Best Practice Manual for Road Accident Reconstruction

ENFSI-BPM-RAA-01

Version 01 - November 2015

With the financial support of the Prevention of and Fight against Crime Programme
European Commission - Directorate -General Home Affairs

Background

This Best Practice Manual (BPM) belongs to a series of 10 BPMs issued by the European Network of Forensic Science Institutes (ENFSI) in November 2015. The series covers the following forensic disciplines:

1. Forensic Examination of Digital Technology
2. Forensic Examination of Handwriting
3. Chemographic Methods in Gunshot Residue Analysis
4. Road Accident Reconstruction
5. Microscopic Examination and Comparison of Human and Animal Hair
6. Fingerprint Examination
7. DNA Pattern Recognition and Comparison
8. Application of Molecular Methods for the Forensic Examination of Non-Human Biological Traces
9. Forensic Recovery, Identification and Analysis of Explosives Traces
10. Forensic Investigation of Fire Scenes which have resulted in Fatalities*
11. Forensic Investigation of Fire Scenes which involve the Clandestine Manufacture of Improvised or Homemade Explosive Devices*
12. Forensic Investigation of Fire Scenes which Involve the Clandestine Manufacture of Illicit Synthetic Drugs*

* *The three specific areas on Forensic Investigation of Fire Scenes (numbers 10 -12) were combined into one BPM 'Investigation of Fire Scenes'.*

In the years 2014 and 2015, so-called Activity Teams have - in parallel - developed the 10 BPMs. The activities were performed within the project 'Towards European Forensic Standardisation through Best Practice Manuals (TEFSBPM)' and co-ordinated by the ENFSI Quality and Competence Committee. The realisation of the BPMs was supported by the Prevention of and Fight against Crime Programme of the European Commission – Directorate General Home Affairs (code: PROJECT HOME/2012/ISEC/MO/4000004278). The core project concept was that the BPMs will enhance the quality of the forensic services available to law enforcement and justice across Europe and thereby encourage forensic standardisation and cross-border cooperation between countries.

ENFSI expects that the issuing of this series will stimulate the improvement of already existing BPMs as well as the creation of new BPMs on disciplines that are not covered yet.

Acknowledgements
Lina Lazarenko (Forensic Science Centre of Lithuania), Bogdan Bobos (National Institute of Forensic Expertise, Romania), Henrikas Vaitekunas (Forensic Science Centre of Lithuania), Lembit Teesalu (Estonian Forensic Science Institute), Virginijus Pacebutas (Forensic Science Centre of Lithuania), Janis Bernans (State Forensic Science Bureau, Latvia), Oskars Irbitis (State Forensic Science Bureau, Latvia), Zakaria Tetradze (National Forensics Bureau, Georgia) and David Gvelesiani (National Forensics Bureau, Georgia) are thanked for their contribitions to the realisation of this BPM.

Official language
The text may be translated into other languages as required. The English language version remains the definitive version.

Further information
For further information about this publication, contact the ENFSI Secretariat. Please check the website of ENFSI (www.enfsi.eu) for update information.

Best Practice Manual for Road Accident Reconstruction

CONTENTS

1. AIMS

This Best Practice Manual (BPM) aims to provide a framework for procedures, quality principles, training processes and approaches to the forensic examination of road traffic accidents. This BPM can be used by Member laboratories of ENFSI and other forensic science laboratories to establish and maintain working practices in the field of forensic Road Accident Reconstruction that will deliver reliable results, maximize the quality of the information obtained and produce robust evidence. The use of consistent methodology and the production of more comparable results will facilitate interchange of data between laboratories.
The term BPM is used to reflect the scientifically accepted practices at the time of writing. The term BPM does not imply that the practices laid out in this manual are the only good practices used in the forensic field. In this series of ENFSI Manuals the term BPM has been maintained for reasons of continuity and recognition.

2. SCOPE

This BPM is aimed at experts in the field and assumes prior knowledge in the discipline. It is not a standard operating procedure and addresses the requirements of the judicial systems in general terms only.
The Best Practice Manual of Road Accident Reconstruction addresses the entire accident reconstruction process including the presentation of evidence in court and encompasses the specific aspects related to resources, validation, methodology, quality assurance and case assessment.
Accident reconstruction represents a comprehensive process of interpretation of the evidence associated with a collision and applies physical principles in order to reveal how the collision occurred. Road accident analysis reveals information which is useful for establishing the guilt of the participants.
There is a wide range of activities that may be encountered by road accident experts. The manual provides a list of the essential parts of road accident analysis, with a brief description. The activities that are described in this BPM are:

- analysis of the data taken from crime scene investigation
- interpretation of traces or any other data, which can be used in determination of collision location and mechanism of collision
- reconstruction methods (hand calculation, simulation programs)
- speed calculation
- possibility of avoidance

3. DEFINITIONS AND TERMS

For the purposes of this Best Practice Manual, the relevant terms and definitions given in ENFSI documents, the ILAC G19 “Modules in Forensic Science Process”, and in standards like ISO 9000, ISO 17000 and 17020 apply.
The following definitions are relevant to this document:
Road accident – unintended event that involves at least one road vehicle in motion and leads to personal injury or property damage, or both.
Deceleration – the rate of decrease in the speed of a vehicle or a moving part.
Stopping distance – the distance necessary to stop the motion of a vehicle with maximum deceleration.
Danger – the likelihood of a hazard to be involved in causing an accident.
Technical cause - a misnomer loosely applied to the most obvious or easily explained factor in the cause of an accident or the most easily modified condition factor

4. RESOURCES

4.1 Personnel

People are the most important resource in any forensic application. In order to allow staff to work effectively and efficiently, everybody concerned in the process should understand the nature of the tasks and the qualities required to perform them.

If there is a requirement within a particular legal system for personnel to possess qualifications and/or experience at a specific level then these should be quoted. Road accident experts should have knowledge of the theories, analytical techniques and procedures (including health and safety requirements) applicable to road accident analysis, competence in the evaluation and interpretation of findings in road accident analysis, knowledge and experience of the requirements and procedures of the criminal justice system for the presentation of evidence, both written and oral.

Specific knowledge in the field of accident reconstruction is:

- criminalistics (interpretation of traces)
- vehicle dynamics
- collision mechanics (impact theories)
- time-distance analysis (kinematics calculations)
- basic knowledge of crash-worthiness
- human factors (e.g. perception and information processing, driver perception-response time, individual and age differences)
- vehicle technology, especially concerning steering, braking, rolling, passive and active safety systems
- computer simulation techniques
- digital photography, digital imaging techniques and photogrammetry
- preferably basic knowledge of complementary examinations in road accident analysis (forensic medicine, electron microscopy, IR spectrometry, spectral analysis)
- road infrastructure
- basic knowledge related to accident scene examination

Practical knowledge obtained by work in the field is necessary.

4.2 Equipment

The equipment that can be used in the laboratory for road accident analysis consists of:

- PC (central unit, external hard disc, monitor, printer, scanner)
- Photo and video cameras (digital SLR cameras at least 6 MPx, Lenses with a focal range 28 - 200 mm)
- Optical microscope
- Measurement devices: measuring tapes, wheels and scales, yardstick, total stations and laser rangefinders
- Decelerometer
- Digital tachograph reader
- Lux meter

At the time of writing, the software considered eligible by ENFSI members and commonly used in the field of accident reconstruction is:

- PC CRASH
- VIRTUAL CRASH
- HVE
- V - SIM
- ANALYZER PRO
- CARAT
- MADYMO

- PC RECT
- PHOTOMODELER
- COLLISION ACCIDENT ASSISTANT
- PEDESTRIAN ACCIDENT ASSISTANT
- AUTOVIEW
- PAM CRASH
- LS DYNA

4.3 Reference materials

Reference materials regarding Energy Equivalent Speed (EES) could be used from different recognized sources (eg. CD EES Catalogue by Dr. Melegh Gabor, NHTSA, Transport Canada, AZT-catalog, www.crashtest-service.com)

4.4 Accommodation and environmental conditions

There are no specific requirements for a Road Accident Analysis laboratory suite.

4.5 Materials and Reagents

There are no specific materials and reagents used in Road Accident reconstruction.

5. METHODS

5.1. Vehicle to vehicle accidents

5.1.1 General findings

5.1.1.1 Various impact theories

Engineering mechanics is the science that considers the motion of bodies under the action of forces and the effects of forces on that motion. The basics of mechanics, relevant in the field of accident reconstruction are:

Impact theories

- Impact theory of Galilei, Huygens and Newton
- Impact theory of Hertz and Saint Venant

Newtonian axioms

Laws of friction

General theorems of mechanics

- Linear momentum theorem. Linear momentum conservation law
- Angular momentum theorem. Angular momentum conservation law
- Total kinetic energy theorem
- Total mechanic energy conservation law

Supplementary hypotheses to classical collision theory

- Restitution hypothesis according to Newton
- Collision coefficient hypothesis according to Poisson
- Direction hypothesis according to Marquard (1962)
- Classical impact model of Kudlich-Slibar (1966)

5.1.1.2. Reconstruction parameters

- Coefficient of restitution

The coefficient of restitution is defined as the ratio between restitution and compression impulse. Expressed in a more useful form, the coefficient of restitution, e, is the ratio of the post-impact separating velocity of the colliding bodies to their pre-impact closing velocity.

Values of coefficients of restitution can be positive or negative, depending on the type of collision

The restitution coefficient is an impact or collision parameter, which characterizes the energy loss of the collision, not of individual vehicles. It is possible to relate individual, vehicle/barrier values, e1 and e2, and determine a single combined value for a collision of those specific vehicles. The expressions of stiffness equivalent collision coefficient of restitution and mass equivalent coefficient of restitution are deduced in the literature [1]. Generally, the higher the residual deformations of the vehicles the lower the coefficient of restitution.

- Energy Equivalent Speed (EES)

The plastic deformation energy of the damaged car is expressed as the kinetic energy of the car with the virtual velocity value EES. For an authentic EES-estimation various crash-tests with different conditions are necessary, because the energy absorption depends on various parameters. The EES parameter represents (according to the International Standard definition ISO/DIS 12353-1:1996(E): *"The equivalent speed at which a particular vehicle would need to contact any fixed rigid object in order to dissipate the deformation energy corresponding to the observed vehicle residual crush."*
EES is a scalar quantity, having magnitude but no direction. EES values can be calculated for different types of vehicles using various approximation equations. Similarly, it is possible to determine the deformation energies in the case of a collision with a stationary deformable obstacle. If no similar tests are available for comparison purposes, then the deformation energy can be calculated from the damage measured on the vehicle using either the speed-deformation curve generated from a number of impact results at various speeds or a force-displacement curve prepared from a single impact test. Other methods used to calculate EES are: energy grids [2] or approximation equations.
In the absence of making detailed measurements on deformed profiles or calculations, EES can be estimated taking into account the following factors [3]:

- maximum residual crush
- width of the damage zone
- minimum residual crush
- displacement of the engine block
- cabin deformation
- any other major structural changes

The EES parameter can be estimated by comparison using EES databases (reference materials). The EES databases contain photos of damaged vehicles categorized into vehicles' model, collision type and collision severity. This enables the user to estimate the EES parameter of the vehicle involved in the case, based on a comparison of the damage.

- Equivalent Barrier Speed (EBS)

In addition to comparative analysis of vehicles involved in collisions with known EES parameters, it is possible to carry out measurements of the damage profile. The reconstruction method used to determine the deformation energy, and subsequently, the EBS parameter, is the method developed in the CRASH 3 program. If there is a vehicle deformed in an accident, *EBS* represents the speed with which an identical vehicle would have to collide with a stiff and non-deformable barrier to obtain identical permanent damage.
For collisions of cars with relative velocities greater than 30 km/h, these parameters can be treated as almost identical, considering the deformation profile measurement error.
The energy calculation is based on residual damage and its starting point is the method introduced by Campbell for collisions with fixed rigid barriers [4].
In the damage algorithm it is assumed that kinetic energy consumed during the collision is equal to the work done for deformation and that there is a linear relationship between the force per unit width acting on the vehicle during the collision and the deformation's amplitude [5]. Thus, to

define the dependence force/unit width - deformation it is necessary to know some coefficients, called stiffness coefficients.
In road traffic accident reconstruction it is possible to use the stiffness coefficients determined in two ways. If there is no a collision test conducted on the specific vehicle model, the so-called vehicle class coefficients are to be used [5]. Stiffness coefficients for different vehicle classes, depending on wheelbase and weight, have been presented by Sidall and Day in SAE Paper 960897 [6].

- Drag Factor

A vehicle's acceleration or deceleration is related to its drag factor, . Drag factor is defined as the force required for acceleration (or deceleration) in the direction of the acceleration (or deceleration) divided by the object's weight.
Reference [7] gives a range of drag factors for several surface descriptions. Reference [8] gives Collin's drag factors.

5.1.1.3. Phases

It is fair to say that reconstruction works backwards in time. It starts with the vehicles at rest or some other known post-crash condition and works backwards through the post-crash, or run-out phase, then through the crash phase and finally through the pre-crash phase, at the beginning of the event. This is a process of working from the knowns, captured in the post-accident measurements, photographs and physical evidence, towards the unknowns, which are the speeds and other conditions from the beginning of the event.
The methods to be presented are retrospective reconstruction methods, based on the final positions of the vehicles involved in the collision, considering the post-collision phase, collision phase itself and the ante-collision phase in succession.
In traffic accident reconstruction it is required, as a general overall objective, to determine the circumstances in which the event occurred. Noting that the expert report could contain case-specific questions, the main objectives of a traffic accident reconstruction, required in most cases by the customers are:

- trajectory analysis and determination of point of impact and relative position of the vehicles at the time of the collision
- determination of vehicles' velocities
- avoidance of the possibility of the accident

Addressing these issues is important in solving the case, namely in establishing the guilt of the participants, by the judiciary.

5.1.1.4. Collision location

Central to the concept of accident reconstruction is the idea that evidence is left behind after almost every event, and that almost every observable feature has causation. Without being exhaustive, the main evidence analysed in the reconstruction are:

- tire marks
- damage marks
- material marks (paint, fibres)
- objects and debris
- soil traces
- liquid traces
- biological traces (blood, tissue, hair, etc)

Following this analysis, a trajectory analysis can be performed, based on the positions of traces created and knowing the post-collision movements of the vehicles. This may or may not involve a specialized simulation program. In ENFSI Institutes, PC Crash, Virtual CRASH and HVE programs are used, the first one being the most commonly used program.

Traffic accident reconstruction, therefore, involves a trace analysis, which is the basis of solving issues like trajectory, point of impact determination and relative position of the vehicle from the moment of collision. Interpretation of traces is thus a prerequisite in choosing an appropriate computing device in the determination of impact velocities of the vehicles which have collided. This is carried out in two ways, both used at European level in the field of reconstruction.

5.1.2. Determination of vehicles' speed using simulation programs (Computer Method)
Another objective to be analyzed in traffic accident reconstruction is to establish vehicles' speeds at the moment of imminent danger of impact. This objective is solved either by using simulation programs, or through an analytical backwards calculation.
Simulation programs generally produce kinematic and dynamic modelling of vehicles' trajectory and collision modelling, by iterative calculation. The computer simulation uses the rest positions of the vehicles involved in the accident, fixed during the crime scene investigation. Using the positions of the traces left at the scene and the mechanical model, presented in [9], the vehicles' velocities are calculated. It has to be mentioned that the PC Crash program allows a crash parameters optimization process (point of impact, contact plane angle, pre-impact directions, vehicles' positions, restitution coefficient, contact plane coefficient of friction). Impact parameters are thus automatically varied to minimize the error between rest positions entered, resulting from reconstruction, and those calculated. Optimization is generally achieved by genetic method, using the least squares method. The program allows for optimization using two other methods: linear algorithm (Gauss-Seidel) and the Monte Carlo method ([9]. HVE and Virtual Crash are also two programs that can be used in this field.

5.1.3. Determination of vehicles' speed using analytical backwards calculation (Reconstruction-by-hand methods)
Another method for determining impact velocities is the so-called "manual calculation" (calculation by hand) which is based on backwards calculation. The post-collision phase and collision phase are analyzed successively, giving vehicles' post-collision velocities and then their impact velocities.
Along with computerized iterative-calculation based methodology, several sets of relations for calculation of linear and angular post-collision velocities were established. This relation is based on specific Newtonian mechanics equations, using some coefficients resulting from a theoretical and experimental study.

5.1.3.1. Determining the post impact speeds
In order to determine the velocities is necessary to know the linear displacement of the centre of mass of the vehicle, from the point of impact to the rest position, the angular displacement during post-crash movement, the wheels' status (free rolling wheels, locked wheels, wheels without pressure and wheels with increased resistance due to damage from impact), the drag coefficient and, in some cases, the coefficient of rotational resistance. These values involve some approximations (e.g.: a medium deceleration for the entire trajectory). The most important analytical approaches in the area of determining the post-impact speeds are represented by research that have resulted in the establishment of three sets of relations, known in the literature as Marquard [10], McHenry-Marquard [11] and Burg [12] relations.
As a general principle, applied to all the approaches mentioned above, trajectory analysis is based on the relation between work and energy, corresponding to the post-crash movements.

5.1.3.2. Impact velocities determination using the Drive Balance Method and EES Method
These two methods will be treated simultaneously because of the similarities between them. The Drive Balance Method uses the law of conservation of linear momentum and the EES Method uses both the conservation of linear momentum and energy laws [3], [13], [14], [15].

Using these laws, equation systems are formed which have the impact speeds of the vehicles as unknowns.
The Drive Balance Method is based on writing two equations derived from the projection of the law of conservation of linear momentum on a two-axes coordinate system and it requires knowledge of the following inputs:

- post-collision linear momentums, both in direction and in magnitude for both vehicles
- directions of both linear momentums, prior to collision, namely the directions of both impact velocity vectors

The EES method uses both conservation of linear momentum and energy laws and requires knowledge of the following inputs:

- as in the first method, post-collision linear momentums, both in direction and in magnitude for both vehicles
- the direction of velocity vector for one of the vehicles (vehicle no. 1)
- the deformation energy values for both vehicles (the EES parameter values)

Check calculations [3]
For both methods, when possible (when the damage profile can be analyzed), a check calculation requires a comparison between the actual angular velocities (determined from the post-collision rotation angles) and the theoretical angular velocities determined by the following steps:

- establishing the principal direction of force - PDOF
- establishing the vector velocity difference
- establishing the vector linear momentum difference
- determining the centroid of damage area (CoD)
- determining the impact force lever arm, knowing the fact that the impact force goes through the centroid of damage area
- checking the law of angular momentum by determining the theoretical angular velocity and comparing it with the actual angular velocity (angular velocities must have the same sign and do not differ in magnitude by more than one s^{-1})

For the EES method, a second check represents the comparison of actual velocity vector angle of vehicle no. 2 based on the traces left, not used as input data, with the theoretical angle, calculated based on the system of equations.

5.1.4. Determination of initial vehicles' velocities
Within Sections 5.1.2 and 5.1.3, computer and manual methods were presented which allow the vehicles' impact speeds to be determined. When, prior to the collision, some deceleration could be identified, it is necessary to determine the initial velocity, namely the velocity of the vehicles from the moment of imminent danger. Pre-crash phase analysis, therefore, entails determining initial velocities of vehicles, the distance existing to the point of impact at the moment of hazard and examining the possibilities to avoid the road event. Generally, in the pre-crash phase, the forces acting on the vehicle are either constant or time-dependent.

5.2. <u>Pedestrian Accidents</u>
5.2.1. General findings
A vehicle-pedestrian collision can be defined as a physical contact of the pedestrian with a motionless or moving vehicle. The essential tasks in the reconstruction of a pedestrian accident are to determine the relative position of the vehicle and the pedestrian, the collision location and the vehicle's impact speed. In the end, as in vehicle-to-vehicle accidents, the avoidance considerations are established.

5.2.2. Collision location

One important task in accident reconstruction is to establish the collision location. In order to do that, if skid marks of the vehicle were found, it is necessary to find out whether, in the course of these marks, tracks irregularities are present. Other important traces in establishing the point of impact are any the abrasion marks of the pedestrian's shoes, some objects belonging to the pedestrian (e.g. cap, bag, etc.) which are easily detached at the moment of impact, and debris, glass and paint flakes.
In order to determine the collision area, a graphical method was proposed, which is known in the literature as the "Limit Method". In this method the following factors are used [16]:

- Rest position of the pedestrian
- Pedestrian's throw parabola
- Car's rest position
- Car's brake parabola
- Location of the first and the last flakes of car paint
- Local limits (location of objects belonging to the pedestrian)
- Speed limits according to estimations by vehicle damage and pedestrian injuries

This method can define distance limits as well as speed limits in order to derive the actual impact position

5.2.3. Computer simulation models

In computer simulation, two main approaches are followed: multibody models, in which body segments are assumed to be rigid, and finite element models in which body segments are assumed to deform according to their material properties. In some cases these two approaches are combined. The multibody models have the advantage of quick computation. Finite element models are attractive in deriving injury parameters but they are very complex, and long simulation times are required.
The most important multibody crash simulation software today is Madymo but in European expert practice the most commonly used are the PC Crash and Virtual Crash multibody models. The finite element model allows the prediction of stress and deformations in the body resulting from a set of boundary conditions. These models require the use of specialized software applications such as PAM CRASH or LS DYNA. The finite element method is not widely used in accident reconstruction because it requires a long computation time.

5.2.4. Analytical Methods

One of the primary objectives of a reconstruction is to determine the vehicle's impact speed. A review of the literature regarding vehicle - pedestrian collisions leads to three methods for evaluating vehicle speeds. These methods are based on:

- Pedestrian injuries
- Vehicle damage
- Pedestrian throw distance

The assessment of vehicle speed from pedestrian injuries and vehicle damage is subjective and generally serves as a check for the regression analysis based on the pedestrian throwing distance.

5.2.4.1. Pedestrian Injuries

Several studies have documented the injuries sustained by pedestrians in real accidents and by cadavers in impact tests. The goal of these studies was to correlate the injuries of the pedestrian with a likely impact speed range. The studies yielded the following trends and conclusions:

- The severity of the pedestrian injury increased with impact speed
- The pedestrian - vehicle impact (primary impact) is more severe than the pedestrian - road impact
- The young and the elderly are at the highest risk to be injured

It has to be mentioned that vehicle structural characteristics and individual pedestrian characteristics may influence the type of injuries. There was no relationship detected between specific injuries and impact speed, only some general trends were apparent, that can be found in reference [17].

Recent studies agree that the risk of death increases with increasing impact velocity. Pedestrians hit by a vehicle at a speed of 30 km/h or less have a 90 % chance of survival, but less than 50 % if the impact speed is 50 km/h or greater. Pedestrian death probability as a function of the car's impact speed can be found in reference [18]. Injury data alone is insufficient to allow a precise estimate of impact speed but it may be used to support other analysis techniques.

5.2.4.2. Vehicle damage

Forward projection typically has damage located on the front of the vehicle. Due to the limited extent of pedestrian motion over the vehicle it is more difficult to estimate an impact speed from vehicle damage resulting from a forward projection.

In wrap trajectories, the main indicator of vehicle impact speed is the location of secondary head contact. It has to be noted that pedestrian height and the length of the vehicle's hood also affects the extent of pedestrian motion over the vehicle's frontal surfaces. Data about vehicles' damage, summaries for forward projection, wrap trajectories etc. can be found in different references [8], [17], [18], [19].

5.2.4.3. Throw distance

One of the most important reconstruction elements is the longitudinal throw distance, which is defined as the distance between the centre of gravity of the pedestrian at the time of collision and in the rest position, measured in the direction of the vehicle's motion. The throw distance is composed of the contact phase, the flight phase (possibly out of a transport phase) and the sliding phase. The throw distance is correlated with the collision velocity.

The main goal of this analysis is to determine the impact speed. In real cases post-impact data is often insufficient to use a pure mathematical model. Conversely, empirical models overcome the difficulty resulting from insufficient data but must be applied within the model limits.

The traditional mathematical approach treats the pedestrian as a projectile. There are many published models but in the forensic context the most important are Collins, Searle, Eubanks, Schmidt, Limpert, Wood and Stcherbatcheff models [8].

Empirical models incorporate many parameters into one or more constants. The result is usually a simple and practical mathematical expression. The most important approaches are : Appel, Sturtz, Wood, Kuhnel, Fugger, Toor, Happer [8].

The assumptions, the expressions of the models and trends in estimating the impact speed are shown in the authors papers or in references [8] and [20]. The disadvantage of the empirical models is that they model the average values of the data so if the sample is limited or the data are affected by the recording techniques it is possible that the empirical model could be inaccurate. It is fair to say that, along with impact speed, the deceleration of the vehicle is an important parameter that influences the throw distance, so that regression which includes the vehicle deceleration is recommended.

5.3. Avoidance considerations

For the legal assessment following impact analysis, it is necessary to examine from a technical perspective, if there had been alternative driving behaviour that could have led to accident avoidance. Initially the distances at which the vehicles were from the point of impact in the moment of hazard have to be established. Knowing the initial speed of the vehicle, the distances needed for avoidance manoeuvres (braking, swerving if suitable) are determined. These distances are compared with the actual distance available so that the avoidance conclusions can be drawn.

Generally, in order to determine the available distance that a driver had to take avoidance manoeuvres, in the first phase, the distance travelled by the vehicle whose driver triggered danger condition (vehicle no. 1) is determined. This driver placed the vehicle on a path that would cross the path described by the other vehicle (vehicle no. 2). Based on this distance and the speed of vehicle no. 1, the time elapsed from the onset of an imminent danger condition until the moment of impact is determined. This is, in fact, the time available to the other driver to take avoidance measures. On the basis of this time and, knowing the speed and the travel regime, the distance is determined at which vehicle no. 2 was at that moment. This distance is compared with the distances needed for avoidance manoeuvres [21], [22], [23]. Thus the conclusions relating to avoidance are formulated.

Even if it is found that the event could not be avoided, the reasons that led to the hazardous situation are also important. In order to do that, the maximum avoidance speed has to be determined by imposing the condition that the available distance should be equal to the distance required to stop.

The speed calculated is the speed which would allow the vehicle to stop in the plane determined by the trajectory of the other vehicle or obstacle position. After that, the judiciary may analyse, based on the conditions present on that section of road, whether or not this speed would have to be used. It is also possible to determine the possibility of avoiding the event, taking into account the permitted speed in the situation as the avoidance speed.

As seen before the question was how much slower a vehicle would have to drive, so that the accident could have been avoided. Avoidance can be seen in terms of space, but there are situations when the avoidance can also be seen in terms of time [16]. Spatial collision avoidance means that the vehicle can stop before the collision location. Temporal collision avoidance means that the vehicle arrives much later at the collision location, so that the other vehicle (or pedestrian) has completely abandoned its trajectory.

Along with the collision and post-collision phases, avoidance analysis can also be performed by analytical calculations and by computer programs.

5.4 Peer Review

All reports of road accident reconstruction should be peer reviewed. The peer review should cover the research part of the reconstruction and the findings.

Peer review must involve both a critical check and a technical review of the report and must be done by a second person who has been authorized and is competent to carry out road accident review.

Peer review must be documented according to institutes' or laboratories' requirements.

6. VALIDATION AND ESTIMATION OF UNCERTAINTY OF MEASUREMENT

6.1 Validation

Validation represents the confirmation, by means of examination and provision of objective proofs, that certain specific requirements for intentional use are fulfilled. In the field of the calculation of the impact speeds of two motor vehicles, ENFSI institutes use validated methods that satisfy the requirements of the customer, whether one is dealing with a determination based on manual calculation or a computer simulation.

The techniques or procedures adopted have been validated worldwide, so, the laboratory is required to carry out a verification exercise to demonstrate that it can achieve the same quality of results in its own environment. In these cases, a vehicle-to-vehicle or vehicle-to-pedestrian test has to be made. Both a computer simulation with the aid of the PC Crash software (but also with other simulation programmes) and the manual backwards calculation methods (the EES Method and the Drive Balance Method) represent methods acknowledged by the RAA EWG working group within ENFSI and within EVU. As far as the computer reconstruction method is concerned, involving software programs that are used worldwide, the specialized literature describes numerous validation activities carried out by the software producers, [24], [25], [26], [27], [28], [29], different authors [30], [31], [32], or research institutions [33], [34]. These confirmed both the correctness of the results obtained via these software programs and the uncertainty of measurement. Manual backwards calculation has been presented and analysed in many specialized works [3], [12], [13], [14], [15], [35], [36]. Both method categories were, however, analysed at the ENFSI institutes in order to verify if their main characteristics meet the requirements of the laboratory and of the client, and this was carried out mainly via the following techniques:

- experimental research carried out by ENFSI, by conducting certain crash tests and comparing the measured values with the ones determined by calculation, using the methods under discussion:
- inter-laboratory proficiency testing
- evaluation of the factors that influence the result
- evaluation of the uncertainty of the results
- comparison of the results obtained via other methods (study of tachograph recordings, analysis of video images which, in some cases, capture the event)
- verification that the requirements can be met by using the method (comparative analysis with other categories of methods and questionnaires for evaluating customer satisfaction)

The input data, however, is not of such high quality in the case of real accidents, so that both the computer reconstruction and backwards calculation are affected by greater errors. For this reason, in the case of both methods, their respective sources have to be identified and elements have to be established for the determination of uncertainty of measurement.

6.2. <u>Estimation of the uncertainty of measurement</u>

Road accident reconstruction methods are based on equations specific to collision theory (energy, momentum, and angular momentum conservation) and are not the cause of any significant errors by themselves. The errors occur out of the need to approximate certain parameters (the drag factor, the motor vehicle wheels' status in the post-collision phase, the EES parameters, the masses of the motor vehicles) or from the way in which the examination of the scene is conducted following the accident (the accuracy of the measurements carried out). The uncertainty of measurement associated with determining the vehicles' impact speeds, can be determined and expressed with the aid of the simulation programmes using an optimisation process. [9], [26] [29]. If required, the errors can be expressed in numeric or percentage values and should state the optimisation algorithm which was used.

7. PROFICIENCY TESTING

Proficiency tests should be used to test and assure the quality of Road Accident Reconstruction. A list of currently available PT/CE schemes as put together by the QCC is available at the ENFSI Secretariat. "Guidance on the conduct of proficiency tests and collaborative exercises within ENFSI" [38] provides information for the ENFSI Expert Working Groups (EWGs) on how to organise effective proficiency tests (PTs) and collaborative exercises (CEs) for their members.

Performance of proficiency tests (PTs) and collaborative exercises (CEs) relates to the systems within the laboratory, but may also provide some information on the performance of individuals participating in the tests. The laboratory's level (frequency) of participation in proficiency tests and collaborative exercises may be dictated by the laboratory policy or by the availability of suitable tests.

Participants in the tests should follow the laboratory Standard Operating Procedures for casework. They should not give the test any special treatment that would not be given in the same circumstances to routine casework. When the expected results in PT/CE have not been achieved, the laboratory is responsible for:

- root cause analysis
- corrective and preventive actions
- implementing improvements
- reviewing the effectiveness of corrective actions
- reviewing the effect on previously performed casework

The ENFSI Road Accident Analysis Expert Working Group arranges or recommends proficiency tests or collaborative exercises in which laboratories should participate if it is applicable to their scope. A list of currently available PT/CE schemes is available at ENFSI RAAWG.

If there are no PT's/CE's available in the road accident analysis field, participants, depending on available resources, either create a PT themselves or purchase it from suppliers. To achieve a higher accuracy, tests should be purchased from certified suppliers who have the required measuring instruments and experience. PT's should be designed so that test conditions match actual traffic accident conditions as closely as possible. If possible, real crash tests with known starting parameters should be performed. Such tests can be purchased from suppliers (eg. http://www.dsd.at/, http://www.crashtest-service.com/ etc.). Depending on the type of PT, it is possible to create laboratory tests with existing resources and through direct measurement, such as by vehicle braking tests. To prepare the trial, vehicle technical data, track measurements and data on weather conditions should be at expert's disposal. When creating this type of test it is necessary to take into account the accuracy of the available measuring instruments and their possible impact on the calculation result. To achieve a higher accuracy it is necessary to perform measurements with several measuring instruments simultaneously, as well as using video recording equipment.

8. HANDLING ITEMS

8.1 <u>At the scene</u>

The examination of the scene is the first and most irreplaceable investigative activity to be conducted after the occurrence of a traffic accident. The inspection is generally done by police and provides the most essential part of the important evidence.

The examination of the scene of the accident must be conducted at the right time, thoroughly, accurately and objectively, ensuring the success of all further investigative activities.

Most of the accident traces are subject to changes with increasing time after the accident, so they should be secured as soon as possible.

If the initial examination of the accident scene has been conducted inadequately or any new circumstances become apparent, additional or repeated examination may be conducted.

In order to record the measurement results, a scheme containing all the essential data relating to the scene of the accident and the event itself has to be made.

Accident evidence and data to be recorded at the scene includes:

- Accident date, time, place
- Information about persons involved, witnesses
- Road conditions
    - carriageways, lanes, sidewalks, shoulders, road surface marking

    - widths of the elements of the road and the difference in heights between the elements of the road
    - the type and the precise characterisation of the road surface
    - condition of the shoulders
    - whether the road is horizontal or has a longitudinal or transverse gradient; any inclination present must be measured
    - the height of kerbs will be recorded provided that sidewalks and dividing strips separated with kerbs are present
    - if a traffic accident has occurred on a bend or immediately after a bend, the radius of the bend must be determined
    - condition of the road as caused by the meteorological conditions
    - visibility conditions
    - road signs and traffic lights
- Marks left by vehicles or vehicle parts at the scene of the accident
    - skid, yaw and scratch marks, marks created upon rolling of wheels
    - rapid changes in directions of tire marks, segments of skid marks that have been created on various types of road surface and segments that pass through various road surface conditions
- Any pieces of debris, glass fragments, fluids, soil, bits of paint, etc., separated from the vehicle
- Rest positions of vehicles involved in the traffic accident
- Dragging marks and biological traces of any deceased/injured persons. Rest positions of deceased/injured persons
- Any damage caused by the accident and other marks that are important as regards evidence will be recorded (deformations, tears, scratch marks, scrub marks, deposits, etc.)
- Condition of the steering and braking systems, lamps, tyres
    - in the case of a traffic accident that has occurred in the dark or in poor visibility, the preserved parts of the bulb must be searched for in the broken lamp, if required, and taken as evidence
- Vehicle load
- Condition of vehicle interior
- Tachograph chart/recording

Accident scene must be photographed (road, all marks, traces, vehicle damage, vehicle locations etc.)

8.2 In the laboratory

Before starting work on any case the examiner should carry out an assessment of the information available and the items provided for examination in the light of the agreed customer requirement. The examiner should seek to redress any deficiencies through consultation with the customer.

9. INITIAL ASSESSMENT

In order to conduct a road accident expert assessment, the following information is usually needed:

- all available information from the road accident scene (documented scene inspection results by police, witness reports, photos, accident description etc.)
- in the case of a traffic accident with deceased/injured persons, information about locations and nature of injuries is usually needed. Therefore materials submitted by the customer must include the report of the medical expert

If there is not enough initial data it will be necessary to ask the customer for missing information (additional or repeated inspection of the accident scene and/or vehicles, photos, documents etc). Investigative experiments may also be conducted in order to resolve any outstanding issues at the scene of the accident.

10. PRIORITISATION AND SEQUENCE OF EXAMINATIONS

Routinely the road accident forensic expert's reconstruction is carried out from documents, so that there is no risk of damaging the objects of research. In order to obtain the best final result it is recommended that other examinations (for example, paint, glass, plastic, forensic pathologist etc.) are performed first, if there is a need to carry them out.
Before commencing road accident examination the urgency and priority of the customer (client) should be considered. For example it is important to conduct an examination as soon as possible if the law officers need to decide whether a person should remain in custody.

11. RECONSTRUCTION OF EVENTS

The main task of Road Accident reconstruction is the reconstruction of events. Road accident reconstruction takes into account previously existing studies, such as metallographic, forensic medicine, paint, traces on clothes or shoes and so on (if there is reason to do them). Therefore, Road Accident reconstruction summarizes the results and reconstructs the sequence of events. Reconstruction sequences are described in the "Methods" section.

12. EVALUATION AND INTERPRETATION

In accident reconstruction a lot of elements must be considered during the evaluation and interpretation process. All the information received, relating to reconstruction, must be gathered. Each element must be taken into account in order to establish an overall opinion related, finally to the cause of accident. Interpretation and evaluation must be used to draw conclusions related to the point of impact, speed values, possibilities of avoidance and technical causes of the accident.

13. PRESENTATION OF EVIDENCE

The overriding duty of those providing expert testimony is to the court and to the administration of justice. As such, evidence should be provided with honesty, integrity, objectivity and impartiality.
Evidence can be presented to the court orally and/or in writing. Only information which is supported by the examinations carried out should be presented. Presentation of evidence should clearly state the results of any evaluation and interpretation of the examination.
Written reports should include all the relevant information in a clear, concise, structured and unambiguous manner as required by the relevant legal process. Written reports must be peer reviewed.
Expert- witnesses should resist responding to questions that take them outside their field of expertise unless specifically directed by the court, and even then a declaration as to the limitations of their expertise should be made.
The use of graphics, schemes and other visual information can be a helpful aid in presenting the information clearly, particularly analytical results.

14. HEALTH AND SAFETY

There are occasional health hazard issues with items submitted for road accident examination, including biological contamination (for example clothes with biological material). Personal protective equipment (lab coats, glasses, gloves etc.) must be used and caution must be exercised when examining these types of items.

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16. AMENDMENTS AGAINST PREVIOUS VERSION

Not applicable (first version)

APPENDIX
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ENFSI-BPM-RAA-01

Version 01 - November 2015