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RECONSIDERING ACCIDENT CAUSATION ANALYSIS AND EVALUATING THE SAFETY BENEFITS OF TECHNOLOGIES: FINAL RESULTS OF THE TRACE PROJECT

Yves, Page

RENAULT

Thierry, Hermitte

Cyril, Chauvel

LAB

Pierre, Van Elslande

INRETS

France

Julian, Hill

Alan, Kirk

VSRC

Loughborough University

United Kingdom

Heinz, Hautzinger

IVT

Sylvia, Schick

Wolfram, Hell

LMU

Germany

Kosmas, Alexopolous

Menelaos, Pappas

LMS

Greece

Aquilino, Molinero

Jose Miguel, Perandones

CIDAUT

Jose Manuel, Barrios

IDIADA

Spain

Paper Number 09-0148

ABSTRACT

The objectives of the EU-funded project TRACE (TRaffic Accident Causation in Europe, 2006-2008) are the up-dating of the etiology of road accidents and the assessment of the safety benefits of promising technology-based solutions.

The analyses are based on available, reliable and accessible existing databases (access to which has been greatly facilitated by a number of partners highly experienced in safety analysis, coming from 8 different countries and having access to different kinds of databases, in-depth or regional or national statistics in their own country).

Apart from considerable improvements in the methodologies applicable to accident research in the field of human factors, statistics and epidemiology,

allowing a better understanding of the crash generating issues, the TRACE project quantified the expected safety benefits for existing and future safety applications.

As for existing safety functions or safety packages, the main striking results show that any increment of a passive or active safety function selected in this project produces additional safety benefits. In general, the safety gains are even higher for higher injury severity levels. For example, if all cars were Euro NCAP five stars and fitted with EBA and ESC, compared to four stars without ESC and EBA, injury accidents would be reduced by 47%, all injuries would be mitigated by 68% and severe + fatal injuries by 70%.

As for future advanced safety functions, TRACE investigated 19 safety systems. The results show that the greatest additional safety gains potential are expected from intelligent speed adaptation systems, automatic crash notification systems, and collision warning and collision avoidance systems. Their expected benefits (expected reduction in the total number of injured persons if the fleet is 100% equipped) are between 6% and 11%. Safety benefits of other systems are more often below 5%. Some systems have a very low expected safety benefit (around or less than 1%).

INTRODUCTION

The European Council for Automotive Research (EUCAR) launched in 2001 an initiative to develop a systemic approach to the problem of road safety: **Integrated Safety**. The idea was to revisit the Safety problem with a holistic System Approach. In 2008, a few projects (AIDE, PREVENT, EASIS, APROSYS, SAFESPOT, CVIS, WATCH-OVER, etc.) have already produced methodologies and results. Just a few of these research integrated projects or sub projects (i.e. Aprosyst, Prevent-Intersafe) called for prior analysis in order to start further tasks (development of models, simulations, technologies, demonstrators, tests, etc.) on a thorough understanding of the real-world problems. Consequently, this knowledge is sometimes considered as a missing plinth.

Simultaneously, an eSafety Forum was established by the European Commission DG Information Society in 2001 as a joint platform involving all road safety stakeholders. The Forum adopted twenty-eight

recommendations towards the better use of Information and Communication Technologies (ICT) for improved road safety. But, even though former research in accident causation and impact assessment produced a tremendous amount of knowledge, the exact nature of the contribution that ICT can make to road safety could not be determined because consistent EU-wide accident causation analysis was not sufficiently available to gauge this impact. Consequently, the first of these recommendations sought to consolidate analyses from existing accident and risk exposure data sources for a better understanding of the causes and circumstances of road accidents and to determine the most promising and/or effective counter measures. The second recommendation called for the establishment of a common format for recording accident data to develop an information system covering all EU Member States.

Simultaneously, The EU was funding an important project, SafetyNet (The European Road Safety Observatory), which particularly aims at making consistent accident data collection protocols in several EU countries and at constituting an accident databank on injury and fatal accidents.

But the project had just started in 2004 and would provide neither accident data, nor accident analysis in the short term. Moreover this project did not aim at identifying relevant methodologies to evaluate the effectiveness and efficiency of safety systems based on technology. To try to overcome these problems in the short term, one of the e-safety Working Group (Accident Analysis) examined available data sources which were known to them.

The analysis confirmed the hypothesis of the working group that although many information sources already existed, they were not enough as they currently exist to provide Europe with the analysis it needs because the picture obtained was a mixed one. Some data sources were never designed for the purpose of coordinated analysis and therefore have little potential. Some others have their main focus on passive safety, biomechanics or traumatology and do not give much insight into the *causes* of the accidents they contain. Others have considerable potential.

Based on this qualitative analysis of existing sources the working group recommended to the eSafety Forum that existing sources could nevertheless help to give a better understanding on accident causation and to evaluate (at least partially) the effectiveness of some on-board safety functions, if shared analysis mechanisms are employed to interrogate the different data sources and share the results.

The TRACE proposal was born. It was submitted to the EU in 2005, with two main objectives:

- The determination and the continuous up-dating of the **etiology**, i.e. causes, of road accidents and the assessment of whether the existing technologies or the technologies under current development address the real needs of the road users inferred from the accident and driver behavior analyses.

- The identification and the **assessment** (in terms of saved lives, injuries mitigation and avoided accidents), among possible technology-based safety functions, of the most promising solutions that can assist the driver or any other road users in a normal road situation or in an emergency situation or, as a last resort, mitigate the violence of crashes and protect the vehicle occupants, the pedestrians, and the two-wheelers in case of a crash or a rollover.

This current paper gives a synthesis of the principal striking TRACE outcomes. It is therefore a non-comprehensive summary of what is available in the 32 technical and scientific reports that TRACE has generated. The reader is highly encouraged to look at the technical reports for a more in-depth inquiry into TRACE objectives, challenges and achievements.

The paper is split up into 3 chapters. The first one 'Methodologies' briefly reports about methodologies developed in TRACE with regards to human factors analysis and statistics. The second one 'Accident Causation' reports about the first objective of the project, whereas the third one 'Evaluation' reports about the second objective.

Please see [27] for further information regarding the project structure of TRACE and the involved partners.

METHODOLOGIES

Human Factors

Accident causation can seem misleadingly simple, nearly obvious. It is thus often assumed that there is one cause or one road user responsible for an accident and that it would just take determining that cause or this responsible road user, suppressing the first and punishing the second, to prevent the accident occurring. Maybe such a view had reached a relative validity in the old times of the driving system when monolithic defects were easy to diagnose. However, it is less and less proving to be efficient as the system is continuously improving on the basis of research and developments addressing the different components involved. The problem is that, more and more, a cause becomes a cause only if it combines with several other hidden ones, and the so considered 'responsible road user' is more and more the heir of the influence of these combination of factors intervening in the driving interactions. Road safety of the 21st century has become a matter of complexity, apart from some residual extreme cases showing

atypical accident patterns (e.g. involving big holes on the road, breakdown of the car brakes, aberrant drivers' behaviours). In order to keep improving safety, it has become essential to study this complexity. And the more we will gain in safety, the more thorough research works will be necessary to go on progressing.

The European TRACE project is turned towards developing a better understanding of accident causation, in order to reach the definition of more appropriate preventative measures, involving notably electronic safety functions.. Along this objective, Work Package 5 'Human Factors' of this project has been designed to contribute to the development of a deeper analysis of the difficulties encountered by the human component, the road user, in order to promote an improving of the driving system which is put at his disposal. The work done in TRACE WP5 has led to several operational grids of analysis, in line with theoretical models, which offer a means to progressing the understanding of the human role in accident generation, and in the methods allowing a better diagnosis of the causes of human errors, violations, and exceeding capacity. The underlying concept behind these grids is oriented toward a 'safe system model', keeping in mind that the purpose of any device dedicated to a human use should be conceived and built in a way of neither being problematic nor dangerous for its users. So should be the driving system.

In a first step, a grid has been created for analysing the operational difficulties that human beings can find in driving, potentially resulting in accidents [16]. This grid delineates so-called 'Human Functional Failures' (HFF) representing the weaknesses and limits in adaptive capacity of the human functions (perception, comprehension, anticipation, decision, action) to which drivers appeal in order to drive efficiently. And as far as an accident is not intentional for anyone (otherwise it is no more an accident) each HFF is considered as the result of a malfunction characterizing the driving system as a whole. It is a symptom which manifests a wrong interaction between a road user and his driving task environment. Human failure should not be considered – which is often the case - as the cause of the accident but rather as a weak link in a malfunction chain, this chain being necessary to find out if any efficient solution is thought to be defined. Thus, once a human functional failure is diagnosed, it still has to be defined which factors and which contexts have originated it.

The problem with many accident causation coding systems currently used across Europe is that they do not separate the 'errors' (or human functional failures) from the 'factors' which lead to these

failures. The second step of the methodological work consisted in building a grid allowing the determination of all the elements (factors) - would they be referring to the road layout, the vehicle parameters, the driver or the traffic surrounding - that could originate or favour a Human Functional Failure, not confusing these factors with their consequences [17]. A complementary grid also provides a classification of 'pre-accident driving situations' in which human failures occur. These pre-accident driving situations are built from a combination of: 1- the types of driving tasks (e.g. overtaking, crossing, turning), 2- their location (e.g. intersection, straight road, roundabout) and 3- the potential conflicts met in the situation (e.g. pedestrian crossing, oncoming vehicle, car door opening). The precise characterisation of these pre-accident situations in accident studies allows definition of the circumstances in which road users find difficulties.

A third step of this methodological work consisted of providing a method allowing the aggregation of similar accident processes on a multidimensional level (a scenario) [18]. The method consists in building typical scenarios of human failure production, integrating the elements studied in the previous steps. The Typical Human Functional Failure Scenarios represent the regularities which can be found in the process governing similar accidents. They are expressed under the shape of chains which connect a pre-accident situation, explicative elements involved, a consequent human functional failure and a resultant critical situation leading to a crash configuration. But a main difficulty in the determination of all these detailed variables is the necessity to base them upon in-depth accident data performed by specialists in the different domains. In order to allow accidentologists using data that doesn't fulfil these ideal conditions (i.e. in-depth, involving psychologists), we have defined the most frequent scenarios found in the study of a large sample of in-depth accident cases, on which to base in order to recognize the overall process on a 'family air' basis, which can be done from less in-depth data.

A last methodological work performed in TRACE WP5 is differentiated from the previous ones in its more prospective purpose. It was aimed at enlarging the classical view on driving behaviour determinants by incorporating the social and cultural dimensions as further upstream factors of human functional failures. Factors such as culture, social status or specific social group membership have an identifiable influence on individual behaviour. It presents a scheme of analysis built upon the notion of 'social spheres' [19]. This scheme is aimed at showing the relative influence of the different layers ('spheres') of socio-cultural variables that are located outside the individual

sphere and which can potentially have a latent or manifest influence on the production of an accident. The integration of such socio-cultural background variables in the analysis of human failure production has the potential to increase the understanding of the accident causation process and to find additional means to fight against. These aspects should notably be taken into account when dealing with driving aids, so as to appropriately answer the needs and constraints coming from different drivers' social groups.

The different deliverables of WP5 have been provided to progress the search for understating accident causation and its underlying and upstream determinants. As such they contribute to the European TRACE project objectives of promoting a scientific knowledge on accident causation, so as to better defining the safety measures able reducing it. In this respect, the overall point of WP5 is to remind that the road user is the core of the driving system, and human performance the measure of its effectiveness. That is why possible human failures must be studied in-depth, their causes and producing contexts clarified in order to put forward the most efficient measures able at harmonizing human travelling behaviour inside the traffic system. The methods proposed regarding as 'Human Factors' allow a more integrative approach inside accident research in Europe. This is being done in numerous studies conducted in TRACE operational work packages, addressed to the different road user groups (elderly drivers, PTW, passenger cars, gender issue, etc.), to the main identified driving situations (intersection, specific manoeuvres, degraded situations, etc.) and to the most involved factors (vigilance, attention, experience, infrastructure, etc.). These different studies increase the understanding regarding human factors in accident causation and the necessity to develop a safe system well addressed to human needs. And the 'human factors' methods put forward in TRACE WP5 will be useful and constructive when considering the building of a comprehensive European road safety observatory.

Statistical Analysis Methodologies

The overall objectives of TRACE WP7 'Statistical Analysis' have been twofold:

- to improve statistical methodology for diagnosis of road safety problems and evaluation of promising technological solutions
- to provide methodological advice and statistical services to other TRACE work packages.

In its empirical part, the TRACE project exclusively relies on *existing* European data on traffic safety. Thus, statistical methods for collecting accident and

exposure data have not been treated. Rather, quantitative methods serving the following purposes have been investigated:

- methods for improving the usability of existing accident and exposure databases
- methods for traffic accident causation studies
- methods for accident and injury risk studies
- methods for safety functions effectiveness evaluation and prediction.

WP7 has also provided traffic safety researchers with a statistical expansion method for addressing accident causation issues at European level accounting for the fact that accident and exposure data availability varies substantially between the countries.

In all these areas the scientific work under WP7 has developed operational statistical models in the conceptual framework of general "systemic" theories of the accident generating process. Emphasis was put in WP7 on careful selection, adaptation and application of appropriate classical and newer implementation-ready methods from the various fields of the statistical sciences. For all results both scientific rigor for the statistical community and accessibility for empirical accident researchers had to be achieved. The principal aim of WP7 was to provide best practice examples of high-quality traffic safety research using up-to-date statistical methods.

Improving the usability of existing accident databases.

The purpose of this activity has been to enable traffic safety researchers to make best possible use of existing European accident and exposure databases [21]. Therefore, the task has covered methods to overcome typical accident and exposure data quality problems like missing values, missing variables and biases due to selective data collection.

Under certain conditions data quality problems of the types listed above can be overcome using appropriate statistical methods: imputation methods for treating data with missing values, data fusion methods for supplementing missing variables and weighting and expansion methods for reducing biases due to selectivity of sampling in in-depth studies have been studied.

Frequently, researchers need to address accident causation issues at the European level in situations where no complete empirical data is available. Therefore, an expansion method for creating synthetic tables at EU level, by combining detailed data from regional studies or national sources with coarser structural information on traffic accidents in Europe as a whole under an appropriate statistical model, has been developed.

Analysis methods for accident causation studies.

It is obvious that accident causation analysis is a

matter of importance in TRACE. In order to provide appropriate methodological support to the operational work packages, this task deals with analysis methods for accident causation studies. Emphasis lies on exploratory or hypothesis-generating methods, as confirmatory or hypothesis-testing methods of accident and injury risk analysis [23].

First, a theoretical framework for causal analysis in accident causation research has been proposed and problems linked with establishing causal relationships have been discussed. Then, in view of the huge volume of many accident databases, some data mining tools have been investigated which are highly relevant for accident experts. Specific 2D graphical representations (self-organizing maps) of the different risk factors can provide, at a glance, a qualitative understanding of possible accident causes. In a subsequent step, information theoretic methods (mutual information ratio) can be used to quantify more precisely the impact of each single factor. By automatic learning, a function can be constructed to forecast, for instance, accident severity given a set of pre-selected factors.

In addition, nonparametric statistical methods which do not require any model presumptions have been examined and applied to measure the relationship between injury risk and potential determining factors.

Analysis methods for accident and injury risk studies.

In studies of traffic accident causation, researchers frequently aim to assess risk factors for accident involvement and accidental injury. Consequently, this task provides the operational work packages of TRACE with appropriate methodological tools from accident and injury epidemiology [22].

As different types of accident and exposure databases are encountered in the TRACE project, special emphasis is placed on study designs which fit to the available data sources. Among other things, it has been shown how to conduct accident causation studies using easily accessible routine accident and exposure data under different study designs such as, for instance, the case-control design. Analysis methods for accident causation studies relying exclusively on accident data (concept of induced exposure) have also been critically examined. The tailor-made statistical tools treated in this task enable accident researchers to identify whether there is a relationship between a set of potential risk factors and accident involvement or accidental injury.

In order to make the statistical concepts and methods easily accessible also to researchers who are not experts in statistics and/or epidemiology, numerous examples and detailed empirical case studies have been integrated in the technical reports.

Evaluation of the safety benefits of existing safety functions: statistical methodologies.

The aim of this task has been to develop and improve quantitative methods for ex post evaluation of the effects of specific in-vehicle safety functions. Appropriate analytical approaches have been investigated for this purpose. The methods developed under this task have been extensively applied in TRACE WP4 "Evaluation" [24].

The scientific work deals with statistical methods for evaluating safety features which are already on the market. The methods - exclusively relying on empirical traffic accident data - are not only suitable for the evaluation of individual safety devices but may also be applied to assess any combination of passive and active safety features. It is shown in detail how to compute accident avoiding effectiveness as well as injury avoiding and injury mitigation effectiveness taking account of confounding factors where necessary. The methodology is demonstrated on real-world data examples.

Concluding remarks. Basically, the scientific work carried out under TRACE Work Package 7 "Statistical Methods" has dealt with the following two questions:

- How can statistical methods contribute to improve our empirical knowledge on traffic accident causation in Europe?

- How can statistical methods contribute to identify safety systems suitable for traffic accident prevention and accidental injury mitigation?

The application of statistical methods in the field of traffic safety has a long tradition. Thus, it was clear from the outset that among the statistical sciences especially the discipline of *epidemiology* offers a wide variety of concepts, methods and models that can be applied either directly or after some proper adaptation to answer the above research questions.

- Study of the *incidence* of accidents and of the frequency distribution of accident characteristics is essentially a descriptive exercise. This, however, does not mean that only the methods of descriptive statistics are relevant. As accidents and accidental injuries occur randomly, analytical methods based on probability models, e.g. models and methods of sampling theory are needed already at this stage.

- Research on the *determinants* of road traffic accidents can best be conducted under an epidemiological framework providing the accident researcher with suitable study designs and analysis tools. Study of determinants considers the *aetiology* of accidents and accidental injury. In this context, of course, a distinction has to be made between potential and proven aetiological agents. Especially when

using routine data on traffic participation and accident involvement the empirical findings referring to risk factors for accident involvement may be largely descriptive and should not be over-interpreted in a causal sense.

- Likewise, assessment of the *effectiveness* of innovative safety systems already launched onto the market must also observe the methodological principles developed in epidemiology. Ex post evaluation of new safety systems should especially utilize the methodological principles developed for observational studies where it is difficult or even impossible to find a control group in the classical sense. As has been shown in the TRACE Reports, proper epidemiological model building is essential if meaningful conclusions on the effectiveness of single or multiple safety functions are to be drawn.

As can be seen, statistical methods in general together with specific concepts established for high-quality epidemiological research are indispensable tools both for establishing accident causation factors and for evaluating safety systems aiming at accident prevention and injury mitigation.

In the TRACE reports, a large number of classical and newer statistical methods, including methods from the field of artificial intelligence, have been investigated and explored for use in accident causation studies and safety system assessment. As can be expected, these methods differ in their degree of suitability for accident research purposes. In the conclusions, this aspect is addressed. In addition, it is always clearly stated whether or not the method under consideration is accessible to traffic safety analysts not specializing in statistics or should better be applied by statistical experts only.

Not surprisingly, one comes to the conclusion that high-quality research on traffic accident causation presupposes correspondingly high methodological standards. These standards, of course, can best be ensured in interdisciplinary teams involving experts from statistics and epidemiology. The TRACE project serves as a good example of this.

Data

Work Package 8 was the data provision work package of the TRACE Project [25]. The analysts working in the other Work Packages were able to request data from designated data providers. The objective of Work Package 8 was not to produce a database of harmonised data. It was to provide suitable aggregated data (crosstabulations) from existing individual databases that analysts could consider in answering the specific research questions of the Work Packages.

The main features and achievements of the work of Work Package 8 are summarised below.

An effective Data Exchange Methodology that is both understandable and suitable has been put in place, allowing TRACE to make the best use of existing data.

Participants in Work Package 8 have successfully prepared large, complex sets of data tables for the analysts in the Operational Work Packages of TRACE.

- At least 940 requested tables, in 83 worksheets, as part of 23 data requests have been handled.
- Approximately 3,700 tables of data have been prepared and returned to analysts. The concept of counting data packages and monitoring effort has had to evolve and be reshaped as the project developed but the volume of data exchange is as large, if not more, than originally planned.
- In light of an expected lack of risk exposure data, analysts have been provided with a tool to understand and access a wide range of data already published.

Recommendations for future European data gathering activities are made, along with support to current initiatives from a TRACE perspective:

- Continuing harmonisation of variables and definitions, for descriptive, in-depth and exposure data. This would allow both easier data provision and analysis.
- Development of a Pan-European accident classification coding system. Accident classification is an important step in both understanding accident causation and evaluating the potential of new safety systems.
- Harmonisation of accident causation coding systems. Any proposed systems should be tested against the broad and in-depth questions posed in the TRACE tasks.
- Development of European field operational tests. An understanding of human interaction with new vehicle technologies (both for safety and comfort) will allow a much fuller evaluation of the potential effect of such devices on safety.
- Development of European risk exposure data. Greater availability and depth of risk exposure data would allow a new perspective on the analysis of accident causation.
- Further development of the CARE database and interface. More countries would allow a better European context, and further development of the interface would give more flexibility when examining specific accident scenarios.

ACCIDENT CAUSATION

Current knowledge needs to be structured and linked to specific research angles and analysed according to specific methodologies to avoid misunderstanding and to allow a clear view of what accident causation is. Therefore, TRACE had three different research angles to cover accident causation issues:

- The **Road user approach**: it allows identifying specific causation factors for specific road users.
- The **Types of situation approach**: as the road user can be confronted with different driving situations, that can develop into different emergency situations, that deserve specific analysis regardless of the road user type.
- The **Types of factors approach**: factors can be identified and observed according to social and cultural factors, factors related to the trip itself and factors related to the driving task.

These 3 approaches are developed according to three different kinds of analyses:

- A macroscopic statistical analysis aimed at describing the main problems.
- A microscopic analysis aimed at describing the accident mechanisms with the use of in-depth data.
- A risk analysis aimed at quantifying the risk factors in terms of risk, relative risk and, where possible, attributable risks.

TRACE produced a lot of research outputs combining these three approaches and these three types of analysis. We are reporting below only the main findings [1, 2, 3, 4, 5, 6, 7, 8].

Types of factors

A variety of theories on accident causation exists and up until today no synthesis has emerged [5]. Theories

and models reflect peoples' views on reality to explain complex relations in simplified ways. The motivation lies in the belief that every accident can be prevented, if the causes for this accident can be eliminated. Accident Models help to understand the occurrence of traffic accidents and give answers to questions on how and why accidents happen, where and when they take place, and who is involved, and furthermore to find according preventive measures.

Epidemiological studies can reveal risk factors for crashes that increase the chance for an accident to occur or the chance for someone to cause, or just be involved in an accident. Additionally, in-depth accident research identifies factors that contributed to a specific accident and are able to explain the occurrence of the accident. This is done by applying causality to certain factors that led to the accident. Most in-depth accident databases provide a list of factors, from which the investigator can choose the factors that contributed to the accident. Some investigation classifications code key events or triggering factors, in addition to also considering the most important factors, or the last factors, that finally caused the accident in the causal chain in time, respectively.

Of course, usually one factor cannot cause an accident. Most often a combination of contributing factors, forming a sufficient cause, leads to the accident [5, 16].

In the model, the classification of accident related factors is two dimensional. One dimension is expressing the time (accident process) by levels, and the other dimension reflects the origin from where a factor stems from (from a "traditional view") by components. Generalised examples are used in the table 1 to visualize the classification of factors.

Table 1. Classification of accident related factors

Levels and Components	Background factors	Trip related factors (task 3.3)	Driving task associated factors (task 3.4)
Environment	Modes of Transport, Climate	Road characteristics	Road and light condition
Vehicle	Vehicle fleet, safety standards	Vehicle type and maintenance status	Vehicle condition and performance
Human	Transportation politics, Socio-demographic characteristics (task 3.2)	Physical and mental state	Actual behaviour and performance

The analysis showed that already on a random choice of cases, a lot of sociological and cultural factors are

found, that influence the following acts, behaviours, vehicles involved in the accident etc. But, of course it

is not possible to explain every accident in sociological terms. And this is not wanted from a prevention point of view, which in modern society of course tries to protect the individuals but also tries to give responsibility back to the individual. It is however, necessary to know the underlying reasons for some factors found on a trip or even driving task level. Sociological and cultural factors are just one component of the background factors, although strong interactions between those factors and environmental and vehicle related factors on a background level can be expected.

It has been possible to identify not only the most 'typical' characteristics of accidents where trip related or driving task-related factors are involved but also to identify the main reasons for what went wrong in the accidents where these factors and their associated characteristics, are present.

After screening literature and accident databases to find, define and classify relevant factors, the results from methodological WP's were also taken into account to decide how to proceed. It was decided to especially analyse accidents where the following factors contributed by statistical database analysis and some of the factors also by in-depth case analysis: alcohol, vigilance, experience, vehicle condition, road condition and layout, attention, sudden health problems, speed (including 'inappropriate speeding' and 'illegal speeding'), and technical defects.

Factors are regarded to be relevant either by risk increase or by high prevalence as contributing to accidents. After screening literature and accident databases to find, define and classify relevant factors on the trip and driving task level, the results (methods) from methodological WP's were then applied to accidents caused by the relevant factors.. Following factors were analysed by statistical database analysis and by in-depth case analysis applying the WP5 human functional failure analysis: alcohol, vigilance, experience, vehicle condition, road condition and layout, attention, sudden health problems, speed (including 'inappropriate speeding' and 'illegal speeding'), and technical defects.

According to the different methods and databases used the results are manifold when analyzing accident causation from a factors point of view. One interesting result e.g. is that an alcohol related accident is predominantly found for pedestrians and/or cyclists in the UK, Germany and the Czech Republic, whereas in Spain, Italy, and France all road user groups are affected. Another example for the results is the notion that if a young driver (<25years) is involved in a driving accident with frontal impact on a rural road with a speed limit between 60 and 100km/h in winter and nighttime, then it is very

likely that the road condition and layout contributed to this accident. And the next example stems from the functional failure analysis for alcohol related accidents: Whereas the primary active road user (the one inducing the accident situation) often is the impaired one showing loss or restrictions in consciousness and ratio, for the opponent often visibility (of the active road user) plays an important role in contributing to the accidents occurrence. The failures of "Expecting a non-priority vehicle not to undertake a manoeuvre in intersection" or "Road user surprised by a pedestrian (or two-wheeler) on approach" shows a tendency for the fact, that the primary active road user (here: the alcoholised one) performed unforeseeable actions that were not possible to see (visibility) or predict from the opponents point of view and the accidents therefore hardly to avoid.

In general it has been possible to identify not only the most 'typical' characteristics of accidents where trip related or driving task-related factors are involved but also to identify the main reasons for what went wrong in the accidents where these factors and their associated characteristics, are present.

Types of users

TRACE WP1 (Road Users) addressed the analysis of the different accident causation mechanisms of each of the road user groups (passenger car occupants, powered two wheelers, van, bus and trucks occupants, pedestrians and pedal cyclists, elderly people and gender related crashes). Some of the findings for passenger car occupants are reported below, after having given a look at the general statistics of mortality (figure 1), which show that other road users are also of high interest in terms of mortality and accident process. Other findings for the other types of users are available in the TRACE reports [1, 2].

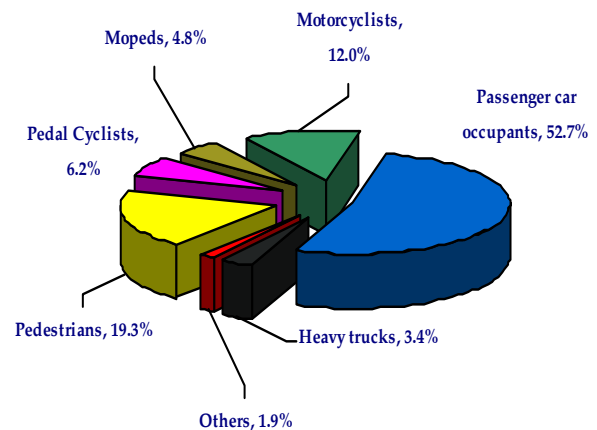


Figure 1. Distribution of Road Fatalities on the European Roads (Source: ERSO).

Passenger Car Drivers. When examined from the angle of human functional failures, it can be noted that cars drivers are particularly prone to perception errors, this category of failures being observed in 35.7% of the cases that compose the studied sample.

The most frequently identified pre-accident situations are spread between the driving 'Stabilized' situations and the tasks to perform when managing intersection crossings ('Going ahead on a straight road' 15.2% and 'Crossing intersection with a priority vehicle coming' 12.7% are the most frequent pre-accident situations observed in the sample).

The study of explanatory elements also brings information on the way functional failures occur. Several elements come out ('Atypical manoeuvres from other users', 'Road over familiarity or monotony of the travel', 'Choice of too a high speed for the situation', etc.), but it can be seen that again the distribution of the elements is wide-spread.

These results shed light to the interest of looking at the data in a more relevant way than the overall one, so specificities can emerge more clearly. Two categories of crashes have been studied: Single cars accidents and cars vs. other road users.

When analysed separately, the drivers of the single car accidents sample feature a specific profile. Firstly because their accident happens when the task to perform is quite simple: the pre-accident situations are always related to stabilized situations and more specifically to guiding the vehicle on the carriageway (either on straightway road or during curve negotiation).

Additionally, the human functional failures associated to those drivers are typical of losses of control. Here are found, in 40 % of cases, handling difficulties (associated with attention impairment or external disturbance such as wet carriageway or wind blast).

The losses of psycho-physiological capacities are also found in the same proportions (38.7%) as being the cause of the single car accident. This loss is mainly due to psychotropic intake (alcohol for the major part of the drivers) but the drivers falling asleep account for 15.4% of those accidents.

At last, in 1 case out of 5, the drivers have had troubles to perform a correct evaluation of a road difficulty. Those losses of control are related to changes in road situations in almost 1 case out of 4 but the layout is not the only element that should be underlined here. The majority of factors are endogenous, that is associated to drivers' states or their conditions of task realization. What is found as having an influence on the losses of control are: in one third of the cases, the alcohol intake; the speed chosen by the drivers (36.7%); the level of attention

allocated to the driving task; and at last the level of experience of the road users, either concerning their driving knowledge, the familiarity they have of their vehicle or of the location of the accident.

All these explanatory elements have a role when combined with each other until the drivers fail to perform the task, although quite simple, as if this particular association of parameters was having influence on the most rooted abilities developed in driving activity, the skill-based ones. On the other hand, the accident mechanisms observed for the group of multi-vehicles collisions are various. First in the tasks to realize: they cover many pre-accident situations and concern stabilized situations as well as intersection crossing of specific manoeuvres. This heterogeneity is also found in failures and explanatory elements. It is then with the help of the typical generating failure scenario that light is brought on the specificities of this population.

Perceptive failures are central in these kinds of accidents and they reveal the multiplicity of the problems encountered by the drivers when they interact with others:

- Visibility constraints are decisive in almost 6% of the accidents cases, especially when they prevent the drivers from detecting the atypical manoeuvre of the other road users.

- The search for directions and the monitoring of potential conflict with others are the causes of monopolisation of the driver's attention, leading him to not detect the relevant information.

- A low level of attention devoted to the driving task has also impact on the detection of the other, especially if the task to perform is familiar and if the environment is dense and the traffic important, or if the driver is lost in his/her thoughts.

Misleading indications are also at the origin of some 'Processing' distortions. A same indication sometimes having several meanings and being then ambiguous, the driver undertakes the wrong manoeuvre regarding the other's behaviour.

The wrong expectations concerning the others' manoeuvres are also very represented in this sample of passenger cars drivers. Although those manoeuvres are sometimes difficult to anticipate, the rigid attachment of their right of way status that the drivers develop is generally at the core of the scenarios putting forward those 'Prognosis' failures and scenarios.

Types of situations

TRACE identified four specific groups of situations covering the majority of the real-world driving situations:

- Stabilized Traffic Scenarios concerning every normal driving situation that can become risky due to specific failures (e.g. guidance errors) or sudden conflict situations with other road users.
 - Specific Manoeuvre Scenarios including accidents due to scenarios created by performing specific driving manoeuvres (e.g. overtaking, U-turning, car-following, joining a carriageway, etc.).
 - Degradation Scenarios gathering accidents concerned with the presence of factors which degrade the road way, the environment (fog, heavy rain) and trigger accidents.
 - Intersection Scenarios that concern every situation occurring at or close to an intersection.
- Examples of analysis concerning the three first situations are given below. Intersection scenarios are reported in a separate paper .


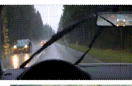

Stabilized situations. These situations represent 49% of the total number of situations in EU27 and 33% of the total number of injury accidents in Europe (estimation relying on results coming from Spain, UK, France, Greece and Czech Republic). The main results regarding the identification of the causes are the following:

In-depth analysis	Collision with a pedestrian	Lane departure/ run-off accident	Accident with more than one vehicle
Key events	Pedestrian has a recognition error, crossing or invading the road illegally. Also, the pedestrian made an error recognition and low level of attention	Speeding Decision error Alcohol impairment Low level of attention Environmental perturbation Complex or difficult site, narrow road	Opponent error: Speeding Opponent car decision error Stabilized car decision error Stabilized error: Not keeping safe distance Stabilized error: Low level of attention
Human Functional Failures	Detection: The passenger car driver was surprised by the pedestrian non visible	Diagnosis stage: The passenger car driver has an erroneous evaluation of the hazard in a context of playing driving and of an although known bend. Handling stage: Guidance interruption consequently to attention orientation towards a secondary task	Handling stage: The stabilized vehicle sudden encounter of an adverse disruption. Loss of psycho-physiological capacities consequently to a falling asleep or ill-health from the opponent vehicle. Detection: Late detection of the slowing down of the vehicle ahead
Risk factors (Increase)	Straight sections Pedestrian gender (male)	Driver gender: male Bad weather conditions Single carriageway road Sharp curve Night lightning	Slight curves Bad weather conditions Night lightning Double carriageway road

Specific manoeuvres. These situations represent 7% of the total number of situations in EU27 and 24% of the total number of injury accidents in Europe (estimation relying on results coming from Spain, UK, France, Greece and Czech Republic). The main results regarding the identification of the causes are the following:

Key events	Overtaking	Turning left	U-turning	Changing lane
Key events	1. Internal conditions of the task: a. incorrect driving manoeuvre b. Poor evaluation / anticipation 2. Driver behaviour Looked but did not see			
Contributing factors	1. Inadapted speed 2. Careless, reckless or in a hurry 3. Risky driving 4. Excessive speed	1. Automatic driving 2. Global time constraint 3. Risky driving 4. Mobile mask	1. Risky driving 2. Global time constraint 3. Low level of attention 4. Careless, reckless or in a hurry	1. Recklessness 2. Risky driving 3. Alcohol / drugs 4. Inadapted speed
Human functional failures	1. Decision 2. Action 3. Diagnosis	1. Perception 2. Decision 3. Diagnosis	1. Perception 2. Decision 3. Diagnosis	Not available
Counter-measures	- To adapt the speed to the situation and to the legal limit speed - Collision warning system - Collision avoidance system - Inter-vehicle communication system - Lane changing assistance - To respect laws - ECOTCS	- Inter-vehicle communication system - To respect laws - To help the driver to see	- Help sp of monitoring rear-vehicle communication system - To respect laws	- Inter-vehicle communication system - Alcohol and drug prevention - To adapt the speed to the situation and to the legal limit speed

Degradation situations. The accidents in degraded conditions (in dark and/or bad weather conditions only) represent 35% of the total number of injury accidents in EU27, 46% of the overall fatalities (3% of the casualties in degraded situation) and 39% of severely injured (14% of the casualties in degraded situation). The main results regarding the identification of the causes are the following:

	Key events	Human functional failures
	<input type="checkbox"/> "Risk taking" was the most commonly identified factor group within degraded lighting, degraded weather and degraded road surface <input type="checkbox"/> "Distraction" was also a commonly occurring factor group within carriageway hazards, along with "visibility impaired" <input type="checkbox"/> "psychological condition", "distraction", "road condition", "visibility impaired" were also prevalent.	<input type="checkbox"/> The presence of degradation in general mainly led to either failures in detection (i.e. the degraded situation restricted the road user's visibility) or failures when taking action (i.e. the degradation directly affected the road user's control of their vehicle, such as when manoeuvring around a bend). <input type="checkbox"/> Accidents where degraded lighting was a cause mainly led to failures in detecting a conflict ahead, <input type="checkbox"/> In accidents where degraded road surfaces were a cause, the road user experienced a failure when trying to keep control of their vehicle ("taking action") <input type="checkbox"/> Both degraded weather and hazards were found to lead to a failure in two ways, either in detection (visibility restricted) or when taking action (keeping control of vehicle)
		
		

EVALUATION

The second principal aim of TRACE was to investigate the impact of advanced safety functions on reducing several types of injury crashes involving passenger cars or restricting (mitigating) crash consequences (so-called safety benefits). WP6 provided at the beginning of the project a list of the most promising safety functions that address current and future accident types on European roads. The evaluation has been performed from two different perspectives:

- Assessment of the potential proportion of injury accidents that could be avoided and of the potential proportion of injury accidents whose severity could be reduced, for safety functions, of passenger cars, not already on the market (this is the so-called *a priori effectiveness*).
- Assessment of the actual proportion of injury accidents that could be avoided and of the actual proportion of accidents whose severity could be reduced, for safety functions, of passenger cars, already on the market (this is the so-called *a posteriori effectiveness*) once the cars are equipped with existing functions.

A Priori Effectiveness

Different methods have been applied and different data used [9, 10, 11, 12]. The allocation of the safety functions to different methods is presented in table 2. These different methods are presented extensively in the TRACE reports. It is also argued why different methods were necessary and why, given the low effectiveness of some safety functions, it is assumed

that the discrepancies between the methods are not introducing too much bias in the comparison of the results.

Table 2. Safety functions selected for evaluation and method used for evaluating the safety benefits

#	Safety System	“Target population” method	Method		
			Effectiveness evaluation	Unit HARM	Neural Networks
1	Tyre Pressure and Monitoring	X			
2	Lane Keeping Support	X			
3	Lane Changing Support	X			
4	Cornering Brake Control	X			
5	Traffic Sign Recognition	X			
6	Intersection Control	X			
7	Intelligent Speed Adaptation		X		
8	Blind Spot Detection		X		
9	Alcolock Key			X	
10	Advanced Automatic Crash Notification			X	
11	Night Vision			X	
12	Collision Avoidance				X
13	Predictive Brake Assist				X
14	Dynamic Suspension				X
15	Drowsy Driver Detection System				X
16	Advanced Front Light System				X
17	Rear Light Brake Force Display				X
18	Collision Warning				X
19	Advanced Adaptive Cruise Control				X

The target population method (calculating only the proportion of crashes addressed by the function) is used only for cases where this population is low and does not imply a full calculation of effectiveness. Neural Networks are used to investigate the impact of primary safety functions on restriction of accident consequences. The proposed approach investigated the effectiveness of several safety functions on different accident configurations, by estimating the influence of each safety function on different accident parameters. The evaluation is performed in terms of assessment of the potential proportion of accidents whose severity could be reduced, for each safety function. Other methods are chosen according to the function under study, availability of data and relevance of the method. Full definitions of the functions are described in the TRACE reports. We are just reporting here their generic titles which are sufficient to understand the concept but not to understand how they work. The main results coming out from the analysis are presented in table 3. This table shows the overall

effectiveness evaluation results for the selected nineteen (19) primary safety systems for *passenger cars* that have been studied in TRACE. In table 3 the safety systems effectiveness is presented in terms of:

- **Fatalities saved:** The percentage of fatalities that could be saved by the safety function if the fleet is 100 % fitted with this particular function.
- **Serious injuries saved:** The percentage of serious injuries that could be saved if the fleet is 100 % fitted with this particular function.

It should be noted that, in this table, the absence of calculated values in fatalities saved for some of the safety systems occurs because these values have not been calculated (and thus are not available) and does not suggest that those systems do not provide any benefits in terms of fatalities saved. Additionally, it should also be noted that in some cases the percentage of the effectiveness in terms of fatalities saved is higher than the corresponding percentage in terms of serious injuries saved. However, this does not imply that more fatalities (in absolute numbers) than serious injuries would be saved, since in most

accident configurations the number of injuries is much higher than the number of fatalities.

The results show that the greatest additional safety gain potentials are expected from intelligent speed adaptation systems, automatic crash notification systems, and collision warning and collision avoidance systems. Their expected benefits (expected

reduction in the total number of injured persons) are between 6% and 11%. Safety benefits of other systems are more often below 5%. Some systems have a very low expected safety benefit (around or less than 1%).

Table 3. Potential safety benefits of safety systems

Safety System	Safety Function	Effectiveness (%)	
		Fatalities Saved	Serious Injuries Saved
Intelligent Speed Adaptation (**)	Drive Safe	17	11
Advanced Automatic Crash Notification (***)	Rescue	10,8	-
Advanced Adaptive Cruise Control	Drive Safe	-	11
Collision Avoidance	Drive Safe	-	9,1
Collision Warning	Drive Safe	-	6,6
Traffic Sign Recognition (*)	Drive Safe	-	5,8
Lane Keeping Assistant (*)	Drive Safe	-	5,7
Night Vision	Visibility	3,5	4,8
Blind Spot Detection (*)	Drive Safe	2,5	4
Lane Changing Assistant (*)	Drive Safe	-	3,1
Alcolock Key(***,#)	Drive Safe	6	3
Drowsy Driver Detection System	Drive Safe	-	2,9
Intersection Control (*)	Drive Safe	-	2,3
Cornering Brake Control (*)	Braking Systems	-	2,3
Tyre Pressure Monitoring and Warning (*)	Drive Safe	-	1,3
Rear Light Brake Force Display	Visibility	-	0,8
Advanced Adaptive Front Light System	Visibility	-	0,6
Predictive Assist Braking	Braking Systems	-	0,2
Dynamic Suspension	Handling/Kinematics	-	0

* The potential magnitude (target population) of the effectiveness has been calculated

** The numbers are for the 'Driver Select' ISA configuration which has been estimated as the most effective

*** Results based on non-European data

For the Alcolock Key the results for the mode "All newly registered vehicles (First full year)" with effectiveness 25% is used which gives the highest results but it is above the average performance of Alcolock key

N/A Not Applicable

- Value not available

A Posteriori Effectiveness

The first task of this part was to select the safety applications to be studied. Depending on the availability of crash data and also considering the

actual low penetration rate of active safety functions, we have selected for evaluation the Electronic Stability Control (ESC) and the Emergency Brake Assist (EBA) systems.

As for the passive safety systems, newer cars are designed to offer good overall protection. Car structure, load limiters, front airbags, side airbags, knee airbags, pretensioners, padding and non aggressive structures in the door panel, the dashboard, the windshield, the seats, the head rest also participate in supplying more protection. The whole package is then very difficult to evaluate separately, one element independently from the others. We have then decided to consider that we would evaluate in TRACE the safety of the whole package, this package being, for the sake of simplicity, the number of stars awarded at the Euro NCAP testing.

The challenges were to compare the effectiveness of some safety configuration SC I with the effectiveness of some safety configuration SC II [14, 24]. A safety configuration (SC) can be understood as a package of safety functions.

Ten comparisons have been carried out and the evaluations presented in table 4 are now available [15].

The evaluation of the potential safety benefits of existing safety functions is expected to be carried out at the EU25 or EU 27 level. It would mean that:

- either the relevant data is available at that level and the above-mentioned analysis is done with the European data
- or the relevant data is not available at the EU level and the analysis is done with the data available in a selection of countries, the results being *expanded* at the EU level with an appropriate technique.

The relevant data is actually not available at the EU level. We have then chosen to conduct the analysis with the French data and try to expand the results at the EU level if possible.

As explained and discussed in the TRACE reports, the data relevant for such an analysis is a macroscopic accident dataset in which we can get information about vehicles involved in crashes (and especially their equipment) and about the crash and the impact configurations. We chose to use the French Injury Crash census.

Table 4: Evaluation of the effectiveness of existing safety package

	Reduction in injury accidents (accident avoidance)	Reduction in all injuries & fatalities	Reduction in severe injuries and fatalities
Safety benefit of EBA given that the car has four stars (Euro NCAP).	-3.2%	7.8%	14.6%
Safety benefit of ESC given that the car has four stars and an EBA.	5.2%	10.3%	16,8%
Safety benefit of ESC given that the car has five stars and an EBA.	3.2%	10.7% (*)	23.4% (*)
Safety benefit of the fifth star given that the car has four stars and an EBA.	6,4%	8,3%	N.A.
Safety benefit of the fifth star given that the car has four stars, an EBA and an ESC.	19.3% (*)	33,8% (*)	35,1% (*)
Safety benefit of EBA and ESC given that the car has four stars.	18,6%	36,3% (*)	42,3%
Safety benefit of EBA and a fifth star given that the car has four stars.	28,2% (*)	36% (*)	37,5% (*)
Safety benefit of ESC and a fifth star given that the car has four stars and an EBA.	22% (*)	38,6% (*)	37,1% (*)
Safety benefit EBA, ESC and a fifth star given that the car has four stars.	47,2% (*)	67,8% (*)	69,5% (*)
Safety benefit of a fifth star and removing an ESC given that the car has four stars, an EBA and an ESC.	2,1%	N.A.	N.A.

* Statistically significant

The French accident national database gathers all information on every injury road accident occurring

all over France during a year. This database only focuses on accidents in which at least one road user

sustains injuries. No property-damage accident is registered in this database. The information is collected by the Police forces on the scene of the accident. On the basis of the police report, usually used for forensic purpose, they also have to fill in a statistical form called BAAC (Bulletin d'Analyse d'Accident Corporel) bringing together all the characteristic of the accident.

Among all the vehicles within our injury accidents database, a selection has been made in order to retain only crashed vehicles that were pertinent for the analysis.

Firstly, we selected French vehicles whose model year stands between 2000 and 2006. We restricted our analysis to four and five star vehicles, excluding three stars vehicles. It was useless to keep vehicles with model years prior to year 2000 since considerable improvements have been brought to car crashworthiness since the late nineties and the additional benefits of newer passive or active safety devices must be compared to vehicles built just prior to these improvements and not a long time ago.

We also selected cars fitted with ABS since this is now standard equipment.

The presence of EBA and ESC in the car also had to be stated. The vehicles with optional equipment were not taken into account, as we could not be sure if the safety function was really on board. There were some special cases where the optional equipment has been considered as if it was not present on the vehicle (ESC equipment for the Megane for instance since the equipment rate for some vehicles was known to be very low).

We must explain that the injury severity codification was changed in 2005 in France (the split between slight and serious injuries changed towards a split between slight and hospitalized injuries). There is not any evident correlation between the new and the former classification. It becomes impossible to aggregate data of accidents occurred before 2005 with those concerning accidents from 2005 on, at least if the analysis deals with injury severity. Therefore, we had to perform our analysis on the accident cases that occurred in 2005 and 2006.

The last selection concerned the use of the seat belt and the seating position in the vehicle; only the belted driver and front passenger were selected for the analysis.

Available in our sample were 15 466 four star vehicles and 4 610 five star vehicles.

The main striking results coming out from the analysis are what we call the '*overall effectiveness*' of the selected safety systems with breakdown by injury severity levels (table 4). This '*overall effectiveness*' represents the percentage of reduction in injury accident and injuries that would be observed

if all cars would be fitted with the system(s) under consideration, compared to cars of a reference group. Reference groups are not always the same, the less equipped reference group being 4 star cars without EBA, without ESC.

This overall effectiveness is derived from the *specific effectiveness* which is the effectiveness of the safety configurations which applies only to accident types or impact types for which the safety systems are designed for.

The main outcome of this analysis is that any increment of a passive or active safety function selected in this analysis (5 stars, Emergency Brake Assist, Electronic Stability Control) produces additional safety benefits. In general, the safety gains are higher for higher severity levels [15]. For example, if all cars were five stars fitted with EBA and ESC, compared to four stars without ESC and EBA, injury accidents would be reduced by 47.2%, all injuries would be mitigated by 67.8% and severe + fatal injuries by 69.5%.

The results are very positive and encouraging, showing great potential for the generalization of the selected safety applications and validating the choices made so far by the various stakeholders who have been pushing the installation of safety technologies in the passenger cars for years.

CONCLUSION

Apart from considerable improvements in the methodologies applicable to accident research in the field of human factors, statistics and epidemiology, allowing a better understanding of the crash generating issues, the TRACE project quantified the expected safety benefits for existing and future safety applications.

- As for existing safety functions or safety packages, the main striking results show that any increment of a passive or active safety function selected in this project produces additional safety benefits. In general, the safety gains are even higher for higher injury severity levels. For example, if all cars were five stars and fitted with EBA and ESC, compared to four stars without ESC and EBA, injury accidents would be reduced by 47%, all injuries would be mitigated by 68% and severe + fatal injuries by 70%.

- As for future advanced safety functions, TRACE investigated 19 safety systems. The results show that the greatest additional safety gains potential are expected from intelligent speed adaptation systems, automatic crash notification systems, and collision warning and collision avoidance systems. Their expected benefits (expected reduction in the total number of injured persons) are between 6% and 11%. Safety benefits of other systems are more often below

5%. Some systems have a very low expected safety benefit (around or less than 1%).

ACKNOWLEDGEMENTS

TRACE is a project of the Sixth Framework Program funded by the European Commission (DG Info) under the conditions of RTD funding. It brings together 21 institutes, full partners or sub contractors coming from 8 countries. The Commission and the partners are greatly acknowledged for their active participation in the TRACE project.

Data provided to the TRACE project came from private databases owned by the participants or from public databases courtesy of National Agencies. The authors would like to thank all data providers.

The views expressed in this work belong to the authors and are not necessarily those of the UK Department for Transport or Highways Agency, who made the UK data available to the Vehicle Safety Research Centre at Loughborough University for the TRACE project.

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