Project No. 635895 — InDeV

InDeV: In-Depth understanding of accident causation for Vulnerable road users

HORIZON 2020 - the Framework Programme for Research and Innovation

Deliverable 7.9

Final Report

Due date of deliverable: 31.10.2018
Submission date: 19.11.2018

Start date of project: 01.May 2015
Duration: 42 months

Organisation name of lead contractor for this deliverable:
Federal Highway Research Institute (BASt), Germany

Revision 2.0 (18-12-18)

Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Document information

Authors

Anatolij Kasnatscheew, Federal Highway Research Institute (BASt), Germany (WP5)
Piotr Olszewski, Warsaw University of Technology (WUT), Poland (WP2)
Aliaksei Laureshyn, Lund University (LU), Sweden (WP3)
Thomas B. Moeslund, Aalborg University (AAU), Denmark (WP4)
Evelien Polders, Hasselt University (HU), Belgium (WP6)

Project Coordinator

Aliaksei Laureshyn

Department of Technology and Society

Lund University

Box 118

221 00 Lund, Sweden

Phone: +46 46 222 91 31

Email: aliaksei.laureshyn@tft.lth.se

Coordinator of WP 7

Susanne Schoenebeck

Section 'Accident Analysis and Safety Concepts, Road Safety Economics'

Federal Highway Research Institute (BASt)

Post Box 10 01 50

D-51401 Bergisch Gladbach

Project funding

Horizon 2020
Grant agreement No. 635895

Revision and History Chart

Version	Date	Comment
1.0	18-11-09	Version before review
1.1	18-11-19	Final Version
2.0	18-12-18	Final Version after Review meeting

This project has received funding from the *European Union’s Horizon 2020 research and innovation programme* under grant agreement No 635895

The present document is a draft; the approval from the EU Commission is pending.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AIS	Abbreviated Injury Scale
CADaS	European Common Accident Data Set (common structure including a minimum set of standardised data elements)
CARE	Community database on Accidents on the Roads in Europe
EC	European Commission
EU	European Union
HEATCO	Project 'developing Harmonised European Approaches for Transport Costing and project assessment'
InDeV	Project 'In-Depth Understanding of accident causation for Vulnerable road users
IRTAD	International Road Traffic Accident Database
MAIS	Maximum Abbreviated Injury Scale
PET	Post-Encroachment time
QALY	Quality-Adjusted Life Year
RGB	red-green-blue
RNSA	Road Network Safety Analysis
RSA	Road Safety Audit
SEC	Socio-Economic Costs
SafetyCube	Project 'Safety Causation, Benefits and Efficiency'
STRADA	Swedish Traffic Accident Data
TTC	Time-to-collision
VRU	Vulnerable Road User

1. Executive Summary

The EU-financed project InDeV (In-Depth understanding of accident causation for Vulnerable road users) has developed methodologies, concepts, hardware and software to analyse the road safety situation with the emphasis on vulnerable road users (VRUs).

Within five content-related work packages (2-6) particular aspects have been addressed, such as:

- Accident databases and accident costs,
- recording, analysing traffic conflicts and evaluating recorded field data and
- creating guidelines and a manual with instructions for road safety practitioners.

The other two work packages of the project were WP1 on project management issues and WP7 on dissemination issues.

Underreporting of traffic accidents is a significant problem and most of road users in unreported accidents are VRUs. It is advisable to find a common strategy to deal with underreporting for the sake of complete accident statistics and costs. This strategy should involve complementing police road accident data with hospital data.

There is a need for harmonisation of accident data collection and cost calculations regarding the definitions and procedures of data collection and the verification among the EU countries. It is recommended to include single accidents (VRU accidents constitute the majority of these) in the relevant definitions and thereby consider them in official accident statistics and costs for all EU countries. Both ‘serious’ and ‘slight’ injuries need to be defined comprehensively. Defining injuries based on ‘MAIS3+’ injury level, recently introduced by the EU, is a step in the right direction.

It has been ascertained that the identification and analysis of black spots at intersections considers only motorised traffic and does not include VRUs. To counteract this fact, an integrated approach has been developed in order to improve the safety assessment of VRUs. It is recommended to use the method synergy matrix (see Table 3.1).

Concerning accident cost calculations in all EU countries it was found that the methodologies are generally very heterogeneous in terms of monetisation method, component structure, data source etc. However, some clarity has been gained. A harmonising process ought to be initiated. Furthermore, casualty related costs (excl. property damages) of VRUs are higher than of non-VRUs. It is recommended to consider this aspect in cost-benefit-analyses and indicate it generally in economic cost calculations. Complementary to the existing injury severity levels, the definition and introduction of an additional injury category based on the actual medical impairment and level of disability can enhance the estimation of accident costs.

In the scope of developing tools for automated traffic encounter data collection and analysis following recommendations are made. Experience gained shall be disseminated and promoted for further research fields, such as:

- The combination of RGB and thermal cameras,
- Data recording from drones and from the combination of RGB and Lidar sensors,
- Application of Deep Learning algorithms for an analysis of specific traffic scenarios and for detection of different weather conditions.

The portable pole can be used definitely in other works where the goal is cheap and easy data collection in locations lacking obvious camera mounting opportunities.

The watchdog system for traffic encounter detection has been fully developed and is already being used in many countries of the world. It has become important to ensure an easy use of this application and to collect experience for further development of the system.

The validation of surrogate safety measures against recorded accidents has been hampered by the different underreporting documentation among countries and the very low accident numbers on individual sites in general. Further research and development work on validation is needed to be investigated.

Concerning the measurement of exposure it is recommended to use the number of encounters between individual road users, not the units of traffic flow.

It is not recommended to define traffic conflicts with very wide thresholds (above 2 seconds). Furthermore, a ‘serious’ conflict situation, especially with VRU participation, shall be defined by new factors, such as kinematic energy, suddenness etc.

For the purpose of predicting the future motion of road users on video data more advanced methods are needed, such as the natural adaptation of the path and of the speed to the manoeuvre being performed. It is recommended to do research on improvement of these indicators.

A huge and valuable data set has been collected and is now available for further research in order to analyse specific traffic scenarios and to detect different weather conditions using the automated traffic system. However, to apply Deep Learning algorithms, even more annotated training data is required. It is recommended to share the gained data-set publicly and give the researcher community the opportunity to test new ideas, theories and algorithms.

The apps for data collection on incidents/accidents (self reporting of accidents, naturalistic walking and cycling) have been developed in InDeV and can now be promoted and applied by both practitioners and researchers.

The final goal to create reference guides has been reached after the following steps:

The newly created handbook gives support for VRU safety analysis. It is recommended to promote the handbook among practitioners.

Besides the handbook, the InDeV toolbox consisting of two manuals (A and B) helps to analyse the safety situation of VRUs by observing surrogate safety measures.

Both the handbook and the toolbox need to be promoted and disseminated among practitioners in order to reach a higher safety level not only for VRUs but for all road users.

2. Introduction

InDeV (In-Depth understanding of accident causation for Vulnerable road users) has contributed to the overall aim set out in the European policy objective of halving road deaths by 2020 by providing a toolbox for understanding accident causes for vulnerable road users (VRUs) and by developing a framework for good practice for a comprehensive assessment of socio-economic costs related to road-accidents involving VRUs.

This final report reflects the outcome of the project InDeV. It summarizes the goals, processes, results and conclusions of the individual work packages of the project. Additionally, possible exploitations, i.e. impacts and benefits, are introduced per chapter and are outlined in the final chapter ‘conclusions’.

3. Work Package 2 – Review of study methods and identification of critical sites and situations for VRU safety

3.1. Goals of WP2

The main objective of WP2 was to critically review the usefulness of the currently used methods for accident causation studies with relevance to VRUs and to assess the quality and availability of data with relevance to VRU safety problems. The review was meant to identify gaps in the currently used study methods and recommend improvements. In addition, the aim of WP2 was also to identify typical locations and situations where most VRU accidents occur which would help in selecting sites and situations for observational studies. Typical situations where most VRU accidents occur can be characterised by location type, facility type, geometry and other conditions. Vulnerable road users covered by the review and accident data analysis comprised the following groups: pedestrians, cyclists, moped riders and motorcyclists.

3.2. WP2 Process

The review of the study methods related to vulnerable road user safety that are used today covered the following categories of methods: epidemiological studies based on accident and injury data; in-depth accident investigations; naturalistic driving studies; behavioural observations; traffic conflict studies; and self-reported accident studies. The review consisted of two parts: a systematic literature review and a questionnaire survey.

A scoping review of the available scientific literature was conducted that covered four types of safety-related studies: naturalistic driving studies, behavioural observations, traffic conflict studies and self-reported accidents. These are the areas on which most research effort has recently been focused. In total, over one thousand scientific publications were included in the scoping reviews. Full reports on the results of the four scoping reviews were published as separate parts of the WP2 deliverable.

Questionnaires were sent out to partners in all InDeV countries to obtain information and a critical appraisal of the currently used study methods related to VRU safety. A second questionnaire survey among InDeV partners was conducted in order to assess the quality and availability of accident data in their respective countries.

Statistical analyses of accident data from the available data sources were conducted to produce a list of the most typical locations and situations critical for VRU safety. It was hoped that the results would enable identification of conditions and factors that have a negative impact on VRU safety. The analysis was based on data from international as well as some local accident databases. To get an overview of the problem of VRU accidents, analyses of international accident databases (CARE database) were conducted. To compare these figures with other countries of the world, additionally the IRTAD database was used.

In addition, Danish and German national databases were used to conduct analysis of the 3-digit accident classification which contains more detailed information than CARE – namely data on the manoeuvres of all accident participants.

The partner-countries where observational studies were planned proposed a list of feasible locations for both long-term and short-term observations. The selection was based on accident data, practical requirements and desired characteristics of the sites. The characteristics of the initially proposed locations were carefully examined and the required number of sites was selected in the municipalities involved.

3.3. WP2 main results and conclusions

The survey results show that epidemiological studies based on accident and injury records form the basis of traffic safety assessment in every partner country. General accident reports help to identify the time trends of accident occurrence and to compare the safety situation among countries and cities. Benchmarking between countries can help to monitor progress towards the targets for traffic safety improvement and to assess the relative importance of problems. While the exact causes of accidents cannot be determined, the contributing factors can often be deduced. Identification of dangerous locations is performed using black spot analysis and network safety analysis. Both are important and useful for VRU safety assessment – black spots identify dangerous intersections and road crossings and network analysis identifies dangerous road links. The exposure measures used should be appropriate for VRUs and include pedestrian and bicycle volumes in addition to motorised traffic volumes.

The literature review and survey on accident data quality conducted among InDeV partners show that despite efforts to harmonise the definitions of injury road accidents and their severity at the European level, differences exist both in the definitions and their interpretation. Even in the case of the fundamental concept of “road accident/injury accident”, the definitions used by some countries differ slightly from the CARE standard.

The European CARE accident database was set up with a comprehensive structure and scope of information as defined in the CADaS glossary. The advantage of using CARE for safety research is that it is a disaggregate database, i.e. detailed cross-classification analyses can be made. However, not all countries provide all data according to the guidelines. The possibilities of safety analysis would be greatly improved if the guidelines were followed exactly by all countries.

Data on fatalities are quite comparable between the InDeV partner countries: the 30-day road accident fatality definition is used. CARE definitions of injury severity are applied in only 3 out of 7 countries. There are also considerable differences among countries in terms of accident data collection and data verification procedures, which results in varying levels of underreporting of the different accident categories.

A literature review of naturalistic driving/riding/walking studies shows that this method can provide important insights into the understanding of the causation factors of accidents with VRUs. So far, naturalistic data from VRUs have mostly been collected via equipped motorcycles or bicycles. Accidents and critical situations were detected based on kinematic triggers such as acceleration, rotation, etc. only in few cases. The potential for such detection was shown through studies of falls among the elderly.

Behavioural observation studies are an important tool to understand the causes of accidents that involve VRUs because such studies provide insight into the behavioural processes that lead to an accident. A review of about 600 publications on road user behavioural studies shows that these are mainly used to monitor traffic events and to evaluate safety improvement measures. Behavioural observations seem very useful to examine how road users interact with each other or navigate through a crossing.

Certain topics were found not to have been the subject of much research, for example behaviour of powered two-wheeler riders.

The observation and analysis of traffic conflicts as surrogates for accidents has two main advantages: conflicts occur more frequently than accidents and observing them allows for better understanding of the processes that may lead to accidents. The scoping review of literature shows an increase in the use of traffic conflict studies, in particular those using video analysis. The review also shows that although there is a number of validation studies on the relationship between conflicts and accidents, most of these are quite old. Recently, new indicators with high potential have been suggested and there is a clear need for new validation studies that use video analysis tools, in particular for conflicts involving VRUs. Nevertheless, a combination of conflict studies with other types of behavioural observations and accident analyses provides better insight into road safety problems (see Table 3.1).

The self-reported accident study method is relevant as it provides knowledge on accident causation as well as events that led to the accident. Next to the linkage of police and hospital record (see Table 3.1 and Table 6.1) this method provides information on accidents that are not reported to the police, thus making it possible to estimate the level of underreporting. A systematic literature review shows that the practice for collecting self-reported accidents varies and most studies focus on car accidents. Self-reported accidents are used to evaluate safety measures, estimate the total number of accidents and to identify accident causation factors.

Safety of vulnerable road users in Europe was assessed based on analyses of CARE accident database for years 2009-2013. In the whole European Union, VRUs constitute 46% of all traffic fatalities and 53% of all seriously injured persons. Pedestrians comprise 21% of all fatally injured traffic victims in EU28, followed by motorcyclists (15%), cyclists (7%) and moped riders (3%). Trends of VRU safety in EU28 are generally positive - during the five-year period 2009-2013 the number of fatally injured has decreased by: 20% for pedestrians, 14% for cyclists, 41% for moped riders and 27% for motorcyclists.

The majority of VRU fatal injuries occurred in built-up areas for: pedestrians (70%), cyclists (56%) and moped riders (57%). However, over half of motorcyclist fatalities (60%) occurred in non-built-up areas. In all EU28 countries combined, 75% of VRU fatal injuries occurred outside junctions. It seems that about twice as many VRUs are fatally injured at junctions without traffic signals as at junctions with traffic signals. In EU28 countries combined, 48% of VRU fatal injuries occur during daylight but there are large differences between VRU categories and areas. A majority of cyclists (57%) and motorcyclists (64%) are fatally injured in daylight conditions. The frequency of cyclist, motorcyclist and moped rider fatal injuries is the highest in summer months (June-September) but for pedestrians it is higher in winter time (October-December).

Statistical analyses of data from international accident databases show that relatively high numbers of cyclist fatalities per million inhabitants can be observed in countries where cycling is very common and the bicycle is used as a daily transportation means like in the Netherlands and Denmark. Similarly to pedestrians, elderly people have the highest risk of getting fatally injured as cyclists in most countries, due to their vulnerability. The detailed age group analyses for pedestrians and cyclists show clearly that the fatality rate for elderly is significantly higher for people aged 75 years and above. For moped riders, the highest numbers of fatalities per million inhabitants can be observed in the age group from 15 to 17 years, when many young people are starting their career as motorized traffic participants. The highest fatally rates for motorcyclists are in the age group of novice drivers and the middle-aged persons, between 25 and 64 years old.

Based on analysis of the 3-digit accident classification used in the Danish and German national databases, it was established that the biggest concentration of accidents with VRUs in urban areas occurred at roadway exits of signalised intersections. These locations are dangerous because crossing pedestrians and cyclists are in conflict with turning motorised vehicles. Uniformity of sites was considered important to make accident modelling easier. Based on these criteria, 25 locations in participating municipalities were selected for observational studies.

3.4. Exploitation (Impacts and Benefits)

Based on the review of road safety analysis methods, several general recommendations for improving VRU safety assessment were put forward. The standard definition of injury accidents adopted by the EC (CARE database) covers virtually all traffic accidents involving VRUs with the exception of single pedestrian accidents (falls). It is recommended to include this additional category in VRU safety assessment studies as well as in economic calculations of the total accident costs.

As there is no clear definition of what constitutes an “injury” suffered by a victim of a road accident, the term “injury” should be defined for the sake of consistency. The categorisation of injury severity of road accident victims poses considerable challenges. The EC’s current efforts are aimed at producing a reliable system of reporting the numbers of the severely injured in different countries based on MAIS3+ injury classification. Although implementation of this method is not without difficulties, it is a milestone in the work addressing the problem of serious road traffic injuries.

There is a need to harmonise not just the definitions of injury and its severity but also the procedures for accident data collection and verification among the EU countries.

One way of improving police accident data quality is to verify these data using hospital/medical records. Guidelines for the integration of police and medical data based on best practices (e.g. the STRADA system in Sweden) would be very useful.

Overall, there is a lack of appropriate exposure measures for the calculation of safety indicators for VRUs. When analysing and identifying black spots at intersections and road crossings, pedestrian and bicycle volumes should be used in addition to motorised traffic volumes.

In an effort to obtain improved results, an integrated approach to VRU safety assessment has been proposed. The study methods discussed in the WP2 report (Olszewski et al., 2016) differ in terms of their approach, data collection methods and the specific aims. The various methods often complement each other in terms of the results that can be achieved with a specific objective in mind. This complementarity is presented in the form of a synergy matrix (see Table 3.1). Seven specific aims are listed against six assessment methods. The matrix should help to decide which combination of methods to use in order to achieve a specific objective. The use of a mix of different methods can often produce more accurate, more comprehensive and faster assessments.

Table 3.1: Synergy matrix of VRU safety assessment methods.

Aims	Method					
	Epidemiological studies	In-depth investigations	Naturalistic driving	Behavioural studies	Traffic Conflict studies	Self-reported accidents
Assessing and monitoring the safety situation	M			C		M
Determining risk factors	C	M	C	M	C	C
Identifying critical locations (black spots), RNSA	C		M			
Determining accident contributory factors		M		C	M	C
Assessing data quality/underreporting*[1]	C	C				C
Estimating accident costs	M	C				C
Before-and-after evaluation	M			C	C	

Source of Information:

M	Main
C	Complementary

[1] The preferred tool for assessing underreporting of serious injury accidents is linkage of police and hospital accident records (see also Table 6.1).

4. Work Package 3 – Observational studies

4.1. Goals of WP3

The general objective of this WP was to collect and analyse sufficient amounts of safety-relevant events on the sites with VRU accidents. More specifically, the objectives were formulated as:

- Work out an optimal strategy for observational field studies of VRU-safety in terms of duration, equipment, set-up, etc.;
- Calibrate and validate surrogates measures of safety and behavioural indicators against accident records;
- Calibrate and validate the technical tools developed in WP4;
- Demonstrate the usefulness of the method and identify the most prone VRU safety problems.

4.2. WP3 Process

The work of the WP was organised in five tasks as described below.

Pilot set-ups

The main bulk of the field data was collected using video recording and consequent video processing. The purpose of this task was to support the technical team (WP4) in decisions on the choice of the camera equipment and camera installation strategies by providing a meaningful context of what traffic data to be collected and for what purposes. For example, a decision was made on which traffic environments (signalized intersections) and which conflicting manoeuvres (right/left turning motor vehicles vs. cyclists/pedestrians) will be studied, which limited the options for the camera perspectives that could be usable.

During the initial test of the camera kits designed by the project team, it was decided that for practical reasons it was more efficient to hire external companies for doing the short-term filming (less travels involved, reliability of the equipment, possibilities for remote check and control, etc.).

Long-period observations

The purpose of this task was to collect the same type of data over on interactions of VRUs and motor traffic for a sufficiently long period of time to cover variations in weather and lighting conditions (primarily for testing the robustness of the video processing tools) as well as various traffic conditions. The expectation was also to record real accidents that could be used to validate the surrogate measures of safety.

Short-period observations

In this task, video recordings were made in 3-week periods at several similar sites in partner countries, totally 25 sites. The list of sites/countries is provided in Table 4.1:

Table 4.1: List of studied sites per country.

Country	Sites count
Sweden	3
Denmark	4
Netherlands	4
Spain	3
Poland	4
Norway	3
Belgium	4
Total	**25**

Data processing and validation of safety indicators

The initial plan for the video data processing is presented in Figure 4.1.

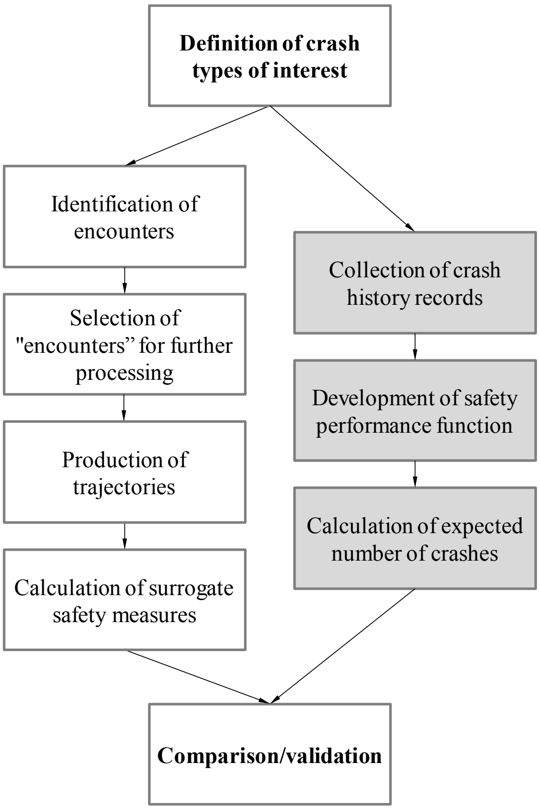
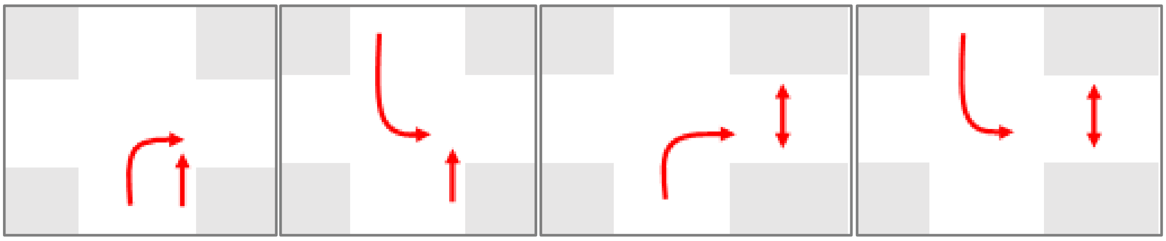


Figure 4.1: The general planned workflow for the validation of surrogate measures of safety.

The crash/conflicts types of interest were identified in WP2 based on the frequency of the given crash types in CARE database (which, in practice, was limited to the data from Germany and Denmark as the only two countries using manoeuvre coding system when reporting accidents). This was also complemented by a manually coded accident records from two major cities in Sweden (*Björnberg*, *2016*). The studied manoeuvre types are presented in Figure 4.2.



a) b) c) d)

Figure 4.2. Most frequent crash types selected for further analysis: a, b) motor vehicle right/left - cyclist straight; c, d) motor vehicle right/left – pedestrian crossing the intersection approach.

The crash/conflicts types of interest were identified in WP2 based on the frequency of the given crash types in CARE database (which, in practice, was limited to the data from Germany and Denmark as the only two countries using manoeuvre coding system when reporting accidents). This was also complemented by a manually coded accident records from two major cities in Sweden (*Björnberg*, *2016*). The studied manoeuvre types are presented in (*Madsen et al.*, *2016*), allows detection of simultaneous presence of two road users by observing ‘activity’ within a certain area (a detector) of the video image. By strategically choosing the location of the detectors it is possible to filter out only road users performing a certain manoeuvre of interest (e.g. only left-turning cars).

Another relevant tasks was also to examine the distribution shape of the surrogate measures of safety covering normal traffic performance as well as the extreme unsafe situations. To collect data on the ‘normal’ encounters, the trajectories were produced for all the encounters of the relevant types during one day at each study site. Since the ‘normal’ encounters are much more frequent while the unsafe situations are rare, the initial plan was to combine data from one-day (all encounters) and three-weeks (only severe ones) to get a reliable estimate of the surrogate measures distributions.

The data was used for testing a number of theoretical hypotheses about surrogate measures of safety that are described in more details in section 0.

Naturalistic cycling/walking study

In order to collect naturalistic data, including near-misses and accidents of cyclists and pedestrians, a prototype of a mobile app was developed that monitored the telephone sensors and activated a reported routine once a potential safety-relevant event was detected. The bicycle and pedestrian collisions and falls were simulated by a stuntman and using a crash-dummy and these data was used for tuning the detection algorithms.

Another version of the app was created that allowed the users to report safety-relevant events in a similar manner, but as a respond to scheduled reminders and not to activation of the event-detection algorithm. This app was used for a self-reporting study in four countries.

4.3. WP3 main results and conclusions

Pilot set-ups

A technical kit for long-term video recording was successfully designed and tested. It turned out that time synchronisation of multiple cameras was an issue hard to resolve and even the external companies specialising on video recording failed to deliver perfectly synchronised videos.

Another practical challenge was obtaining the necessary permissions and clearances for using the video recording equipment. First, the rules (and their application practices) are quite different among the countries. In several countries it was not possible to film with high resolution, in Sweden it was not allowed to film with regular RGB cameras but only thermal ones and in Germany filming was not allowed at all.

On the positive side, using thermal video turned out to be very practical since the produced material does not allow identification of people or vehicle number plates (i.e. the data is not personal and less strict rules apply) while it is still easy to interpret the images in terms of which road users are moving where. The thermal cameras also perform much better in low-light conditions and do not record the moving shadows of the road users in sunny weather.

Long-period observations

The recording kits designed in InDeV were successfully used for long-term recordings in Poland, Belgium and Spain. During this time, several construction improvements were made addressing the problems discovered during the field operation (e.g. overheating during summer).

Short-period observations

The short-period observations were performed using the equipment designed by InDeV and employing external companies.

Data processing and validation of safety indicators

Several studies have been performed using the trajectory data collected in the project. The most important outcomes are summarised below.

- **Cross-country accident models**

Accident models were developed with different levels of data aggregation (per manoeuvre type, per VRU category, etc.). Despite the generally low number of accidents, the models performed quite well from a statistical perspective (model fit to the data, CURE-plots, etc.). However, the actual meaning of the modelling results turned out to be very contradictive, e.g. Sweden appears to have the highest accident risk while countries like Poland and Spain are the safest. Most probably, the reason is the different levels of accident under-reporting among the countries, which is indirectly supported by previous studies on under-reporting.

From the perspective of validation of surrogate measures of safety, since the level of accident under-reporting differs between countries, it appears that the traditional validation (comparing conflict with accident counts) is not really a feasible option in cross-country datasets like the one in InDeV and other, indirect methods of validation should be pursued.

- **Merging one-day and three-weeks datasets**

The original idea was that the encounters for one day can provide a good base for estimating the distribution of a tested surrogate measure of safety for ‘normal’ traffic conditions. The extreme end of the distribution, covering the most severe events, requires longer observation time, thus the manually selected conflicts during the three weeks period can be used (adjusted for the time duration).

It turned out it is not possible to find a simple merge the two datasets (one-day and three-weeks) by setting a simple threshold defining which dataset to use for which part of the distribution. For all indicators and threshold values tested, a clear jump before/after the threshold could be observed. This indicate that the human observers who selected the severe events were quite restrictive in their judgements.

It appears that the human perception of what is a severe situation is governed by more factors than a simple indicator like Time-to-Collision (TTC) or Post-Encroachment Time (PET) can capture. This is supported by examining the situations with very low PET or TTC values, many of which do not appear dangerous at all despite the low space/time margins between road users. Obviously, other parameters like speed, approach angle, suddenness, etc. play important role and affect the human observer's judgements. This problem might be even more important in situations with VRUs as it is very common that cyclists and pedestrians get involved in 'tight interactions' with motor vehicles once the speeds are low and the drivers are aware of their presence. Clearly, further elaboration on what indicators are best at reflecting the perceived severity of a traffic situation is necessary.

- **Event-based exposure definitions**

Conflict counts (or even accident frequency) do not say much if not related to the exposure – the amount of 'activity' generating the accidents. Traditionally, the exposure in traffic safety studies is measured by traffic flow(s), though many limitations of this measure have been pointed out (e.g. absence of a collision risk in single passages unless a counter-part is also present, non-linearity of the relation with accidents, etc.).

A more logical way to define exposure is to base it on events that have a probability to develop into an accident, for example a simultaneous presence of two conflicting road users in vicinity of the conflict point (encounters). Based on InDeV data, several operational definitions of the encounters have been tested. The differences in definitions were mainly based on how the groups of arriving road users are treated. It turned out that the relation between traffic flow(s) and the frequency of encounters is very similar to the non-linear relation between the flow and accidents often found in the accident modelling research, often referred to as the 'safety in numbers'-phenomenon. Moreover, the relation between the encounters and accidents is almost linear.

The important conclusion is that the major part of the non-linearity in the relation between flow and accidents (safety-in-numbers) might be a result of improper choice of the exposure measure. This result strongly supports the recommendation of using event-based exposure units instead of traffic flow in safety studies.

- **Relation between surrogate measures of safety and exposure**

The old-fashioned validation studies of surrogate measures of safety often searched for correlations between the number of observed traffic conflicts (defined based on certain indicators and thresholds) and the number of reported or estimated accidents at the same site. However, there is a serious flaw in such approach since both conflicts and accidents are products of exposure. It is natural to expect more accidents and conflicts at locations where more people are driving, cycling and walking. Moreover, if the exposure is defined as a number of relevant encounters, the traffic conflicts become a sub-set of exposure units with higher severity. Thus, the question of finding a 'proper' threshold for conflict indicators can be specified to 'at which threshold the conflicts stop being a mere measure of exposure and start revealing differences in accident risk level (probability of accident given an encounter)?'

A test of most commonly used indicators (TTC, PET) with different threshold levels was performed on the InDeV dataset covering encounters from different countries known to be very different in safety levels. A set of Poisson regression models relating the number of conflicts (for each threshold value) to a product of encounters and a country-specific coefficient was developed. Since the number of encounters is controlled for, the remaining country- coefficients represent the risk-level of the countries.

The result shows that until very low threshold values (1-1.5 seconds for both TTC and PET) the model fails to meaningfully distinguish the risk levels among the countries, indicating that conflict definitions with higher thresholds are directly proportional to the encounters. In practical terms, it means that doing conflict studies using such definitions brings no additional value compared to direct counting of the encounters.

While the conflicts based on low thresholds could distinguish between the countries, the safety ranking obtained was not always easy to interpret. It is expected that the improvement of the indicator calculation procedures (e.g. using better motion prediction techniques) should remedy the situation.

Naturalistic cycling/walking study

The detection of the cyclist/pedestrian falls was possible using sensor data from a mobile telephone. However, it was not possible to make a universal app that would work on any telephone model due to low quality of the sensors and as a result a large variety in readings even among the phones of the same model. A problem of battery draining due to constant sensor data analyzing was also noted, which potentially could discourage people from using the app.

Using an app as a self-reporting tool showed promising results as it is possible to collect information on a much larger number of accidents compared to what is available in the traditional data sources (e.g. police accident records).

4.4. Exploitation (Impacts and Benefits)

Several important conclusions could be drawn from the video data analysis:

- Validation of surrogate measures of safety against accident data might not be a feasible way, particularly due to low numbers of accidents registered and often unknown under-reporting rates. Alternative indirect validation methods should be investigated.
- Encounters perform much better as a measure of exposure and might explain the safety-in-numbers effect to a very high degree.
- Traffic conflict definitions with very inclusive thresholds are not recommended. The reason is that basically the conflicts then become a subset of the encounters and a measure of exposure failing to bring any added value of measuring the accident risk (probability of an accident given an encounter). As a rule of a thumb, ‘conflicts’ defined as TTC or PET above 2 seconds should not be used at all.
- The simple indicators like TTC or PET, particularly when applied on situations with VRUs, often fail to reflect all the important aspects that make a situation ‘serious’. While the use of human judgements of severity as a ground truth can be questioned, it is obvious that other parameters, like the speeds, kinematic energy, element of surprise and suddenness of the situation are important to define the ‘true’ severity dimension.
- Further improvements in how indicators are calculated are necessary. Particularly in case of TTC and other indicators that require prediction of the future motion, more advanced methods that consider the natural adaptation of the path and speed to the performed manoeuvre are necessary.

The unique video and trajectory dataset collected in InDeV is a real ‘treasure’ that can benefit the researchers working with surrogate measures of safety for many years as new ideas, theories and calculation algorithms can be tested. Public sharing of this dataset (as long as the data protection rules permit) is highly recommended.

The knowledge gained from the app study forces to rethink the way we are dealing with traffic safety analyses. Self-reported accidents can be a valuable supplement to police records. Given that the absolute majority of severe injuries of cyclists and pedestrians in urban conditions are coming from single accidents, further efforts should be invested in developing tools for automated fall detection and data reporting.

5. Work Package 4 – Tools for automated data collection and analysis

5.1. Goals of WP4

This WP was focused on the technical aspects of InDeV. The goals of the WP were twofold. Firstly, to ensure that different types of data – primarily video – was captured and secondly to develop software that eases the processing of the captured data. The two goals had both a practical development component as well as a more research-oriented component. Concretely the objectives of this WP were:

- provide technical support for system setup
- develop an automatic watchdog system that identifies time intervals in a video sequence where possible safety critical events occur
- develop a fully automatic tracking system that extracts and analyses trajectories of all objects in a scene in safety terms
- develop a system that collects data from naturalistic VRU data

5.2. WP4 Process

The work carried out in this WP was organized in four different tasks with purposes and overall approaches as listed below:

<u>System setup</u>
Since massive amounts of video data were to be recorded at different sites for both short term and long term filming, a thorough investigation regarding hardware selection was conducted. This included an identification and analysis of the involved parameters, development of different prototype systems and collaboration with commercial companies devoted to such tasks. Moreover, more explorative work considered the use of alternative sensors and alternative placement of sensors.
Different approaches to handle the synchronization of the video streams, as well as calibration of the different cameras to the same world coordinate system, have been researched and the best solution developed further and implemented. At one point we approached two commercial companies that took over the recording task – with their own equipment – since the work at this stage was more ‘everyday work’ than research.

<u>Watchdog system</u>
This dedicated a software system should automatically analyse the sensor data from an intersection (or some other location) and provide metadata. While this is still too hard for current systems (see next task) this task instead aimed at an intermediate solution where a system automatically analyses the sensor data and removes huge chunks of sensor data where no events/interactions are occurring and hence the manual annotation task becomes easier.

<u>Automated tracking system</u>
The tracking of all entities at all times in an intersection is a very hard task to automate. InDeV has focused on better understanding the main challenge for 24/7 systems, namely how the weather conditions affect the algorithms. Moreover, recent advances in data-driven methods (Deep Learning) have been adapted and modified to specific issues related to the InDeV context.

Mobile application for naturalistic walking/cycling data collection
Besides data from intersections, InDeV was also focused on better understanding accidents in general traffic scenarios. To this end we built on the notion that accident data from individuals could enhance our understanding of the safety situation and developed technical tools for collecting such data via smartphones.

5.3. WP4 main results

System setup
A concrete recording system setup has been developed including both RGB and thermal cameras. Normally only RGB cameras are used and we have therefore seen a general interest in the research community regarding this solution. With additional sensors comes the need for spatio-temporal calibration. A portable pole has been designed with the focus on making it robust and stabile during operation. At the same time the pole has a small footprint and is easy to transport and setup. The solution was constructed and used in different scenarios – especially when no infrastructure allows for easy mounting of cameras. More exploratory work included assessment of the viewing point, i.e. does it matter at what height the cameras are mounted? Here a drone-based approach was compared with traditional setups. Also, the combination of camera data and Lidar data was investigated. Both works are ongoing and will be continued after InDeV.

Main output:

- RGB-Thermal camera system for data recording designed, implemented and deployed in real-life
- New portable pole designed, implemented and deployed in real-life
- New research directions initiated
    - o Analysis of viewpoint
    - o Combining cameras and a Lidar

Watchdog system
In this sub-task, we aimed at developing a watchdog system that can remove huge chunks of video data where no events/interactions are occurring. This reduced the amount of video data that has to be manually annotated. The algorithmic principle was based on a user defining different regions in the image and associating these with different detectors (right motion, stand still, etc.). Lastly the user sets up rules based on logic (for example: if detector 1 is activated in region 2 AND detector 3 is NOT activated in region 1, then …) that activated the watchdog, i.e. informed the user that he/she should look at this particular video snippet. By keeping a human in the loop, we developed a robust system less sensitive to the normal trade-off between false positive and false negatives. The system could automatically remove up to 90% of the video data without significantly increasing the error rates.
Besides developing the technology, we have also focused on interfacing aspects, that is, how to ensure that the software is assessable to non-experts in cooperation with municipalities and researchers not familiar with the system. The watchdog system has already shown its success by being used in real-life scenarios for traffic counts, traffic conflict studies, and behavioral studies by a number of different organizations (private as well as public) in 10+ different countries.

Main output:

- New semi-automatic system designed, implemented and deployed in real-life

Automated tracking system
The two main challenges hindering automatic tracking is occlusion and changing illumination. Regarding the former challenge an investigation into drone-based recordings has been conducted

– see subchapter ‘System setup’. For the second challenge a major study has been conducted on how the weather-related phenomena (rain, snow, rapidly changing illumination, fog, and haze) affect the different blocks (detection, tracking and recognition) in a traditional tracking framework. Our objective was to build an understanding of the effects of these weather conditions and their different combinations, and if possible, to mitigate these effects. The main focus has been on rain and snow since these are understudied areas, but highly relevant – especially in the Nordic countries. A huge dataset from many different sites and conditions has been collected, annotated and processed with regards to the effects on segmentation and tracking algorithms providing many new insights. In parallel, a study has been conducted where the hypothesis is that rain and snow detection algorithms can be trained on synthetic data. If this hypothesis can be validated, a huge potential in terms of efficient training of such algorithms can be released. Preliminary conclusions suggest, however, that this is not the case.
Finally, a two-fold collaborative research study has been done between InDeV partners, wherein we investigated how to apply deep learning techniques with the purpose of detecting road users in intersections and how to describe the current state-of-the-art of tracking frameworks to practitioners.

Main output:
- A meta level analysis of the current state of the art in tracking systems has been reported
- An in-depth understanding of the effects of different weather phenomena on tracking frameworks was obtained
- A huge data set was made available
- Several Deep learning algorithms for different detection and classification tasks in traffic scenarios were implemented and tested

<u>Mobile application for naturalistic walking/cycling data collection</u>
Naturalistic App Study: The purpose of this subtask is to develop an app that can automatically detect accidents. Two different approaches have been followed, a machine learning approach and a simpler rule-based approach. In order to obtain training data for these approaches, both simulated falls using a dummy as well real falls using a stuntman have been collected. The data from these tests have been analyzed. It turned out that different types of mobile phones deliver rather different sensor readings of the same event. It has therefore been concluded that an app for accident detection on a particular phone is possible, but a general app that works on a wide variety of phones was not developed in InDeV.
Questionnaire Website and App: A system has been developed which allows researchers to send out questionnaires by email to volunteers. Their answers are saved in a database for future analysis. An app has been developed that can receive the same questionnaires. The results are reported in WP3.

Main output:
- Two self-reporting apps were developed and deployed in real-life. The solutions were limited to individual smart phones and did not generalize well
- Both an app as well as a website interface have been designed, implemented and deployed in real-life

5.4. Exploitation (Impacts and Benefits)

<u>System setup</u>
The fusion of complementary sensors is an intriguing concept, but often hard to do in practise due to spatio-temporal misalignments. The work in InDeV has documented this

– especially for RGB and thermal cameras - and hence provided inspiration for future research, but also a heads-up warning for future projects that might not realize the challenges involved.
The portable pole with the video camera can clearly be used in other works where the goal is cheap and easy data collection in location lacking obvious mounting opportunities.
More research regarding data recording from drones and combination of RGB and Lidar sensors are clearly required. The technical partners in InDeV will follow these research avenues and it is expected that the approaches will play a bigger role in future research projects.

<u>Watchdog system</u>
The notion of a semi-automatic system is viable in many situations and InDeV has clearly shown the potential of such an approach. The system is a huge success in the sense that it has already been used in a number of projects in addition to InDeV. Further research on the technical building blocks is of course possible, but perhaps the most interesting research direction (and further development) is how to ensure that practitioners can easily use such software in their daily work and how systematically collection of experiences can provide feedback to improving the system.

<u>Automated tracking system</u>
Since this is the hardest technical problem to solve much more research is needed before a robust system is available. The primary focus should be on detecting the different weather- and illumination conditions and adapting the different algorithms accordingly. To this end much more annotated training data is required.

<u>Mobile application for naturalistic walking/cycling data collection</u>
The developed data collection technologies can clearly be applied by others, both practitioners and researchers.

6. Work Package 5 – Socio-economic cost analysis

6.1. Goals of WP5

Socio-economic cost calculation of accidents plays a crucial role in road safety politics. Prior to the initiation of a large road infrastructure project a cost-benefit-analysis ought to be conducted. A major part on the benefit side is the potential gain of additional road safety by a reduction of accidents and victims. In order to express this safety in monetary terms relevant cost data is needed. Therefore, countries carry out a calculation of accident costs periodically. However, a detailed and up-to-date cross-country review did not exist until the beginning of the InDeV project.

Vulnerable road users (VRUs) constitute a major proportion of the victims of road accidents and they are more at risk than other road user groups. Essentially, VRUs face three major problems: One is that they are vulnerable due to not being adequately protected and being directly exposed to the forces of an accident. The other problem is that the vulnerable road user group, more frequently than other groups, comprises of people who are in general physically weak, such as children and senior citizens. The last of the three problems is a high underreporting rate. The first two factors lead to a high risk of being injured or killed due to an accident. The consequences of all three issues have a high impact on both individual and socio-economic costs.

Facing these aspects, work package 5 was meant to reach three goals. Firstly, to deliver an overview of methodologies concerning the accident cost calculation from all European countries. The overview would contain information about the cost components[2] considered, monetisation methods applied, the data sources used and how VRUs are considered in the estimation of accident costs. Secondly, to conduct a survey obtaining detailed information on the extent of underreporting in European countries. Thirdly, to develop additional concepts which consider VRU explicitly within the calculation of accident costs, addressing relevant factors such as injury severity, age distribution or underreporting.

6.2. WP5 Process

In order to analyse the current status of accident cost calculations, project partners from InDeV have undertaken a survey in cooperation with the EU research project SafetyCube by distributing a questionnaire to accident cost experts in the EU member countries. The majority of contacted experts gave a sufficient amount of information of their accident cost calculations. Data from those countries, where no contact to experts could be established, were collected by use of document and literature review. The analysis of the data included comparisons of countries regarding the definition of injury severities, the completeness of the components, the chosen method for monetisation, the data sources, the level of unit costs, the concepts for correction of underreporting and other aspects.

[2] Accident costs consist of several components such as pain, medical treatment, loss of production at work and at home, damaged property and administration costs (police, insurances, etc.).

The analysis of accident underreporting was intended to deliver answers to questions, such as: What is the level of underreporting of injury accidents in the European countries? How does the structure of underreporting look like in the particular countries? How big is the impact on accident costs? To give answers to such questions a population survey was conducted in Belgium, Denmark, Germany, Poland, Spain and Sweden in 2016-2017. Once every third month throughout a year respondents received a link to an online questionnaire asking them about any road accidents they might have experienced in the period. Especially data from Sweden, Denmark and Belgium provided extensive information about underreporting of accidents.

In order to point out the influence of VRU accidents on total accident costs various concepts have been developed.

The calculation of ‘average unit costs’ is based on, inter alia, costs per component. The data containing this information comes from the expert survey about the accident cost methodologies. Furthermore, accidents from the CARE database have been retrieved. The calculation uses only cost components which are related to casualties (injured and killed) – not related to accidents (e.g. property damages). The purpose of this specific selection is to contrast costs per casualty of the VRU group with the costs per casualty of the non-VRU group. It has been assumed that one casualty with a particular injury severity causes the same amount of costs regardless of the road user type. The decisive point of this calculation is building an average per-casualty-value over all three injury severities. The calculation per VRU and non-VRU has been performed for most of the European countries and relates to the three specific transport areas: urban, rural and motorways.

A further option is the introduction of an additional severity degree next to ‘slight injuries’ and ‘serious injuries’. Based on the example of Sweden, it is shown in detail how this concept can be applied. Furthermore, the long-term health impacts are included in this calculation as an additional challenge in road safety policy. In order to calculate and compare the specific cost rates (mode of transport, injury severities etc.), information from various sources has been combined which mainly are a survey to patients and registers at the National Board of Health and Welfare from Sweden.

In accident cost analysis the victims’ unit cost applies usually to every victim regardless of its age. However, particular age groups have different impacts on the costs. Therefore, the monetary consequences considering the age of victims (not only transport mode and injury severity) have been analysed. The QALY approach has been used. Against this background, data of a Catalan database has been analysed and the costs for VRU and non-VRU have been compared. Also, considering the victims’ age, the general estimation of accident costs has been calculated.

Considering the variables of statistics, such as: Abbreviated Injury Scale (AIS)[3], victims’ age and even affected body parts, a more thorough data analysis has been performed. The work on the approach ‘adjusted unit costs’ utilised comprehensive data from the Oslo Emergency Ward. A detailed comparison between costs for the VRU groups of bicyclists and pedestrians has been carried out.

Last but not least, the concept ‘unit costs per accident with VRU’ has been introduced which delivers more accurate and stable results when handling small accident subsets. This methodology enables an improved assessment of the costs levelling out

[3] A scale of six degrees on which injuries can be categorised depending on the particular severity.

considerable variation of accident costs over time that occurs with low numbers when using unit costs (per injury and per accident). Not only casualty related but also accident related costs are included in this calculation, such as property damages.

6.3. WP5 main results and conclusions

The results of the expert survey show that divergent ways have been chosen concerning inclusion of components, methods for monetisation and usage of data sources. They also reveal that the problem of underreporting has been solved by very few countries.

The explicit consideration of VRUs is only used in two European countries applying different approaches – Poland and Sweden. Further calculations of unit costs per road user type are not performed by any of the countries.

The definitions of a ‘fatality’ are practically identical in all EU member states. However, a comparison of the definitions of the categories ‘slight’ and ‘serious injuries’ has revealed big differences. These have an additional impact on the extent of total accident costs.

Incomplete accident numbers lead to an incorrect estimation of accident costs. Depending on the injury severity recommended strategies for dealing with underreporting have been drafted (see Table 6.1).

A solution to correct the number (and accident costs) of seriously injured casualties would be to compare the police accident data with data on accident victims from hospitals. A seriously injured person is hospitalised by definition in most of the countries. If a seriously injured patient is registered at the hospital but not at the police as a seriously injured casualty, the official data of accidents needs to be supplemented by this case.

The number of slightly injured casualties shall ideally be completed by estimations found in national surveys.

It is recommended to correct the number of crashes with property damage only by information from insurance companies. Though not all damages after a road accident are reported for reimbursement crash data from insurance companies are nevertheless helpful for making the accident cost estimation more complete. However, only relying on insurance data will not be enough. Therefore, the same recommendation applies as for the case of slightly injured persons: to undertake a survey to complete the picture. Finally, as a subordinate solution it is advisable to make an estimation via rule of thumb by applying the recommended factors of the EU project HEATCO (Bickel et al., 2006).

Table 6.1: Recommended strategies for dealing with underreporting

Accident severity	Recommended strategy
Seriously injured	- Comparison of police accident data with hospital data (see Sweden and Netherlands)
Slightly injured	- Estimations out of national surveys (see Switzerland)
Property damage only	- Data from insurances; - National surveys; - Rule of thumb (e.g. recommended factors in EU project HEATCO)

The harmonisation of accident cost calculations of all EU member states must be continued:

- Equivalent databases ought to be established.
- Relevant components and items must be included uniformly.
- Appropriate methods must be applied uniformly.
- Underreporting must be considered and corrected.
- The unit costs for VRU and other road users have to be indicated explicitly.
- Non-methodological differences should be considered and named in detail during comparisons between countries in order to find further influencing factors.

The self-reporting survey reveals that more than 80% of the self-reported pedestrian accidents are in fact single accidents, which illustrates the need for further investigation of the pedestrian single accidents as the underreporting in this category might be high.[4] The study also provides information about the consequences of pedestrian falls: 16% result in medical treatment, 14% in one or more days of absence from work and 37% in property damage.

Self-reported road accidents have proved difficult to compare with official accident statistics, both due to different national guidelines on what constitutes a reportable accident and to the legal limitations on personal information which may be asked in the questionnaire; this eliminates the possibility of combining information with official accident records. However, based on the collected self-reports it has been concluded that in 8% of the accidents the respondents were in contact with the police.

National differences exist between the levels of reporting to the police, both generally speaking and in specific situations. Still, some common trends were found across the different countries:

- When accidents happen in rural areas, the respondent is more likely to contact the police than if the accidents happen in urban areas.

[4] Using the term ‚underreporting‘ all non-reported accidents are implied here, including those which are not officially defined in many countries such as ‘single accidents’.

- When more than one party is involved in an accident, the police is more likely to be contacted than if the accident is a single accident.
- When an accident results in the respondent being admitted to hospital, the police is more likely to be informed than if the accident does not result in hospital admission.

Between 40 and 60% of all self-reported accidents did not result in the respondent making contact with the police, their insurance company or medical personnel. Hence, self-reports provide information on a substantial number of accidents that are not recorded anywhere in official statistics.

A general overview of casualty related costs per VRU in European countries has been compiled using ‘average unit costs’ to compare between casualty costs (excl. value of property damage) of VRU and non-VRU. The calculated values are averages over all injury severity levels. They reveal that the costs per VRU casualty are consistently higher than costs per non-VRU casualty in almost every country.

The example from Sweden indicates that the use of an additional severity degree refines the result of road safety outcome in a country especially considering VRUs. Based on empirical cost estimates of all casualties the cost related to an average single VRU accident is 30% of the average cost of a non-VRU accident. In order to support road safety it is important to carry out this type of empirical studies and retrieve cost estimates also for this type of accident.

Based on calculations using the QALY approach from the Catalan database it has been found that unit costs per casualty are generally overestimated when the age distribution is not considered. Furthermore, evaluations have shown that costs of VRU casualties are higher than those of non-VRU casualties when the age distribution and injury severity levels are taken into account.

Considering the AIS scale, victims’ age and even affected body parts, a more thorough data analysis has been performed using detailed statistics from Oslo Emergency Ward. This study has delivered important findings: There are significant cost differences between the specific VRU groups ‘pedestrians’ and ‘cyclists’. Furthermore, the calculations have illustrated some possible ways forward, applying it to different and broader data sets, whether for research or practical application of injury valuation.

Using German accident data, a solution to calculate average costs per accident with VRU participation has been proposed that can be used for smaller subsets of accidents, e.g. when calculating the benefits of a concrete infrastructure measure. Not only casualty related but also accident related costs (such as property damages) have been included in this calculation.

6.4. Exploitation (Impacts and Benefits)

The expert survey on accident cost methodologies has provided clarification about the differences between the European countries. Given the diverging results regarding components, monetisation methods and databases, it is recommended to harmonise the different practices to identical methodologies providing results that are easily comparable between the European countries.

The self-reporting survey has shown the extent of underreporting and its (missing) impact on accident costs. Accordingly, total accident costs are underestimated and costs per casualty are overestimated. Especially VRUs are affected by this issue. An integration of a correction system in the accident cost calculation is beneficial for road safety, in particular for safety of VRUs.

Several newly developed concepts (in particular ‘average unit costs’, ‘injury costs considering age of victims’ and ‘unit costs per accident with VRU’) have shown that VRU casualties cause higher socio-economic costs than car drivers (if property damages are excluded). Thus, using adapted accident costs of VRUs explicitly in cost-benefit-analyses leads eventually to higher road safety for VRUs.

Most of the introduced concepts are suitable for an application on national and supranational level, such as average unit costs, additional severity degree or the QALY approach, whereas ‘costs per accident with VRU’ is recommended to be used on local level. Further scientific research on the concept ‘adjusted unit costs’ needs to be conducted. It has the potential to show exact cost differences between the different modes of transport.

7. Work Package 6 – VRU safety analysis toolbox

7.1. Goals of WP6

The objective of this WP was to develop an integrated approach to analyse the road safety situation of vulnerable road users. This integrated approach was created in order to achieve better knowledge on VRUs' accident causation and the course of events in these accidents, thereby providing a good base for selecting effective and efficient road safety countermeasures.

7.2. WP6 Process

In order to achieve this objective, a toolbox has been created consisting of three parts:

- A hands-on manual for a surrogate safety measures software tool;
- A hands-on manual for a naturalistic cycling/walking tool;
- A handbook focusing on road safety techniques to analyse the road safety situation of vulnerable road users.

The two software tools were developed in work package 4 of the InDeV-project. Within this work package we have focussed on creating practically oriented manuals for both tools. Furthermore, we have developed a handbook focusing on the practical application of different road safety techniques typically used to gain insights in the causational factors of VRU-accidents. The handbook also describes possibilities for combining road safety data collected by different techniques. Each partner involved within the InDeV-project contributed to this handbook by writing a chapter on a road safety technique in which they had the most expert experience.

As the developed toolbox is aimed at a wide group of practitioners in the field of road safety (local government officials, road safety analysts and consultants, road designers, etc.), the main challenge was to ensure that the handbook was tailored to their specific needs. Therefore, the first draft of the handbook was discussed with this target group. Each partner involved in the InDeV-project consulted at least three possible end users of the handbook in their respective country. During this consultation process, the end users were asked to browse through the handbook and answer some questions regarding the contents (missing elements, relevance of discussed techniques, etc.) and practicalities (suitable title, printed or digital handbook version, added value of the handbook, writing style, etc.). These results appeared to be very valuable to further improve the handbook contents and writing style.

7.3. WP6 main results and conclusions

The manuals and handbook can be accessed through the following website: www.bast.de/indev-project.

7.3.1. Hands-on manual for surrogate safety measures software

A first result is the creation of the hands-on manual for using the surrogate safety measures observation tool. Apart from technical reports about system design, performance etc., this manual almost entirely focuses on the use of the tool by practitioners and analysts. It provides a step-by-step guide through the different steps of data collection, cleaning, analysis and hypothesis testing.

Additionally, this manual is used in combination with an interactive wiki where the use of the tool will be described with short videos. The idea is that this wiki will serve as a living project, which is periodically updated as the tool further evolves. This wiki can be accessed through this link: https://bitbucket.org/TrafficAndRoads/tanalyst/wiki/Manual.

7.3.2. Hands-on manual for naturalistic cycling/walking study tool

This manual is similar to the manual of the surrogate safety measures tool with the main difference that it presents tools to overcome the problem of underreporting of vulnerable road user accident data in police reports or hospital data. This manual focuses on using naturalistic data collected automatically from the road users. It presents the three smartphone apps developed in work package 4 with the aim of getting more insight and knowledge in accidents among vulnerable road users based on naturalistic data: VRUMonitor Data Logger, VRUMonitor and SafeVRU. The apps and source codes are also available via https://bitbucket.org/aauvap/vrumonitorapp/.

Both manuals strongly contribute to making the tools accessible to a wide range of end users active in the field of road safety.

7.3.3.VRU safety diagnosis handbook

The handbook is entitled: “*How to analyse accident causation? A handbook with focus on vulnerable road users“.* This handbook can be considered as the most important outcome of this work package and is designed to offer road safety professionals easy access to information regarding road safety diagnostic methods as well as how they can be applied in order to identify a certain road safety problem and gain insights in the causation factors of VRU accidents. The focus within the handbook lies on applying the techniques to assess VRU safety; however, the discussed techniques can also be applied to diagnose the safety of other than vulnerable road users.

Since the ambition of the handbook is to become the main reference document for VRU safety diagnosis by practitioners, usability by a large group of end users is the key aspect. The handbook therefore focuses on applying state-of-the-art but accessible techniques that make optimal use of existing data and/or data that is relatively easy and cheap to collect. The book provides guidelines on how to choose the right method to study a particular problem, step-by-step instructions on how to design and perform the study and present and interpret the results. For each technique, additional information is included in text boxes, such as best practices, use cases or practical examples. It also clearly indicates the strengths and limitations of the different techniques and offers suggestions to overcome the limitations of the respective technique by supplementing them with other techniques and data sources.

The handbook consists of the following nine chapters:

- Chapter 1: Introduction. It explains the purpose of this handbook and provides background information about the safety problems of VRUs and the different available road safety diagnostic methods.
- Chapter 2: Accident data and analysis techniques. This chapter addresses several techniques for accident data collection and analysis such as road safety indicators (identifying general trends in VRU safety), accident prediction models,

black spot management, network safety management, collision diagram analysis and in-depth analysis on the level of individual accidents.

- Chapter 3: Self-reporting of accidents and near-accidents. This chapter focuses on using of self-reported accidents and near-accidents to address single VRU accidents and to mitigate issues of underreported or missing accident data.
- Chapter 4: Surrogate safety measures and traffic conflict observations. This chapter focuses on the collection of data on serious conflicts, using on-site observations to identify VRU safety issues at specific locations. The content of the chapter is tailored to the surrogate safety measures tool that is developed in WP4.
- Chapter 5: Behavioural observation studies. This chapter focuses on the data collection of road user interactions and behaviours, using on-site observations to identify VRU safety issues at specific locations.
- Chapter 6: Naturalistic cycling and walking studies. This chapter discusses naturalistic cycling and walking studies as a technique to continuously collect data on VRU behaviour based on the experiences of the developed naturalistic tool in WP4.
- Chapter 7: Site observations of traffic infrastructure. This chapter addresses Road Safety Audits (RSA) and Road Safety Inspections (RSI) as techniques to assess whether the road infrastructure meets the safety demands of VRUs.
- Chapter 8: Estimating the socio-economic costs (SEC) of injuries to vulnerable road users. This chapter is largely based on the improved SEC methodology developed in WP5 and can help the road safety professional to assess the socio-economic costs that are related to specific VRU safety problems, and to prioritize measures that need to be taken.
- Chapter 9: Conclusions. The chapter provides an integrated overview of the road safety techniques discussed and describes recommendations combining several techniques to overcome their separate limitations.

Each chapter also contains an extended list of recommended literature that can be used to deepen the knowledge in the subject and thereby it can be a useful starting point even for researchers new to the field. To summarize, the handbook allows practitioners to collect and analyse data that is specifically related to the safety issues at hand. As such, this handbook supplements other existing documents, allowing practitioners to apply such guidelines and recommendations in a better informed way.

7.4. Exploitation (Impacts and Benefits)

Road safety practitioners and analysts often lack comprehensible tools and guidelines to collect and integrate different types of data, making their diagnosis of VRU safety issues incomplete and prone to bias. Therefore, this integrated approach will allow a wide target group of road safety practitioners and analysts to fill their own ‘micro-level’ knowledge gaps (e.g. detecting problematic locations, regarding VRU in their municipality, insight in the accident causes at the level of a specific intersection or road segment) and support them with better methods to identify and analyse VRU safety issues.

Furthermore, the novel contribution of this work package lies in the development of an integrated safety diagnostic toolbox to investigate accident causation based on a combination of several data sources and research methods. This allows overcoming the limitations of each individual approach. This is especially important for VRU accidents as it is widely acknowledged that they suffer from severe underreporting issues. By combining accident data with self-reported or naturalistic data, the application of this integrated approach provides road safety practitioners and decision makers with enhanced insights in the causal factors that play a role in VRU accidents. In turn, these enhanced insights assist in evaluating the effectiveness of implemented road safety measures and lead to the implementation of more efficient strategies to improve VRU safety.

8. Conclusions

InDeV partners have worked out a bundle of exploitable results giving important recommendations for all EU countries:

WP2 (Review of study methods) & WP5 (Socio-economic cost analysis)

It has been found out that definitions of injury accidents cover most of the relevant accidents, but not the single accidents. Additionally, definitions of injuries are not consistent between EU countries.

It is recommended to include single accidents in the relevant definitions and thereby include them in official accident statistics and costs for all EU countries. ‘Serious’ and ‘slight’ injuries need to be defined comprehensively and consistently. Defining injuries based on ‘MAIS3+’ injury level, recently introduced by the EU, is a step in the right direction.

Underreporting is an ongoing issue for the work on road safety, especially the safety of VRUs. Depending on the accident severity different strategies have been introduced to find correction values with the purpose of completing the accident statistics and – based on them – accident costs. It is advisable to find a common strategy for the EU countries (see Table 6.1).

Generally speaking, there is a need to harmonise the procedures for accident data collection and verification among the EU countries. One way of improving police accident data quality (not only correcting the underreporting) is to verify these data using hospital/medical records. Guidelines for the integration of police and medical data based on best practices (e.g. the STRADA system in Sweden) would be very beneficial for higher data quality.

It has been ascertained that the current identification and analysis of black spots at intersections considers only motorised traffic. VRUs ought to be included in such analyses. Furthermore, an integrated approach has been developed in order to improve the safety assessment of VRUs. Depending on the respective goals (7 in total) a combination of complementary approaches (out of six) is applicable. It is recommended to use the according matrix (see Table 3.1).

Concerning accident cost calculations in all EU countries clarity has been gained. The methodologies are generally very heterogeneous. A harmonising process ought to be initiated.

Casualty costs of VRUs are higher than of non-VRUs. It is recommended to apply the introduced approaches of InDeV and to consider this aspect in Cost-Benefit-Analyses and indicate it generally in economic cost calculations. The definition and introduction of a third injury category for the sake of more detailed and precise statistics and costs shall be considered.

WP3 (Observational studies)

A video recording system has been designed and tested. Different types of cameras have been used for the recordings and it appears that thermal cameras have many practical advantages compared to traditional RGB cameras.

Validation of surrogate measures of safety using the ‘traditional’ comparison with accident records has serious practical hinders as well as theoretical flaws. Low accident numbers, unknown under-reporting rates, as well as the fact that conflicts and accidents are both products of exposure and thus always correlate to some degree are a few arguments to mention. Alternative validation methods should be pursued.

Using encounters as a measure of exposure is highly recommended for safety studies.

Using conflict definitions with ‘inclusive’ threshold values are not recommended. As a rule-of-thumb, conflicts defined as TTC or PET above 2 seconds should not be used.

Further improvements on the calculation procedures for the surrogate indicators are necessary, particularly when it comes to the motion prediction.

Self-reporting of accidents and particularly single falls by cyclists and pedestrians is a rich source of data otherwise not seen in the traditional data sources like police reports. The problem of automated detection of single falls should be further elaborated on.

WP4 (Tools for automated data collection and analysis)

The portable pole can clearly be used in other works where the goal is cheap and easy data collection in location lacking obvious mounting opportunities.

Research on data recording from drones and combination of RGB and Lidar sensors has been initiated. It is recommended to continue promoting this research field.

The watchdog system has been fully developed within InDeV and is already being used in many countries of the world. It has become important to ensure an easy use of this application and to collect experiences for further development of the system.

A huge and valuable data set was made available in order to analyse specific traffic scenarios and to detect different weather conditions using the automated traffic system. In order to apply Deep Learning algorithms, even more annotated training data is required. It is recommended to share the gained data set publicly and give the researchers the opportunity to test new ideas, theories and algorithms

The Apps for data collection (self reporting and naturalistic walking & cycling) have been developed and can now be promoted and applied by both practitioners and researchers.

WP6 (VRU safety analysis toolbox)

While dealing with VRU-Safety analysis issues the newly created handbook gives support. It is recommended to promote the handbook among practitioners.

Next to the handbook, the toolbox consisting of two manuals helps to observe surrogate safety measures and to gain more knowledge about underreporting.

Both the handbook and the toolbox need to be promoted and spread among practitioners in order to reach a higher safety not only for VRUs but for all road users.

To conclude, the impact of this integrated approach on VRU safety therefore takes place in a bottom-up form, as the sum of many small improvements in VRU safety resulting from better informed decisions and interventions at all policy levels and in different European cities and countries. Therefore, this integrated approach also contributes to the ambition of the European Commission to half the number of serious injuries and fatalities by 2030 and achieving the long-term goal of Vision Zero to get to zero fatalities by 2050.

References

Bickel P., Friedrich, R., Burgess, A., Fagiani, P., Hunt, A., De Jong, G. et al. (2006): HEATCO Deliverable 5, *Proposal for Harmonised Guidelines*, University of Stuttgart, Stuttgart.

Björnberg, A. (2016): *Do we learn more from situation based accident coding? Case study of Malmö and Gothenburg*. Degree project. Lund University, Sweden, Transport and Roads, Department of Technology and Society, Faculty of Engineering, LTH. Thesis 295.

Johnsson, C., A. Laureshyn, H. Norén (2018): *T-Analyst - semi-automated tool for traffic conflict anlysis*. InDeV, Horizon 2020 project. Deliverable 6.1.

Madsen, T., C. Bahnsen, M. Jensen, H. Lahrmann, T. Moeslund (2016): *Watchdog System*. InDeV, Horizon 2020 project. Deliverable 4.1.

Olszewski, P., B. Osińska, P. Szagała, P. Włodarek, S. Niesen, T. Kidholm Osmann Madsen, W. van Haperen, C. Johnsson, A. Laureshyn, A. Varhelyi et al. (2016): *Review of current study methods for VRU safety. Part 1 – Main report.* InDeV, Horizon 2020 project. Deliverable 2.1, Lund University Publications.