed by spinal injuries (Table 8).

Spillage accidents or accidents derived from lane departure, whether deliberate or unintentional, mainly result in injuries to the abdomen or chest and lower limb injuries. The most serious injuries, in terms of mean hospital stay and mean cost, occur to the spine, however, due to the small number of patients with a principal diagnosis of this type these values are not considered to be highly significant, similar to the findings for minor external injuries (Table 9).

Accidents resulting from loss of control, compared with collisions, show a slight decrease in head injuries and an increase in injuries to the upper and lower body extremities. A possible explanation for this may be that motorcyclists are frequently involved in this kind of accidents, so that injuries to the upper and lower extremities are more likely as a result of less protection. The number of abdominal/thoracic injuries remains high, however, due to collisions with infrastructure elements. In contrast to the previous types of accident, the most serious consequences in this case are to be found in diagnoses involving the body district of the face, followed by the head, spine districts and the lower limbs (Table 10).

The values obtained for each individual body district associated with a given scenario were then used to make a weighted average of the total cost; a weighted average was chosen because it allows the greater or lesser frequency of the various injuries to be taken into account and therefore gives a more reliable estimate of the cost incurred by the health service in the different types of accident.

The results are shown in Table 11.

From this analysis, it is clear that collision accidents have a greater burden on the health system than the other causes; they cause a higher cost to public health than the remaining two scenarios with an average length of stay of more than 11 days. Those hospitalised people following a lane departure have a length of stay equal to that of collision accidents and a cost slightly lower than the amount spent for those hospitalised following loss of control of the vehicle, whose average length of stay is the lowest of all.

As it is not possible to understand how the different devices can interact with each other, it was necessary to consider each scenario-technology pair of interest in order to understand the *achievable savings* calculated through the following formula, proposed by the authors:

$$R_{ijk} = N_{ij} * C_{ij} * P_k$$

where:

- i is the index of the year: 2017, 2018, 2019

Table 8
Classification by body district of trauma, collision accidents, along the years 2017 – 2018 – 2019 (health data from Piedmont Region).

Injury Group (EUROCOST)	2017			2018			2019		
	Total	Average Stay [days]	Average Cost [€]	Total	Average Stay [days]	Average Cost [€]	Total	Average Stay [days]	Average Cost [€]
Head	104	13.38	10811.42	90	14.48	13248.42	109	11.18	9303.29
Face	36	7.75	4045.81	30	6.80	4071.80	27	4.48	3036.11
Vertebrae/Spine	34	13.76	9296.44	45	12.31	10197.00	36	12.31	10821.25
Abdomen/Thorax	117	10.21	6329.91	133	9.69	6929.37	131	10.92	6498.45
Upper extremity	51	8.73	4883.17	34	10.74	5278.85	44	7.48	4244.62
Lower extremity	126	11.90	6552.82	122	16.69	11060.70	121	12.77	7442.07
Minor external	6	18.17	4210.87	11	7.45	2233.47	16	3.81	1915.81
Other injuries	13	7.23	4964.84	13	21.38	11414.31	9	8.22	5706.44

Table 9
Classification by body district of trauma, accidents from lane departure, along the years 2017 – 2018 − 2019 (health data from Piedmont Region).

Injury Group (EUROCOST)	2017			2018			2019		
	Total	Average Stay [days]	Average Cost [€]	Total	Average Stay [days]	Average Cost [€]	Total	Average Stay [days]	Average Cost [€]
Head	9	6.33	3503.00	10	4.10	4635.20	18	8.72	6993.11
Face	2	8.00	1886.50	4	3.75	2533.75	8	8.63	5677.88
Vertebrae/Spine	4	14.50	9371.50	5	26.40	7993.00	12	12.50	5148.33
Abdomen/Thorax	28	11.25	5168.73	18	9.67	6046.83	40	8.80	6457.03
Upper extremity	10	8.50	3319.29	8	6.38	6891.88	16	17.56	6110.75
Lower extremity	28	11.79	5564.29	35	12.97	8095.20	30	16.33	7899.17
Minor external	1	6.00	1062.00	5	8.20	3953.88	4	35.00	9157.00
Other injuries	1	2.00	1271.00	2	2.40	1250.00	3	25.00	6031.67

Table 10
Classification by body district of trauma, incidents of loss of control, along the years 2017 – 2018 − 2019 (health data from Piedmont Region).

Injury Group (EUROCOST)	2017			2018			2019		
	Total	Average Stay [days]	Average Cost [€]	Total	Average Stay [days]	Average Cost [€]	Total	Average Stay [days]	Average Cost [€]
Head	20	12.65	16240.60	25	9.80	7598.10	14	10.10	11411.00
Face	5	6.60	2780.40	3	5.33	4012.67	2	33.00	30524.50
Vertebrae/Spine	7	9.57	5842.00	19	14.21	12637.40	7	7.00	6376.60
Abdomen/Thorax	30	7.67	5425.57	42	8.67	3688.44	40	9.90	4869.80
Upper extremity	27	4.41	2543.48	15	5.33	3470.13	13	5.70	3599.10
Lower extremity	39	11.90	6552.82	26	8.42	6580.89	15	10.30	6412.20
Minor external	5	3.40	1674.72	2	3.50	1583.50	2	2.00	3141.00
Other injuries	2	2.50	752.00	1	4.00	3492.00	3	7.00	7277.00

Table 11
Average of Average Costs and Hospitalisation, years 2017 – 2018 − 2019 (Piedmont Region health data).

Accident Type	Average of Averages	
	Average Stay [days]	Average Cost [€]
Collision Accident	11.53	7578.97
Accident due to lane departure	11.61	5974.21
Accident due to loss of control	9.06	6291.14

- j is the scenario index with 1 = collision, 2 = lane departure, 3 = loss of control;
- k technology index related to a specific ADAS (AEB, ISA, LKS, BSD, AIS);
- R_{ijk} is the savings achieved in year i for scenario j through technology k;
- N_{ij} is the number of people involved in an accident in year i for scenario j;
- C_{ij} is the average health expenditure in year i for scenario j;
- P_k represents the percentage of injuries/deaths that can be avoided by k technology.

Therefore, the application − for each technology − of the percentage reductions in deaths and injuries obtained through the state-of-the-art analysis provided the following results.

Considering for the different types of accident the technologies that achieve the minimum savings, i.e., ISA in the case of collisions and loss of control and BSD for lane departure accidents, it is possible to outline a Worst-Case scenario, for which the following annual savings are achieved:

- 721,791.79 € for the year 2017.
- 865,914.10 € for 2018.
- 772,957.81 € for 2019.

On the contrary, considering for the different accident types the technologies that allow to reach the maximum savings, i.e., AEB in case of collisions, LKS for accidents due to return to the correct lane and ISA for the "loss of control" scenario, the following total values for the three years are obtained:

- 1,635,576.69 € for the year 2017;
- 1,989,432.63 € for 2018;
- 1,822,044.01 € for 2019.

These values constitute Best Cases against a total cost of 4.7 million € in 2017, 5.6 million € in 2018, and 4.9 million € in 2019.

It must be borne in mind that they were calculated taking into consideration a number of admissions for road accidents that is decidedly lower than the size of the real phenomenon. If we consider, in fact, the percentage of admissions following a road accident for the Piedmont Region reported in the "Annual report on hospitalisation activity, SDO data 2019″ (Ministry of Health – I, 2019), equal to 4.8 % of the total admissions for trauma (41,651), it is possible to give an estimate of the real economic incidence that this phenomenon has on the Health System through the involved Health Authorities.

Considering this percentage, the number of people admitted to hospital following a road accident rises to around 2,000 for the year 2019. Therefore, extending the projections, so as calculated above for 720 hospital admissions, to the real case of 2000 people, the savings that could be obtained thanks to the adoption of ADAS, for the year 2019 alone, range from a minimum of 2,139,300 € to a maximum of 4,991,700 €.

To these items it should be added, at a later stage, the savings that would be obtained for any physiotherapy and rehabilitation services following hospitalisation, which complete the expenditure borne by healthcare, not introduced in the previous calculations because of the difficult method of estimation. Therefore, the resources saved could have a significantly higher weight on annual expenditure than in the calculations, favouring the allocation of these funds to other forms of investment. In addition, non-healthcare costs such as lost productivity, non-economic damages, and the costs of law enforcement could be drastically reduced through the use of mentioned innovative technologies – i.e. the specific ADAS taken into account − for road transport.

9. General comments on results

Road accidents imply a great incidence on hospitalisations as well as on social costs related to Public Health, all over the world.

The quite original data analysis that has been carried out in this investigation resulted in a minimum saving of 700,000 € and a maximum one of approximately 2,000,000 €/year just in one Italian Region as that of Piedmont, on the base of real data related to hospitalisations following road accidents occurred in the years 2017–2019, before the COVID period, which distorted the trends. This value rises to nearly 5 million €/year if we consider hospitalisations from road accidents related to traumas: if all hospitalisations following a trauma are taken into account, the proportion of the total cost due to road accidents has resulted around 7.3 % while accidents accounted for 15 % of the total number of injuries due to trauma.

This paper has provided initially an overview on road accidents, which have shown a significant growth after World War II, together with the spread of motorisation at personal level in most industrialised countries, at those times: road accidents have instead presented a gradual reduction from the late '90s in the same countries, thanks to various initiatives carried out worldwide as well as at national and local level; however, ADAS appear nowadays to be able to make a further breakthrough for reducing accidents.

Economic methods together with different impacts of costs of road accidents on GDP and public health around the world have been analysed. To the unquantifiable human tragedy, the cost of accidents is estimated to be close to 3 % of world GDP, with peaks around 5–6 % in some countries, placing this burden among the first ones on the national budgets, evidently associated to hospitalisations.

10. Conclusions

The attention paid to road safety for preventing accidents and their consequences have increased considerably in last two decades around the world; in Italy, too. The initiatives aimed at prevention have been accompanied by a high level of technological progress in the on-board equipment on automobiles, which is still in evolution.

It is precisely this progress that has enabled the development of ADAS, whose potential, together with the possibilities offered by other forms of behavioural and infrastructural improvement, e.g. the so-called smart roads, has proved to favour greater road safety. In the coming years, the main effects of ADAS are expected to be achieved.

This analysis allows – after having compared the methodological differences in cost estimates and having outlined the role of a data-driven international cooperation – to quantify the potential role of emerging on-board technologies for reducing deaths and road injuries, that is the issue addressed by this paper.

The percentage of admissions following a road accident for the Piedmont Region represents approximately the 5 % of the total admissions for traumas. Contextually, road fatalities in Piedmont, so as in the world, represent a relevant problem of our society being at the top of the causes of death: the ninth leading cause of death in all age groups globally and the major cause of death among teenagers. The incidence of costs for public health associated to road accidents is therefore relevant. However, ADAS may have a role on both the reduction of deaths, and this was out of the scope of this paper, and for public health expenditure: this has resulted to be not a marginal cost for the Public administration albeit sunk in a multitude of costs that Public Health has to face.

The analysed triennium (2017–2019) precedes the COVID-period, which would have been not reliable being associated to restrictions in personal mobility and to lack of staff in those hospital wards different from those directly hit by the pandemic.

Bearing in mind that the data analysed in this research do not represent all the rescues and hospitalisations concerning road accidents, but only those of them associated to Hospitals in the Piedmont Region, it has been possible to provide a cautionary estimation of the real economic impact that this phenomenon has on the Health system.

The diffusion of driving aids addressing the car as a *fail safe* system, so as the train is already, is expected to reduce public expenditure in the Piedmont Region alone in the next years, so that extending the results obtained to the other Italian regions would generate quite considerable results.

Considering once again that healthcare costs are only part of the costs borne by society as a result of such events, the effectiveness of these systems is expected to result proportionately much greater.

It is therefore possible to state with reasonable certainty that such innovations and ADAS technologies are fundamental, not only in order to get closer to ambitious targets of zero fatalities, as that of European Union by 2050, but also to achieve a safer road mobility, useful for both people and for sustainability, in environmental, social and economic terms.

Some first data are currently available on the penetration of ADAS technologies in the Piedmont Region, however they cannot be so far correlated to the actual use of vehicles that are equipped with them and this constitutes a limit for this paper. The analysis of the diffusion of ADAS can represent, for the future, a starting point for other researches aimed at proving and improving the results of this study.

Our more general conclusion is that ADAS result – on the base of the proposed methodology and its application on the case of the Piedmont Region (IT) – a fail-safe measure for road transport, suitable to generate a strong impact on public expenditure on hospitalizations, therefore a policy instrument for both Public Health and for the Transport systems domain.

Technology is indeed useful in assisting drivers and travellers in cars to protect them from accidents, as partially quantified by this paper, and this is in general an aim of engineering so as of ADAS in the analysed context; however, the fact of being assisted must not constitute an alibi to reduce drivers' attention, firstly on prudence and driving style, which implicates intervening on the demand of motorised mobility besides on the supply, that is the focus and at the same time a second limit of this paper.

CRediT authorship contribution statement

Elsa Basili: Validation, Supervision, Resources, Data curation, Conceptualization. **Carla Caschili:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Bruno Dalla Chiara:** Writing – review & editing, Validation, Supervision, Methodology, Data curation, Conceptualization. **Michela Pellicelli:** Validation, Supervision, Resources, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2024.101125.

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