TECHNICAL REPORT

ISO/TR 21934-1

First edition
2021-06

Road vehicles — Prospective safety performance assessment of pre-crash technology by virtual simulation —

Part 1: State-of-the-art and general method overview

Véhicules routiers — Evaluation prospective de la performance sécuritaire des systèmes de pré-accident par simulation numérique —

Partie 1: Etat de l'art et aperçu des méthodes générales

Reference number
ISO/TR 21934-1:2021(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22 *Road vehicles*, Subcommittee SC 36 *Safety and impact testing*.

A list of all parts in the ISO 21934 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Different Active Safety and Advanced Driver Assistance Systems (ADAS), in the following both referred to as active safety technology, have been developed and introduced into the market. The question that goes along with the development and introduction is, what impact these technologies have on road traffic and more specifically, to what extent these technologies prevent crashes and injuries. Such questions are of relevance for different stakeholders, such as vehicle manufacturers and suppliers, road authorities, research organisations and academia, politics, insurance companies as well as consumer organisations.[1]

The answers to these questions are derived from assessment of such technologies in terms of road traffic safety. Different assessment methodologies have been developed in the past and are being used today.[2] In general, the utilized methodologies can be divided in two types of assessment. The first type determines the technology's safety effect after its market introduction. Typically, in this assessment type accident statistics are analysed in order to determine the difference between the accident situation with the technology compared to a control group without the technology.[1] These methods are called retrospective assessment methods. A precondition for these methods is that the technology under assessment has reached a sufficient penetration rate in the market and that sufficient accident cases with and without the technology are recorded for a comparison. The penetration rate does not necessarily need to be related to the whole vehicle fleet, but can also be related to a certain vehicle subgroup or class.[3]–[5] On the other hand, there are methods that predict the technology's effect on traffic in relation to traffic safety before its market introduction.[6][7] These methods are called prospective methods using different approaches and tools.

This document focuses on the **prospective assessment** of traffic safety for **vehicle-integrated technologies acting in the pre-crash phase** by means of **virtual simulation**.

The safety performance of a technology is determined by means of comparing data from the baseline and treatment simulations based on a certain metric. The baseline for the assessment is the situation without the vehicle-integrate technology under assessment present. The virtual simulation with the technology is called treatment simulation.

The described assessment is limited to "vehicle-integrated" technology and does not consider technologies operating off-board. The virtual simulation method per se is not limited to a certain vehicle type. Although the main focus is often on passenger cars, the method is also applicable to motorised two-wheelers as well as heavy goods vehicles. Furthermore, the assessment approach discussed in this document focuses rather on accident avoidance and the technology's contribution to the mitigation of the consequences. Safety technologies that act in the in-crash or the post-crash phase are not explicitly addressed by the method, although the output from prospective assessments of crash avoidance technologies can be considered as an important input to determine the consequences. The extension of the method to technologies, such as automated driving and V2X based technologies, are discussed in the outlook at the end of this document.

In general, the assessment of active safety technologies requires the consideration of interaction with surrounding traffic as well as the host vehicle driver. These interactions increase the complexity of the assessment due to the high number of resulting variables. Consequently, for a comprehensive assessment, the technology's safety performance is analysed in a high number of test scenarios, in order to cover all relevant circumstances that affect the critical situation and crashes. The virtual simulation approach allows for running large numbers of test scenarios while offering a promising combination of safety performance, flexibility, reproducibility, and experimental control. The need for using virtual simulations in the prospective assessment of safety technologies is generally recognized. However, standardized terminology and processes of methodological aspects to perform such assessments are not available to date, which makes results hardly comparable.[1] For this reason, automotive industry, research institutes, and academia joined in the P.E.A.R.S.[1)] (**P**rospective **E**ffectiveness **A**ssessment for **R**oad **S**afety) initiative with the objective to develop a comprehensible, reliable, transparent, and accepted methodology for quantitative assessment of crash avoidance technology by virtual simulation. [1]

This document aims to provide an overview on the state-of-the-art in the prospective assessment of road safety for vehicle-integrated (active) safety technologies by means of virtual simulation, see Figure 1.

After the introductive Clauses 1 to 4, the general method for a prospective assessment study is described in Clause 5, where special attention is given to the definition of the traffic safety evaluation scope and the establishment of the baseline. Clause 6 describes various data that can be used as input for different tasks within the assessment procedure. Then a general virtual simulation framework and various simulation models needed for conducting the simulation are presented in Clause 7, followed by a description of the approaches to quantify the derived safety effect in Clause 8. A description of validation and verification aspects as well as an overview on tools are given in Clause 9. Clause 10 of the document provides a practical example of a comparative study of different simulation tools and discusses the lessons learned. Clause 11 provides conclusions as well as describes limitations for the state-of-the-art methods. Clause 12 provides an outlook towards the prospective safety performance assessment for automated driving as well as the follow up to the current document.

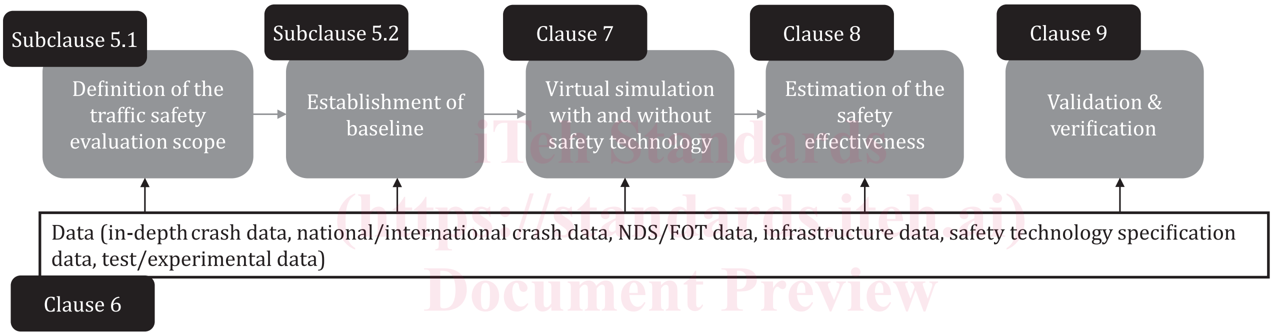


Figure 1 — Overview of the process of prospective assessment of traffic safety for vehicle-integrated safety technologies by means of virtual simulation and the structure of this document

1) P.E.A.R.S. is an open consortium (established in 2012) in which engineers and researchers from the automotive industry, research institutes and academia join with the objective to develop a comprehensible, reliable, transparent and accepted methodology for quantitative assessment of crash avoidance technology by virtual simulation. Partners of P.E.A.R.S. are (status Sep. 2020): Automotive Safety Technologies, AZT Automotive, BMW Group, Federal Highway Research Institute (BASt), Chalmers University of Technology, Continental, Denso, Fraunhofer IVI, Generali, RWTH Aachen University (ika), LAB, Swiss Re, TH Ingolstadt, Technical University Dresden, Technical University Graz, TNO, Toyota, Technical University Dresden, TÜV Süd, University Leeds, UTAC CERAM, Virtual Vehicle, Volkswagen, Volvo Cars, VUFO, ZF. More information at https://pearsinitiative.com/.

Road vehicles — Prospective safety performance assessment of pre-crash technology by virtual simulation —

Part 1: State-of-the-art and general method overview

1 Scope

This document describes the state-of-the-art of prospective methods for assessing the safety performance of vehicle-integrated active safety technologies by virtual simulation. The document describes how prospective assessment of vehicle-integrated technologies provides a prediction on how advanced vehicle safety technology will perform on the roads in real traffic. The focus is on the assessment of the technology as whole and not of single components of the technology (e.g. sensors).

The described assessment approach is limited to "vehicle-integrated" technology and does not consider technologies operating off-board. The virtual simulation method per se is not limited to a certain vehicle type. The assessment approach discussed in this document focuses accident avoidance and the technology's contribution to the mitigation of the consequences. Safety technologies that act in the in-crash or the post-crash phase are not explicitly addressed by the method, although the output from prospective assessments of crash avoidance technologies can be considered as an important input to determine the overall consequences of a crash.

The method is intended as an overall reference for safety performance assessment studies of pre-crash technologies by virtual simulation. The method can be applied at all stages of technology development and in assessment after the market introduction, in which a wide range of stakeholders (manufactures, insurer, governmental organisation, consumer rating organisation) could apply the method.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12353-1, *Road vehicles — Traffic accident analysis — Part 1: Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12353-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
levels of automation
levels that primarily identify how the "dynamic driving task" is divided between human and machine

Note 1 to entry: See Reference [8].

3.2
baseline
initial set of data to which the performance of the technology under study is compared when performing *prospective assessments* (3.7) of the technologies' performance

Note 1 to entry: This concept also complements *treatment* (3.13).

3.3
cooperative
applications based on vehicle-to-vehicle, vehicle-to-VRU and vehicle-to-infrastructure communication

3.4
host vehicle
vehicle, which is subject for assessment, i.e. is equipped with the technology in the treatment simulation

3.5
injury risk function
description of the probability of an injury in relation to crash attributes

Note 1 to entry: The most frequently used injury risk functions describe the probability of an injury occurrence in relation to crash severity, e.g. impact speed or change of velocity.

3.6
projection
indicates what the future changes in a population would be if the assumptions (often based on patterns of change which have previously occurred) about future trends actually occur

Note 1 to entry: Population projections – in the sense of Reference [9] - are estimates of total size or composition of populations in the future, see Reference [10].

3.7
prospective assessment
assessment of the performance of technologies in a predictive way

Note 1 to entry: The assessment can be done, for example, before their deployment into a vehicle population.

3.8
target population
all situations or accidents that are addressed by the function under assessment

3.9
real-world data
data collected in a non-experimental, non-virtual situation

3.10
retrospective assessment
assessment of the performance of technologies after their deployment into a vehicle population

3.11
time series
series of data points indexed (or listed or graphed) in time order

3.12
traffic situation
crash-, near-crash or normal driving situation whose description can be considered for the establishment of the *baseline* (3.2)

3.13
treatment
use of a specific technology to affect the course of an event in a *traffic situation* (3.12) in order to avoid or mitigate crashes

Note 1 to entry: Treatment simulations provide data on the performance of the technology under assessment to compare with the *baseline* (3.2) data when performing *prospective assessments* (3.7) of performance of technologies.

Note 2 to entry: This concept also complements *baseline* (3.2).

3.14
test scenario
detailed description of trajectories, geometrical relations, speeds, etc. of a *traffic situation* (3.12)

Note 1 to entry: See References [11]–[13].

3.15
vehicle-integrated
technology under assessment operating on-board of the vehicle

4 Symbols and abbreviated terms

4.1 Symbols

E	Effectiveness / safety performance
N	Weighted frequency of the metric (e.g. percentage of crashes) in the simulation without the technology under assessment
N'	Weighted frequency of the metric (e.g. percentage of crashes) in the simulation with the technology under assessment
v	Velocity

4.2 Abbreviated terms

ACC	Adaptive Cruise Control
ADAS	Advance Driver Assistance Systems
AEB	Autonomous Emergency Braking
BAAC	Analysis report of road accidents involving physical injury (France)
BASt	Federal Highway Research Institute (Bundesanstalt für Straßenwesen)
CEDATU	Central Database for In-Depth Accident Studies (Austria)
CIDAS	China In-Depth Accident Study
EES	Energy Equivalent Speed
ETAC	European Truck Accident Causation
FESTA	Field opErational teSts supporT Action
FOT	Field Operation Test

GIDAS	German In-Depth Accident Study
HIL	Hardware-in-the-loop
IEC	International Electrotechnical Commission
IIHS	Insurance Institute for Highway Safety
IGLAD	Initiative of Global Harmonisation of Accident Databases
ISO	International Organization for Standardization
ITARDA	Institute for Traffic Accent Research and Data Analysis
J-TAD	Japan Traffic Accidents Databases
KBA	German Federal Motor Transport Authority (Kraftfahrtbundesamt)
LDW	Lane Departure Warning System
LIDAR	Light detection and ranging
MIL	Model-in-the-loop
NASS	National Automotive Sampling System
NDS	Naturalistic Driving Studies
RAIDS	Road Accident In Depth Studies
P.E.A.R.S.	Prospective Effectiveness Assessment for Road Safety
PTW	Powered Two Wheelers
RASSI	Road Accident Sampling System - India
SCP (cr/cl)	Straight Crossing Paths (cyclist from the right / cyclist from the left)
SIL	Software–in-the-loop
TTC	Time to collision
V2X	Vehicle to X (Vehicle and / or Infrastructure) Communication
VIN	Vehicle identification number
VRU	Vulnerable Road User
V&V	Validation and Verification

5 Evaluation objective and baseline of assessment

5.1 Definition of the evaluation objective

Since there are numerous objectives to conduct prospective safety performance assessments, it is important that a precise research question for the assessment is formulated. Then by identifying relevant traffic situations – the target population - to address the research question, a more precise specification and application for a virtual simulation study is provided.[14] Figure 2 shows the place in the process overview.

Figure 2 — Overview of the process — Definition of the evaluation objective

Various objectives to conduct safety performance assessments have been identified,[1] the main ones are:

— quantification of effects (positive and negative) of a certain technology in terms of traffic safety;

— prioritization and optimization of safety technologies during research and development;

— identification of business opportunities and anticipation of regulations and consumer testing.

Furthermore, two types of processes are used to formulate the target for this kind of studies.

— A technology-driven process in which a request is put forward to estimate the safety benefit of a safety technology. This technology can be more or less defined at the time of the study; it can be an idea, a concept, a product under development or a product that already has been implemented but not introduced into the market (also often called a bottom-up approach).

— A traffic safety-driven process in which existing or expected safety problems or certain relevant traffic situations are identified. In this case, the target for the study is not linked to a particular safety technology but to a targeted lack of safety (also often called top-down approach).

Hence, it is important to note that if results between different studies are compared the research question needs to be a) accessible and b) precisely formulated. This requires to rephrase the question asking additional information such as: “What type of safety technology will be evaluated?”, “What data segments will be addressed (pre-impact situation, traffic participants, type of road, etc.)?”, “What time horizon is being considered?”, “Should the installation rate of an optionally equipped safety technology in the vehicle fleet be considered?”, “What metric is suggested for the safety effect?”, “What is the expected accuracy of the result?”, “What could change the consequence on the road, if the cars were equipped with new safety technologies?”.

An adequate example of a properly formulated research question is: What is the relative change in car-to-cyclist crashes due to an autonomous emergency braking (AEB) system with 100 % penetration rate in a specific car in urban car-to-cyclist situations in Germany in two years from now?

Once the research question is set, relevant traffic situations for virtual simulation can be identified, for example the definition of a target population for the study. Relevant traffic situations can be derived by, e.g. analysis of retrospective crash data, naturalistic driving studies, and knowledge gathered during technology development. The outcome of the identification process is an overall description and quantification of the traffic situations and the involved traffic participants of the simulation. When it comes to analysis of real-world crash or near-crash data, various types of classification schemes can be used to set boundaries for the study. Especially important aspect is pre-impact relative movement of involved traffic participants before a crash or near-crash. One example is Straight Crossing Path scenarios (from right: SCPcr / from left: SCPcl), where the car was moving forward, and the cyclist was crossing the path either from left or right, see Figure 3. The pre-impact situation is often accompanied by pre-crash-factors that include parameters that may have influenced the course of events before the crash. Examples are speed-related measures, driver status, and traffic environment related factors such as light condition, road layout, and road status. In addition, the crash configuration can be of interest, e.g. the impact point and direction.

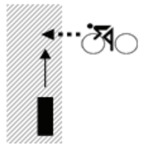
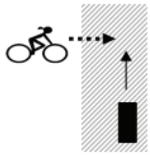
SCPcr	**S**traight **C**rossing **P**ath, **c**yclist from **r**ight	
SCPcl	**S**traight **C**rossing **P**ath, **c**yclist from **l**eft	

Figure 3 — Example from a pre-impact situation classification scheme [15][16]

To summarize, for a fictitious version of an AEB system addressing the example research question above, the target population could be expressed as; SCPcr and SCPcl situations during daylight on roads with lane markings and where the driver is visually distracted.

At this stage it important to mention that the metrics to be used for estimating technology's safety performance consider the potential impacts and the required input data. After establishing a baseline according to the target population (see 5.2), the outcome of simulations with and without the safety technology will be compared by this certain metric. Details with respect to the topic "metric" are presented in Clause 8.

5.2 Establishment of baseline

When target traffic situations are identified which address the research question, a detailed, measurable definition of these situations for the upcoming virtual simulations is provided, i.e. the baseline. In general, the prospective safety performance assessment conducts a comparison between traffic situations without and with the technology under assessment. Thus, the baseline refers to the situation without the technology under assessment present. This includes traffic situations that are needed to evaluate both positive and negative performance, according to the evaluation objective. The establishment of the baseline defines the reference to be used in the upcoming simulations and a real-world reference is essential. Figure 4 shows the place in the process overview.

Figure 4 — Overview of the process — Establishment of the baseline

Three main approaches are distinguished where the cases in the baseline are generated in different ways:

— baseline with original cases of real-world traffic situations,

— baseline with modified cases of real-world traffic situations,

— baseline with synthetic cases based on relevant characteristics of real-world traffic situations.

Below are explanation of each respective baseline.

— **Baseline with original cases of real-world traffic situations**

In a straightforward application, the baseline corresponds to real-world traffic situations that have been reconstructed from crash data or other sources such as NDS/FOT datasets. The cases are represented according to parameters found in the corresponding database (e.g. collision speed and collision angle).[17]-[21]

Furthermore, the crash database parameters can be used in a model to perform a reconstruction of the cases, thus simulation is used to recreate real accidents in order to have a detailed, numerical time series description of the cases in the baseline. An example of this approach is the German In-Depth Accident Study (GIDAS) based Pre-Crash-Matrix (PCM).[22] Typical parameters needed in the PCM database are vehicle trajectories and speed related measures, crash configurations, sight obstructions, information on the traffic environment and driver behaviour.

— **Baseline with modified cases of real-world traffic situations**

As crashes reported in the database reflect the actual crash, with possibly rather old vehicles, replications of the traffic situations with a modern vehicle can be performed, i.e. a re-simulation to establish a baseline with more recent properties of the vehicles involved.[20][23][24]

Another challenge in crash databases is the limited information on pre-crash parameters, for example vehicle trajectories and driver behaviour such as inattention or drowsiness that can be influenced by a safety technology. The use of recorded crashes such as in naturalistic driving studies or usage of event data recorder data can enable more qualitative estimations when available.

If the crash sample does not provide a sufficient representation of the traffic situation identified based on the research question, sampling techniques can be used to create random, synthetic cases based on marginal distributions of event related variables.[25] However, in contrast to the next approach, presented below, the synthetic created cases still reflect the original traffic situation.

— **Baseline with synthetic cases based on relevant characteristics of real-world traffic situations**

Cases for a baseline can also be generated based on the understanding of contributing factors involved in the targeted traffic situations; the crash mechanisms.[26]–[28]

Once these mechanisms are revealed, the situation is modelled using distributions of selected parameters. Sampling methods, for example Monte Carlo simulations, can be used to vary the characteristics of the cases in the baseline, such as driver reaction/response as well as vehicle properties, vehicle trajectories, and traffic and environmental variables.[29] When the simulations for generating situations are performed, only a portion of the cases in the baseline might end up in a collision. The baseline then consists, besides cases where a collision occurs, also of cases without a collision or risk of a collision. These cases can be used to investigate situations, where an activation might not be desired or required.

The baseline is to be used in virtual simulations, with and without the safety technology present. The complexity and the level of detail depend on the way the baseline has been represented and to which degree the safety technology interferes, e.g. to the way that the driver, the vehicle, the surrounding traffic etc. are modelled. The virtual simulation framework and the various models needed are described in Clause 7.

6 Input data

6.1 General

Input data are required for different tasks within the process of assessing a technology's safety performance by means of virtual simulation. These tasks are:

— establishing the baseline of the simulation (see Clause 5.2);

— development, training and parametrisation of models used in the simulation tool - in particular traffic participant (e.g. driver) behaviour models and injury risk function (see Clause 7);

— performing subsample weighting analysis and projection of simulation output (see Clause 8);

— validation and verification of the simulation as well as its models (see Clause 9).

In relation to these different tasks and with regard to the research question, the quality and representativeness of the data sample are important and relevant aspects throughout the process.

In general, a wide range of data is necessary for prospective safety performance assessment. Although in most cases, data from real world are used, the input data do not necessarily need to be gathered in the real world. Verified data from previous simulations or data collected in specific tests may be used as input data for the assessment as well. In the following, the most common relevant data sources are presented and discussed. These sources are (details on the different sources are provided in the sections below):

— safety technology related data;

— accident data (general and/or in-depth data);

— data from naturalistic driving studies (NDS) or field operation tests (FOT);

— infrastructure and traffic data;

— test data gained in a controlled environment, such as test track or driving simulators.

In Table 1 the typical data sources are mapped to the tasks of prospective safety performance assessment.

Table 1 — Overview on often used data types for the different tasks within the prospective safety performance assessment

	Active safety technology related data	Accident data (general data)	Accident data (in-depth data)	NDS/FOT data	Infra-structure and traffic data	Test data (test track, simulator)
Establishing the baseline – direct input (see 5.2)	X		X	X		(X)
Establishing the baseline – modified input (see 5.2)	X		X	X	(X)	(X)
Establishing the baseline – stochastically generated input (see 5.2)	X	(X)	X	X	X	(X)
Development of models (see 7.4)	(X)	(X)	X	X	X	X
Data projection (see Clause 8)		X	(X)	(X)	X	
Validation and verification (see Clause 9)	(X)	(X)	X	X	X	X
NOTE 'X' marks commonly used data sources, '(X)' marks rarely used data sources.						

6.2 Active safety technology related data

The purpose of the prospective safety performance assessment is to determine the safety effect of a certain technology. To perform the assessment, specific information about the technology under assessment is required. The information describes under which conditions (e.g. speed range and environmental conditions) the technology operates, which conditions lead to deactivation as well as how the technology performs its function – sensing, controlling, actuating.[30] For an active safety technology, the intended situation is typically a critical driving situation, such as a potential collision with another object or an unintended road departure. The relevant information can further be split