Future challenges in the reconstruction of traffic accidents involving self-driving vehicles and their further development from a forensic automotive engineering perspective

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Abstract: The spread of (partially) autonomous driving is most likely to lead to the improvement of road traffic safety, therefore the number of accidents and their severity will further decrease. At the same time, it poses new challenges to forensic motor vehicle technical experts since in order to simulate and reconstruct such accidents accurately and reliably it is required to have improved and possibly new accident reconstruction methods. If we study the current developments of the topic, we can see it offers a fairly wide research potential in the coming decades. The purpose of the in-depth research planned in this study is to point out the problems which motor vehicle experts face during the accident reconstructions of (partially) self-driving and connected vehicles (mainly commercial vehicles) equipped with driver assistance systems. Based on the results of the research, it will be possible to develop further on reconstruction methods of such accidents, to develop new methods possibly, also proposals can be made to make automated vehicles even safer.

1. INTRODUCTION

Accidental deaths have also significantly and continuously decreased on the roads of the European Union in the recent period, however, in 2021, even so, estimated nearly 19,800 people lost their lives in road traffic accidents (European Commission, 2022). As a result, traffic specialists still have many tasks to do in order to reduce the number of accidents and the severity of their outcomes as much as possible.

Developments related to vehicle safety have made a significant contribution to the fact that the number of fatal road traffic accidents and serious injuries caused by accidents has decreased in recent decades (European Parliament, 2019).

The spread of automated and connected vehicles will result in huge changes in the field of road transport. By eliminating the majority of human error, the number of road fatalities caused by this will be drastically reduced (European Commission, 2017).

At the same time the reconstruction of accidents involving vehicles equipped with driver assistance systems, (partially) self-driving functions and connected vehicles poses new challenges to forensic vehicle technical experts. New accident reconstruction methods, novel simulation procedures and their continuous development are needed in accordance with the degree of automation of road vehicles.

2. STATISTICAL DATA

Analyzing the statistical data in Hungary, we can see that regarding the last two decades the number of road accidents with personal injuries and the number of people who died due to these accidents has essentially decreased since the mid-2000s. (Fig. 1). Considering the examined period, the fewest accidents causing personal injury were recorded in 2020 (13,778 cases) just as well as the fewest people (460 persons) were killed on our roads this year. In 2021, both the number of personal injury accidents (14,233 cases) and the number of fatal injuries slightly increased (544 people). The development of the number of injured persons shows a similar trend to the development of the number of accidents involving personal injury.

Based on the statistical data, it can be established that the percentage of fatalities compared to the number of accidents involving personal injuries has significantly decreased, from 6.9% (2000) to 3.8% (2021). In the mentioned period, the minimum value was reached in 2020 with 3.3% (Fig. 2). As far as we are concerned the proportional decrease in the number of fatalities compared to all accidents involving personal injuries is due to the significant development of passive safety of the road motor vehicles. The transport policy measures and efforts implemented in recent decades also played a significant role in reducing the number and proportion of accidental deaths.

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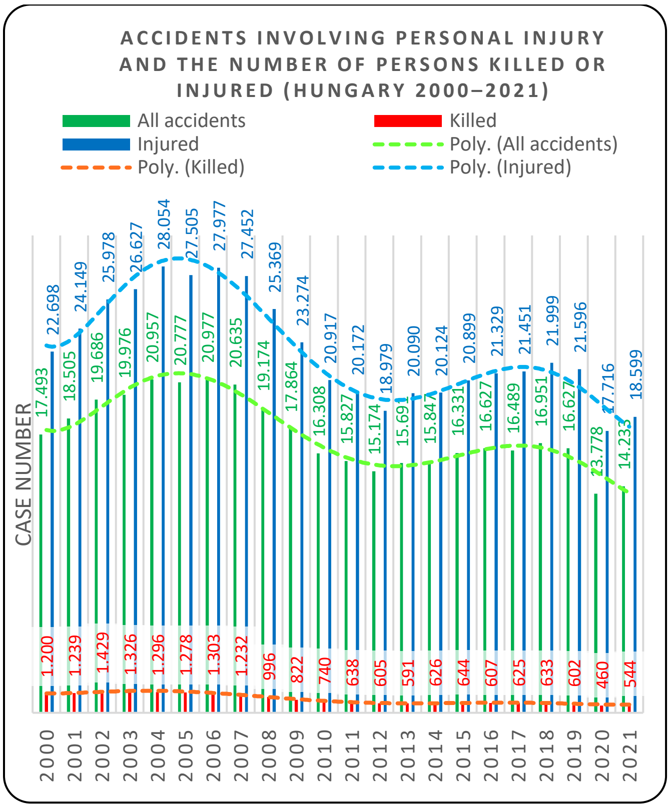


Fig. 1. Road accidents involving personal injury (Source: Created by the authors, based on data from (KSH, 2022a))

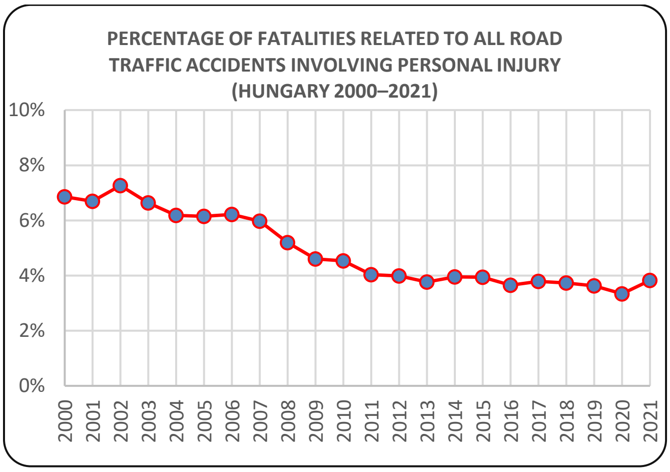


Fig. 2. Percentage of fatalities related to all road traffic accidents involving personal injury (Source: Created by the authors, based on data from (KSH, 2022a))

Analyzing the statistical data of last year (2021) in more detail, we can see that 9.6% of road traffic accidents with personal injuries are caused by lorry drivers. (Fig. 3).

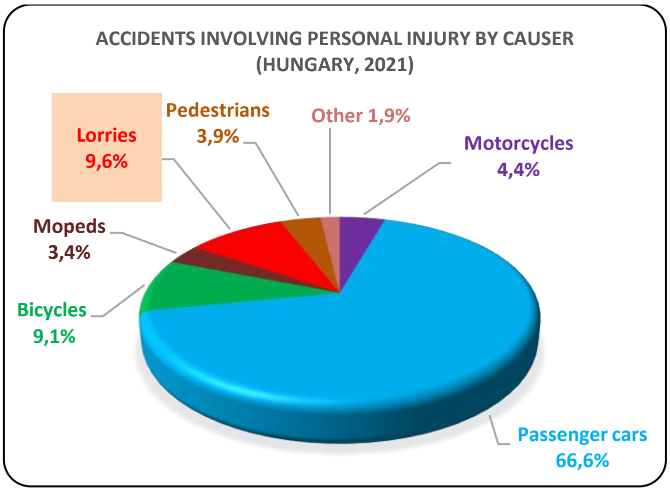


Fig. 3. Accidents involving personal injury by causer (Source: Created by the authors, based on data from (KSH, 2022b))

The spread of driver assistance systems and (partially) self-driving vehicles has crucial importance in terms of reducing the number and severity of accidents, since the vast majority of road traffic accidents still occur due to driver error (Fig. 4.).

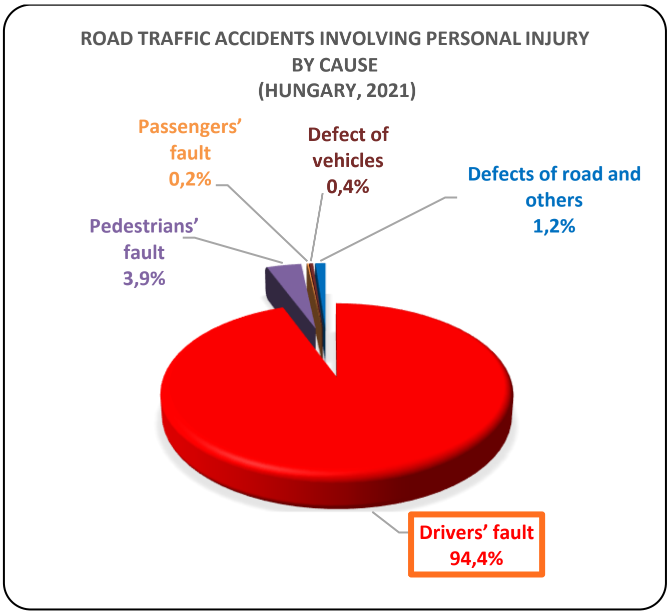


Fig. 4. Road Traffic Accidents involving personal injury by cause (Source: Created by the authors, based on data from (KSH, 2022c))

With the spread of fully automated, self-driving vehicles, human error as a cause of accidents is expected to decrease significantly, and it will represent a smaller proportion compared with other causes of accidents. However human error as a cause of accidents will not completely disappear, let us think of the case of unauthorized intervention in the system, improper use, or incorrect system settings.

The statistical data in Germany show that, despite the significant increase in the number of registered vehicles, the number of people who were killed in road traffic accidents has significantly decreased over the last four decades, essentially to 1/7 (Fig. 5). The reduction in the number of fatalities is due to several different (technological, legal, infrastructural, and health) measures which partially overlap with each other. That is why it is complicated to isolate individual measures and calculate their effectiveness (Winkle, 2022).

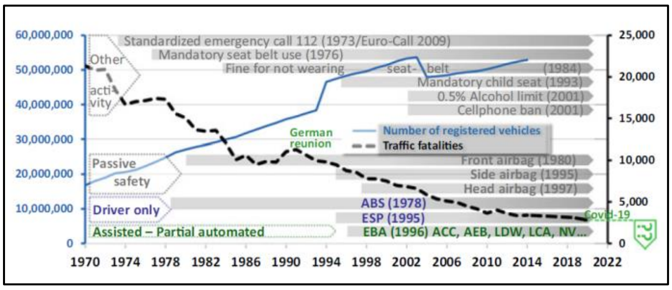


Fig. 5. Traffic fatalities and the registered motor vehicles in Germany (Winkle, 2022).

3. FURTHER DEVELOPMENT OF ACCIDENT RECONSTRUCTION METHODS CONSIDERING THE SPREAD OF (PARTIALLY) SELF-DRIVING AND CONNECTED (COMMERCIAL) VEHICLES

3.1 The necessity of the development of accident reconstruction methods

As a result of the legal requirements for motor vehicles and the rapid technical development of motor vehicles, there is a need for continuous further development of accident reconstruction and simulation methods just as well as for developing new methods.

With the simulation method (Fig. 6) co-developed earlier by the author of this article for the reconstruction of the so-called blind-spot accidents, the visibility of vulnerable road users (VRUs) can be dynamically examined from the driver's cab of the truck (Ignácz & Bell, 2010).

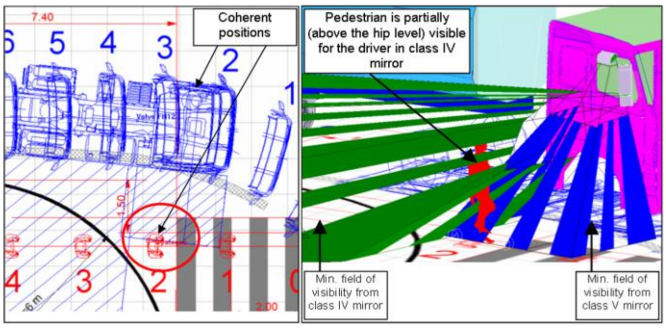


Fig. 6. Analysis of the visibility of vulnerable road user using 2D and 3D visibility models (Ignácz & Bell, 2010)

The accuracy and possible limitations of the newly developed accident reconstruction calculation methods need to be examined and validated with real, well-documented tests as we have already pointed it out during the development of the mentioned previous accident reconstruction method (Fig. 7).

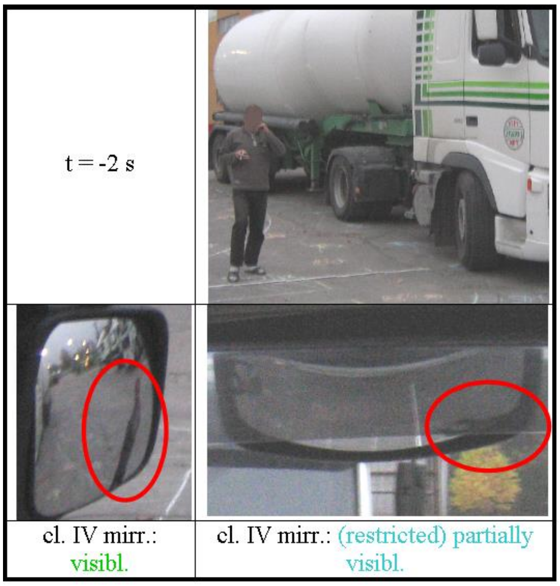


Fig. 7. Validation of the simulation method with real visibility test (Ignácz & Bell, 2010)

3.2 Research to be carried out for the development of accident reconstruction methods

For the development of the planned new accident reconstruction method(s), an expert-level analysis, reconstruction (simulation) and evaluation of a significant, statistically relevant number of real traffic accidents involving a heavy commercial vehicle will be implemented. The planned accident analysis will be carried out with scientific sophistication, the so-called in-depth method since this method makes it possible to draw reliable conclusions regarding the causes of accidents. Accident research projects based on the processing of a large number of cases (N>100 and N>2000), in which the author of this article was also actively involved, proved the effectiveness of this method (Ignácz, 2010; Kőfalvi, 2008).

The accident file selection criteria were chosen as follows:

- Among the vehicles involved in the accident, there has to be at least one that has an (advanced) driver assistance system, certain degree of automation or self-driving function.
- The accident file has to be documented in detail including an accident site map with dimensions, vehicle data, traces recorded at the scene of the accident, and appropriate detailed photo documentation.
- In order to have proper comparability, accidents before and after the date of application (July 6, 2022) of concerning regulations on advanced vehicle systems (EU 2019/2144) should be included in the research.

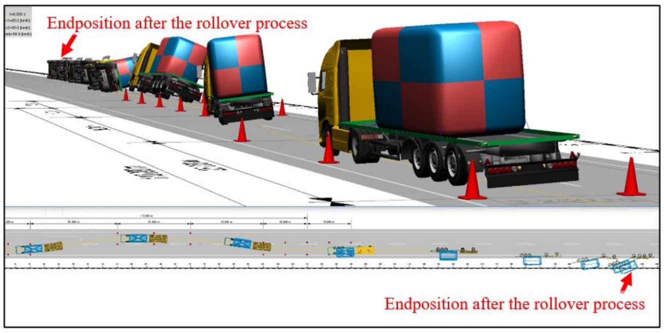
When selecting the accident files, we strive to ensure that out of the vehicles involved in the accident at least one is a heavy commercial vehicle (vehicle category: N2, N3, M2, M3).

3.3 Planned main steps of the in-depth accident analysis

- Selection, acquisition and organization of accident files relevant to the research.
- Selection of relevant data for statistical analysis and sorting them into a database for later evaluation.
- Collection of technical and other data relevant to accident reconstruction / computer simulation.
- Forensic automotive expert-level reconstruction and computer simulation of individual accidents according to the main steps below.
    - Creating scaled, accurate accident site map suitable for computer reconstruction, or taking it from a file, specifying it if necessary, modifying it to scale.
    - If necessary, the creation of a 3-dimensional model of the accident site, e.g. defining it by vector graphic drawing elements.
    - Defining the adhesion conditions valid at the time of the accident at the scene.
    - Detailed identification of the vehicles involved in the accident (based on the vehicle identification number (VIN) or other vehicle identifiers, if applicable), the exact determination of their technical data (dimensions, weight and other technical data, as well as technical equipment).
    - Determining the data of other accident participants (e.g. pedestrians, cyclists) relevant to accident reconstruction (size, weight, age, etc.) from the file or, in case of deficiency, from professional literature.
    - Construction of vehicle deformations with the drawing software of the accident reconstruction program, using vector graphics of the vehicles from the database.
    - Selection of relevant data from the vehicle's electronic system (e.g. EDR) for accident reconstruction (if they are available).
    - Entering the geometric and mass data of vehicles and other participants, as well as other technical data relevant to the simulation into the simulation program (If possible, by loading from a database and by manual correction if necessary.)
    - Compilation of mathematical/mechanical simulation models of the vehicles and other participants involved in the accident in the reconstruction program.
    - Defining the (advanced) driver assistance system or the level of automation in the given vehicle or considering it with other procedures.
    - Performing mechanical/mathematical computer simulation of the accident process.
    - If applicable, the calculation, simulation, or evaluation of the accident avoidability based on the available data.
- Evaluation of the accident reconstruction results, during which the following important issues must be addressed:
    - The primary causes of the accident, with particular regard to the possible influence of driver assistance systems or self-driving functions and human error.
    - Determination of additional factors due to the occurrence of the accident.
    - In the case of a technical failure, a detailed evaluation of its role.
    - Evaluation of avoidability of the accident.
- Making recommendations and presenting conclusions.
    - Making proposals for the further development of accident reconstruction method(s) or the development of a new method.
    - Making recommendations regarding the further development of (advanced) driver assistance systems, self-driving-, or other vehicle safety functions.

3.4 Accident reconstruction software being used in in-depth analysis

The accident reconstructions that are part of the in-depth accident investigation will be performed with the PC Crash 14.0 accident reconstruction program. PC Crash 14.0 is one of the world's leading vehicle simulation software, which is used to reconstruct and analyze road traffic accidents and other incidents. Currently, more than 6,000 installations are used in many countries around the world. The program is used by forensic experts, authorities (police), universities, car manufacturers and insurance companies for educational, research and accident reconstruction purposes (Fig. 8-9). The models in the program have been validated continuously for more than 20 years with numerous crash tests, and the results are regularly published. (DSD, 2022).



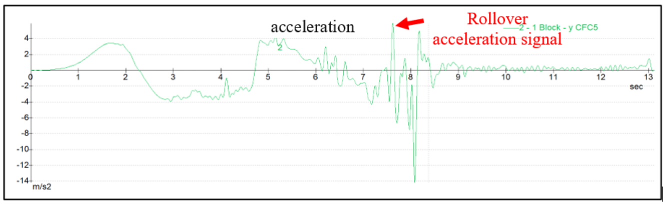


Fig. 8-9. Simulation of the rollover process in the PC Crash software with side acceleration (a_y) curve. (Source: (Ignácz, 2018))

One of the most important aspects of the chosen the program was that with this software it is possible to simulate the accidents of multi-body vehicle assemblies forming a complex mechanical system, which is necessary from our research's point of view.

We use the TruckMaker software (Fig. 10) developed by IPG Automotive to simulate the (advanced) driver assistance systems and self-driving functions in vehicles involved in the accident and, where applicable, to develop proposals for their further development.

Fig. 10. Model environment in TruckMaker (Source: (IPG Automotive GmbH, 2021))

Regarding the simulation and possible further development of partially automated and self-driving functions, we chose this software because it has appropriate vehicle dynamics simulation capabilities and enables the definition and simulation of the currently widely used sensors (lidar, camera, ultrasonic and radar) in the vehicle model (IPG Automotive GmbH, 2021).

3.5 *The current regulation related to increasing the safety of motor vehicles and increasing the degree of automation and its role in our research*

According to the regulation EU 2019/2144 after July 6, 2022, all new type-approved vehicles have to be equipped with the following advanced vehicle systems (European Parliament, 2019):

- **“event data recorder”** (EDR)
- “intelligent speed assistance”
- “advanced driver distraction warning”
- “driver drowsiness and attention warning”
- “reversing detection”
- “emergency stop signal”
- “alcohol interlock installation facilitation”

The event data recorder records and stores information and data critical to the collision in the following sections (European Parliament, 2019):

- shortly before the collision
- during the collision
- immediately after the collision

The event data recorder has to record the following data with a high degree of accuracy, ensuring the preservation of the data (European Parliament, 2019):

- “the state and rate of activation of all its safety systems”
- “vehicle’s speed”
- “relevant input parameters of the on-board active safety and accident avoidance systems”
- “braking”
- “brake activation”
- “position and tilt of the vehicle on the road”
- “112-based eCall in-vehicle system”

The field of use of the data recorded by the event data recorder system is strictly limited for data protection reasons. The data can be used anonymized for accident research and analysis (European Parliament, 2019):

Another important advantage of making the EDR mandatory is that it will be used to identify the active safety systems installed in the vehicle, as well as the exact vehicle type, variant and version (European Parliament, 2019).

For the safety of heavy commercial vehicles and vulnerable road users (VRUs) it has great importance that based on the EU regulation (2019/2144), vehicles of M2, M3, N2 and N3 category are required to be equipped with the following advanced systems (European Parliament, 2019):

- „advanced systems that are capable of detecting pedestrians and cyclists located in close proximity to the front or nearside of the vehicle and of providing a warning or avoiding collision with such vulnerable road users"
- "advanced emergency braking system"
- "lane departure warning system"

Regarding the vulnerable road users' safety, the turn assist system is extremely important. As expected, with the help of this equipment, the accidents of the right-turning commercial vehicle and the vulnerable road users traveling parallel to it or staying close to it will be significantly reduced.

During the in-depth research to be carried out, it is necessary to examine, among other things, how and to what extent the accident statistics will have changed after the date of application of the EU Regulation 2019/2144, with particular regard to accidental death, accidental injury and the course of the accident. In connection with the introduction of the newly mandatory systems, we obviously expect a decrease in accidental deaths and injuries. During the research, we will also examine to what extent making the event data recorder (EDR) mandatory for new vehicle types is going to affect the work of vehicle technical experts. Meeting the expectations, thanks to the mandatory EDR, vehicle experts dealing with accident reconstruction will be able to obtain more detailed information about the accident process, so they can probably reconstruct it more accurately and reliably.

3.6 *The importance of the planned in-depth research regarding accident statistics.*

The currently available Hungarian and European official statistical data do not contain relevant data that are absolutely necessary for the further development of accident reconstruction methods and for an even more detailed exploration of the causes of accidents. For example, there are no data on how many vulnerable road users are involved in accidents each year during conflicts with the right-turning heavy commercial vehicles.

Nor is it possible to find out from the official statistical data to what extent the individual (advanced) driver assistance systems and self-driving functions played a role in the occurrence of accidents.

In order to achieve the mentioned goals, important information can be supplemented by the highly detailed in-depth accident analysis.

3.7 *Some special aspects of* heavy *commercial vehicle accidents and their reconstruction*

One type of commercial vehicle accident with the most serious consequences is when a heavy commercial vehicle turning right comes into conflict with a vulnerable road user (e.g.: pedestrian, cyclist) traveling parallel to it (in the blind spot) or staying close to the vehicle (also in the blind spot).

A significant accident risk factor for VRUs is the form-aggressiveness resulting from the design of heavy commercial vehicles and the mass-aggressiveness resulting from their large mass (Kőfalvi, 2008).

The computer simulation of the movement processes of heavy commercial vehicles (e.g. trailered trucks) and the reconstruction of accidents involving such vehicles are significantly more complex than the computer analysis of the accident processes of passenger cars and require different accident reconstruction methods (Kőfalvi, 2007). The reason for this is the complex mechanical system of commercial vehicles, as well as their special character (Kőfalvi, 2007). Let us just think about the reconstruction of VRU and truck accidents (Ignácz & Bell, 2010). The reconstruction of commercial vehicle collisions with passenger cars is similarly complex (Bell et al., 2011).

3.8 *Improving the traffic safety through new traffic accident reconstruction methods*

Active safety systems, advanced driver assistance systems and automated driving functions are expected to reduce the number of deaths and injuries significantly in Europe, however, not all traffic accidents will be preventable (Paula et al., 2020).

With the help of improved or new accident reconstruction methods, road traffic accidents will be investigated with greater accuracy and reliability. With the exact knowledge of the accident process, even more precise conclusions can be drawn regarding the causes and avoidability of the accident. In addition, specific technical proposals can be developed in the field of further development of (partially) automated vehicles

Therefore, new technical solutions can be developed in terms of driver assistance systems, self-driving functions, and possibly other vehicle safety devices. Altogether they will result in safer vehicles, thus increasing road traffic safety (Fig. 11.). Based on this, the number of accidents and their severity can be expected to decrease.

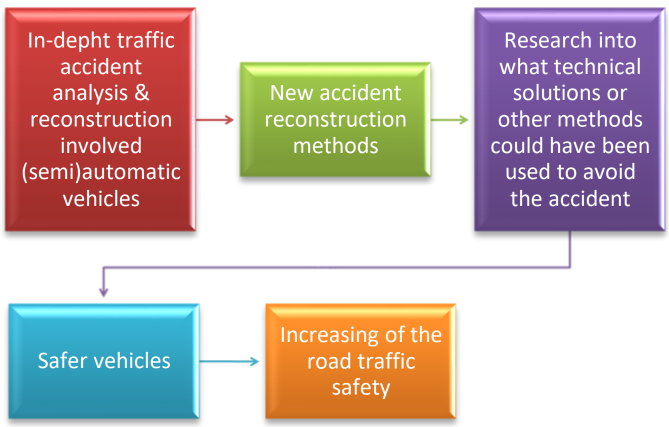


Fig. 11. Increasing the road traffic safety by In-Depht traffic accident analysis

4. APPLICATION POSSIBILITIES OF QUANTUM COMPUTING IN THE RECONSTRUCTION OF ROAD TRAFFIC ACCIDENTS, SELF-DRIVING AND CONNECTED VEHICLES

From the IT point of view vehicles with self-driving functions collect and process a huge amount of data which will increase significantly in the upcoming years and decades. Quantum computing seems to be an extremely promising technology in many areas of automotive technology, whether it is the development of new materials, structural optimization, data security or self-driving functions relevant to our research. It is essential to highlight the data security anomalies related to the communication of connected and self-driving vehicles which can also be answered by quantum computing (Ignácz et al., 2022). Consequently, during data processing and evaluation quantum computing will be an essential link in this process.

In the following part of our research, we will also examine the possibility of how quantum computing methods can be included in the work of motor vehicle technical experts, how they can be used for the reconstruction and research of road traffic accidents and during the development of new accident reconstruction methods.

5. CONCLUSIONS AND FUTURE RESEARCH

Since the majority of road traffic accidents occur due to human error, the automation of vehicles and their equipping with assistant systems and self-driving functions will be most likely to result in a significant reduction in the number of accidents and the number of people who die in road traffic accidents.

With the ever-widening spread of (advanced) driver assistance systems and (partially) self-driving vehicles, the reconstruction of accidents of this type gives automotive (forensic) technical experts new challenges. It is necessary to develop new accident reconstruction methods that can be used to analyze such accidents efficiently and reliably. For the further development of such methods and for the development of new methods, a sufficient number of road traffic accidents, so-called in-depth analysis and a computer aided, automotive expert-level reconstruction are required, which will be carried out in the next phase of our research.

In the in-depth research to be carried out, we will examine and define what new problems and opportunities arise in the field of road traffic accident reconstruction with the spread of self-driving vehicles. Based on the evaluation of the research results, we aim to further develop the current accident reconstruction methods and, where appropriate, develop new methods. In addition, we will point out how the experience gained during the reconstruction of traffic accidents can be used in the development of vehicles, especially in the development of (partially) self-driving vehicles.

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