UDRIVE

European Naturalistic Driving Study

Preliminary analysis plan

Deliverable 11.2

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Executive Summary

Deliverable 11.2 is part of SP1 of UDRIVE. It is integrated in WP1.1 which is dedicated to develop the project's research questions and the preliminary analysis plan. It describes the planned analysis to answer the research questions from UDRIVE.

With this deliverable the first phase of the project, the selection of research questions (SP1) is completed. The work will be continued in SP4 (Analysis) to prepare and perform the actual analysis. To ensure a seamless handover between the subprojects, this deliverable was created in a joint effort between SP1 and SP4 partners. Regular phone conferences and an in-person meeting of partners helped to develop a common understanding about the analysis of planned SP4 tasks and incorporation of research questions from SP1.

Together with SP4 a list of prioritized research questions per task was developed and used as a basis for this deliverable. An initial set of research questions was developed in the beginning of the project about a year ago in Deliverable 11.1 (Pereira, Utesch, Baumann, Bärgman, Petzoldt, Lai, Carsten, Engström, van Nes, Ligterink, Kurol and Winkelbauer, 2013). At that time the focus was on identifying the functional requirements for the data acquisition system (DAS). This set covered a broad range of research questions to make sure that all necessary measures could be identified. The resulting list contained more research questions than could reasonably be addressed within the project, and it was clear that not all requested variables would be available in the end. Now, after more than a year of preparation, most of the required sensors and variables are identified. Thus it was possible to further develop the initial set of research questions and adapt them to the available measures. The selection of research questions was done in close cooperation with SP2 (Data Management). While SP1 provided the needed measures, SP2 translated the measures list to necessary sensors and made an evaluation about what could reasonably collected within the limits of UDRIVE. This exchange led to the configuration of the Data Acquisition System (DAS). The development of research questions was then tailored to the available sensors of the DAS by taking the available variables into account.

A selection was made to identify those research questions that are best suited to address the goals of UDRIVE with the available data sources and within the budget available in UDRIVE. Here the selection of research questions was done in close cooperation with SP2 (Data Management) as well. SP2 provided the list with available variables and SP1 dismissed research questions for which no data would be available. In some cases new research questions were introduced, in other cases the "old" were refined if the development of the project since the last deliverable required an adaptation. The updated list contains 32 research questions from five research areas grouped into 10 tasks:

1. **Research questions for crash causation and risk**

   Research questions for risk calculation (T4.2.2)

   RQN1.1 What are the risks of different driver behaviours?

   RQN1.2 Is there a difference in the driving related risks under several conditions?

   RQN1.3: What is the risk of disregarding safety precautions?

   Research questions for "holistic" crash causation (T4.2.3)

   RQN1.4: How can contributing-factor chain schemas be applied to naturalistic road user data?

   RQN1.5: What are the factors that contribute to the occurrence of safety critical events (SCEs) for lead-vehicle and intersection conflict scenarios for cars and trucks?

   RQN1.6: Are there driver/vehicle/environment factors that frequently occur together in a safety critical event?

2. **Research questions for Everyday Driving**

   Research questions for descriptive analysis of everyday driving (T4.2.4)

RQN2.1: To what extent are driver factors associated with risky behaviour?

RQN2.2: To what extent are environmental factors associated with risky behaviour?

RQN2.3: To what extent are driver assistance systems used?

RQN2.4: To what extent are seatbelts used?

RQN2.5: How does traffic culture influence driving behaviour?

3. Research questions for Distraction and Inattention

Research questions for Attentional Selection Mechanisms (T4.3.2)

RQN3.1: Which perceptual cues reliably capture attention and trigger avoidance manoeuvres in SCEs?

RQN3.2: Why do the reactive attention capture mechanisms, identified in RQN3.1, sometimes fail and lead to crashes?

RQN3.3: What factors determine how drivers proactively allocate their attention in anticipation of how a driving situation will unfold and why do these proactive selection mechanisms sometimes fail?

Research questions for Involvement in secondary tasks (T4.3.3)

RQN3.4: What are the key factors influencing the willingness of drivers to deliberately engage in secondary tasks such as phone conversation, dialling or texting?

RQN3.5: How do drivers adapt ongoing secondary task activities to the evolving driving situation?

RQN3.6: To what extent can an individual's willingness to engage in secondary tasks, and its effects on risk and driving performance, be predicted from psychological tests?

4. Research questions for Vulnerable Road users

Research questions for Analysis of drivers interacting with cyclists and pedestrians (T4.4.2)

RQN4.1: What characterizes Safety Critical events (SCEs) involving motorised traffic and cyclists at intersections?

RQN4.2: How do car drivers behave at intersections in urban areas where they might encounter cyclists? Which 'external' factors (e.g., intersection design) modify those behaviours?

RQN4.3: What characterizes Safety Critical events (SCEs) involving motorised traffic and pedestrians at intersections?

RQN4.4: How do car drivers behave at intersections in urban areas where they encounter pedestrians (normal conditions, i.e. not SCEs)? Which 'external' factors (e.g., intersection design) modify those behaviours?

RQN4.5: Are the VRU (Vulnerable Road User) related SCEs identified by the Mobile Eye (ME) system (ME warnings) correct, relevant, reliable and properly timed?

Research questions for Analysis of PTW (Powered Two Wheeler) behaviour and interactions with other vehicles (T4.4.3)

RQN4.6: How do drivers and rider differ in speed choice?

RQN4.7: What characterises looking behaviour of PTW riders in left turn manoeuvres?

RQN4.8: Which circumstances related to rider, infrastructure and trip have an impact on SCE occurrence?

RQN4.9: What is the role of timely perception of a rider by drivers?

5. **Research questions for Eco Driving**

Research questions for Driving Styles (T4.5.2)

Research questions for effects of driving styles on eco driving (T4.5.3)

RQN5.1: Does the vehicle power-to-mass ratio affect the driving style?

RQN5.2: How much do drivers deviate from the speed limit in free flow situations, and why?

RQN5.3: Are eco-driving and safe driving correlated through increased anticipation of road infrastructure and traffic situations?

Research questions for potential effects of eco-driving (T4.5.4)

RQN5.4: When do drivers brake, and is it necessary to brake in each instance?

RQN5.5: Is eco-driving an observable characteristic of certain drivers?

RQN5.6: Do drivers shift gear to avoid high engine speeds and high fuel consumption?

Within UDRIVE data is collected on cars, trucks and scooters. The selected research questions cover the five UDRIVE research areas listed above. Table 1 shows for each research topic what data they will focus on. Trucks and cars are addressed by all areas, PTWs are addressed by the topics Vulnerable Road Users and Crash Causation and Risk. This has several reasons. The everyday driving of PTW, like speed behaviour, is covered in the topic Vulnerable Road Users. Distraction and inattention is hard to study for PTW riders, as they are less likely to be involved in secondary tasks and it is hardly possibly to observe head and eye-movements because of the helmets. Eco-driving is less of an issue for scooter riders than for car and truck drivers, and also here the adequate measures are not available to study this. As for many of the research questions stated in this document, CAN data is required to study this topic. Since there is no CAN data available from PTWs in UDRIVE these questions cannot be addressed for PTWs. PTW rider behaviour in naturalistic driving is still a young research area which has to be explored before testing hypothesis. As a consequence there are not as many specific research questions as for trucks and cars. In UDRIVE most PTW related research questions are grouped into the area vulnerable road users since PTW riders are part of this group (Table 1).

Table 1: Overview of investigated vehicle types by research area.

	Crash Causation and Risk	Everyday Driving	Vulnerable Road Users	Distraction and Inatention	Eco Driving
Trucks	x	x	x	x	x
Cars	x	x	x	x	x
PTW	x		x		

The document is intended to help UDRIVE analysts plan their analysis, and exchange their ideas with the project partners to identify possible opportunities for harmonization. To allow easy access to each research question a hierarchical approach was used to organize the document. The analysis is described per research question and sorted by research area and analysis task respectively. Each research question is identified by a unique research question number that was first used in D11.1. All research questions that did not change since the first deliverable have the same number. Research questions that are new or have been modified in a major way, are identified with a new ID with increasing consecutive numbers from the previous research questions of the related research topic. The input for each task was written by the researcher leading that activity to ensure a high relevance to the actual analysis that will be performed in the end.

The final analysis and list of research questions will also depend on the quality and amount of data that will be collected later in the project. Further, since much of the intended research is novel and new methods are used, it is not clear exactly how much researcher resources will have to be spent in realising the present research. This means that the final number and scope of research questions addressed in the project may be slightly different from what is included in this deliverable. Thus this report only shows the current status of the set of UDRIVE research questions and corresponding analysis plan. The list and scope may still be subject to change, especially when the first data becomes available. This document will later be updated into the final analysis plan. That is, this document is submitted as Deliverable 11.2, but will serve as a working document until the final analysis plan is submitted.

References

Pereira, M., Utesch, F., Baumann, M., Bärgman, J., Petzholdt, T., Lai, F., . . . Winkelbauer, M. (2013). *Research questions, performance indicators and functional requirements: Deliverable 11.1 of the EU FP7 Project UDRIVE* (www.udrive.eu).

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1 Introduction

Deliverable 11.2 is part of SP1 of UDRIVE. It is integrated in WP1.1 which is dedicated to developing the project's research questions and the preliminary analysis plan. It describes the planned analysis to answer the research questions from UDRIVE.

The writing of both deliverables D11.1 and D11.2 is seen as an iterative process and thus the content of D11.2 will strongly depend on the input of D11.1. For example D11.1 already contains an extensive list of research questions, but the financial and timely scope of the project will probably not permit the addressing of all of these questions in the end. Thus D11.2 will utilize the list of research questions as input and make a selection of the most relevant questions for the project. D11.1 very roughly describes the potential ways to analyse the expected data to address the respective research questions as well. In this document D11.2 catches up and describes the analysis in more detail. It contains a list of the variables that are needed for the analysis, the initial definition of necessary safety critical events (SCEs) or baseline selections where necessary. It also includes a preliminary description of the steps necessary to perform the analysis on the incoming data, a description of the planned analysis procedures themselves and ways to cope with possible challenges like missing or erroneous data.

The aim of D11.2 is to provide a step-by-step description of the analysis to be performed on the eventually available data. By this it serves several purposes:

- As a checklist to see if all data necessary for the analysis is available
- As a reference tool to help check if an appropriate analysis of the research questions with the expected data is possible and that the research questions can be answered
- As a help for estimating the necessary effort for answering a research question
- As a manual for the analysis to be performed. This can speed up the process in the end when time is short.
- To identify aspects of the analysis that can be prepared in advance to speed up the analysis when the first data becomes available. For example start 1) preparing for the definition and evaluation of algorithms to identify SCE, 2) facilitating preparing instructions for the video coding to train coders involved in video annotation, and 3) to allow for harmonization of definitions and implantation of different variables (including annotation).

The first three chapters of this document describe the terms and data sources used in the project and the process of video annotation that will be performed. This is followed by a chapter for each research question topic with separate sections for each analysis task (T4.x.x). This allows the reader to easily jump to a topic of interest and find all necessary information in one place. The structure is defined by short questions asking the analysts to briefly describe a certain aspect of the analysis to be performed. To avoid duplications references to earlier sections were used when appropriate.

2 Definition of terms used

This is a description of the different terms used in the preliminary analysis plan and throughout the project. This is a preliminary analysis plan and definitions may be added, refined and extended later in the project. Some definitions are from the FESTA-Handbook (FOT-NET, 2011), while others are specific to this project.

Raw data

Raw data is data that has been recorded in instrumented vehicles (CAN data, video, GPS logs etc.). This data is by nature heterogeneous: different vehicles will produce different datasets. These datasets are thus not immediately useful for comparison.

Pre-processing

Pre-processing is the action of producing data useable for data analysis. It is performed at Local Data Centres (LDCs) using decryption, harmonisation, synchronisation, quality checks, and data enrichment (e.g. map-matching). Pre-processing harmonisation is included in this task - making sure conceptually similar measures are represented in the same way. Data synchronisation is also performed during pre-processing, and is defined as the aligning of different data sources; creating new continuous data from existing data sources recorded at a defined frequency, possibly using interpolation and re-sampling.

Processing

Processing is the action of calculating additional data (variables) for analysis. Processing is performed at the Central Data Centre (CDC). When data arrives at the CDC it is processed in what is called “initial processing”, which includes the calculation of all derived measures, events, SCEs, etc. for which there are algorithms available in the DriveWare algorithm “bank” at the time of upload. Re-processing will be scheduled to run several times during the data collection phase. At this point new algorithms (for derived measures, events, etc.) as well as algorithms that are changed since the last run, will be applied to all data. As part of the implementation of new variables, the analysts will have the possibility to validate and refine the implementations on subsets of all data.

DriveWare

DriveWare is the set of software tools created within the UDRIVE project to allow for both the handling of data and scripts, and for the visualization of video and other data. Note that in DriveWare the largest unit of algorithm application is a Record, while selection processes produce subsets of Records called Segments for which algorithms to calculate different Performance Indicators is applied as part of the DriveWare platform.

Annotation

Annotation is the process of manually creating data, primarily from watching and coding (annotating) video from the DAS; of either measures or events.

Variable

A variable is a name for grouping any entity that describes data. That is, events, (direct and derived) measures, performance indicators, SCEs, etc. A variable has a unique name in UDRIVE: e.g. mSVSpeed (mean speed of subject vehicle), eOvertaking (overtaking event), SDLP (standard deviation of lane position), and AverageSpeed. The term “variable” will be used relatively loosely in the project. DriveWare does not have limitations on the types of variables to be calculated across a Record or segments thereof.

DAS-data (Data Acquisition Data)

Raw data collected in the in-vehicle DAS.

Direct Measure (also called Measure)

A Direct Measure is in a strict definition (FOT-NET, 2011) strictly logged directly from a sensor, without processing before saving the data to the log file. However, linear transformations like the conversion from m/s to km/h or from CAN to SI units are not considered as changing a measure's state from "direct" to "derived". How the sensor arrives at its output is not relevant for the classification. In UDRIVE a Direct Measure is still a Direct Measure after synchronization, resampling and filtering in the pre-processing step at the LDC. Examples of direct measures in UDRIVE are acceleration, speed, forward video, distance to lead-vehicle, and answers to questionnaires. In UDRIVE video annotations are also considered Direct Measures (the sensor being the annotator). A direct measure is not necessarily time-series data, and can also be event variables.

Derived measure

A derived measure is not directly logged from a sensor, but is the result of either a direct or derived measure that has been filtered or processed in some way, or which is a combination of two or several direct or other derived measures (e.g. as part of the processing at the CDC in UDRIVE). One example of a derived measure is Time-To-Collision (TTC).

Event

Events are either single time-points or segments of time in time-series data for which one or several criteria are fulfilled. An event can be short (e.g. crash) or long, such as 1) start of evasive maneuver, 2) car following, 3) overtaking, 4) speeding. Both SCEs and Non-SCEs are included in this group construct. Events do not include randomly selected segments of time, even if there would be some top level matching. E.g. matched baseline epochs are not events.

Some events will be defined as a segment around an event-anchor. That is, an event that has one time point as the event-anchor and with a start and end time in relation to this event-anchor. For SCEs the SCE-trigger-time is the event-anchor. For position based events, a position is the anchor, i.e. the center of an intersection. How locations (as entities) will be handled is not yet defined in UDRIVE at the time of writing.

Event-anchor

An event-anchor is a time-point around which an event may be defined. Not all events have an event-anchor.

Segment

A segment is a section of time-series data with a start and a stop time, where the start and stop time has been defined in some way. Examples of segments are the individual pieces of continuous data within a trip when a criterion such as "speed greater than 70km/h" has been applied to the time-series speed measure in a trip (Dozza, Bärgman & Lee, 2013). An entire Record is also a segment (longest possible segment in the UDRIVE data) and a single sample can also be a segment, given that some criterion extracted a single sample. Events and SCEs are segments, as are baseline epochs.

Record

A segment used for additional analysis or presentation in the DriveWare analysis software. Typically a Record is all data collected from the time the DAS has started logging data after 'ignition on' in the vehicle, until the ignition is turned off and the DAS has stopped logging. In many previous studies this has been called a Trip, but since this term is ambiguous with respect to the Record definition above, Record will be used. However, it may be that Record and Trip is used interchangeably in UDRIVE documentation due to "old" definitions.

Risky behaviours

These are behaviors in everyday driving which are identified as risky in that they are considered as increasing the risk of a crash. This includes speed violations, short time headways, inappropriate overtaking, etc.

Potential conflicts

A term related to everyday driving, where an everyday driving situation did not become an SCE, but where risky behavior from the driver or other road users could have ended up in an SCE. These are the events in which risky behavior occurs.

Safety Critical Event (SCE)

SCEs are SCE-candidates that have been classified as safety relevant through manual video review according to a pre-defined coding schema. It may also happen that SCEs are found by chance (and not by SCE-candidates), but as long as they then fulfill the strict SCE relevance-classification criteria, they may also be called as SCEs.

SCE-candidate (Safety Critical Event candidates)

SCE-candidates are segments in data around a time (SCE-trigger-time) identified by applying SCE-triggers to time-series data. An SCE-candidate is a segment of time with a start and an end on either side of a SCE-trigger-time. The segment of time allocated before and after the SCE-trigger-time should be defined globally within a project. SCE-candidates are potential SCEs that require manual review of its relevance for traffic safety. That is, video annotators are to be following a strict classification schema to review video of SCE-candidates manually to decide if the SCE-candidates are relevant for traffic safety. They are to classify the SCE-candidates into a few different categories.

SCE-trigger

An SCE-trigger is the algorithm that is applied to time-series measures to identify SCE-candidates. That is, SCE-triggers describe some mechanism in kinematics of the ego-vehicle or interaction kinematics between the ego vehicle and other road-users or infrastructure components. Examples of the former are thresholds on longitudinal or lateral acceleration, possibly complemented with thresholds on derivatives of the same measures. Examples of the latter are 1) TTC below a certain threshold, and 2) a threshold on time-to-line crossing (run-off-road). When the SCE-triggers (algorithms) are applied to the data, a large set of points in time is identified. Many will be adjacent to each other or just close to each other. The large set of points in time (over all trips) that SCE-triggers produce needs to be aggregated into segments of time classified as SCE-candidates. That is, when SCE-triggers are adjacent or close together, they need to be treated as one "event" and there needs to be one SCE-trigger-time. Often the SCE-trigger-time is the first time-instance in a set of SCE-triggers.

SCE-trigger-time

An SCE-trigger-time specifies a certain point in time which will be used to identify relevant events for closer inspection. It is used as an anchor to specify the starting point of a time segment from which data will be extracted.

Non-Safety Critical Event (Non-SCE)

Non-SCEs include all events that are not classified as SCEs with respect to the strict classification schema applied to SCE-candidates. Non-SCEs can be single points in time (e.g. start of evasive maneuver), or a segment of time (e.g., overtaking or car-following). Non-SCEs do not include baseline epochs since there is a component of random selection in extracting baselines. A Non-SCE may have an event-anchor.

Baseline epoch

A baseline epoch is a segment of time with all data related to this segment (e.g. time-series, segment attributes and video) that is identified by a random selection process to represent general driving. Baseline epochs are often used for comparison with SCEs to investigate prevalence or risk (e.g. odds ratios). Baseline epochs may be selected either completely randomly or by matching to the comparison SCE, e.g. by driver, trip, speed, time-headway, etc. Appropriate baseline selection strategies are essential for correct interpretation of results.

Performance indicator

Performance indicators are quantitative or qualitative indicators, derived from one or several measures and expressed as a percentage, index, rate or other value, which is monitored at regular or irregular intervals.

A denominator is necessary for a performance indicator. A denominator makes a measure comparable (per time interval/per distance/in a certain location). For many performance indicators either time or distance can be used in the denominator (e.g. number of overtaking manoeuvres in a trip, percentage of exceeding the posted speed limit for a driver, average speed over an event, standard deviation of lane position for a segment of time, etc.). In DriveWare Performance Indicators are typically calculated for each Segment extracted from the chosen set of Records based on some selection criteria (algorithm).

Time-series data

The in-vehicle DASs provide continuous information for many measures (Direct Measures). Most of these are time-series data. After pre-processing, the time-series data used in UDRIVE are likely synchronized to 10Hz.

In addition to automatically collected time-series data, annotations will produce annotation-based time-series data. This will include variables such as glance direction, POV (Principal other vehicle) occlusion and driver activities. This information comes from manually annotated video, but is still time-series data.

For time-series data, data instances in the database will typically be of a 100 millisecond (0.1 s) driving duration associated with a single value for variables such speed, acceleration, glance direction etc. A Record therefore consists of thousands of such consecutive samples, while e.g. an SCE or a Non-SCE consists of hundreds of samples (synchronized data for all time-series data for a 100ms segment).

Segment attribute

For both quantitative and qualitative analysis the time-series data can be transformed into segment attributes. Segment attributes are one or a few values (numerical or categorical) that describe the entire segment in some way. Segment attributes can have several different data sources. First, aggregations of time-series data in some form such as application of mean or standard deviation (Dozza et al., 2013), describing an entire segment of data as one (or a few) value(s) attributed to the segment. Second, continuous variables can be summarised (or simplified) into categorical variables i.e. low speed, normal speed, high speed, excessive speed. For qualitative analysis, experts view plots of time-series data together with segment attributes, sequences and video, as part of the analysis process.

As an example, time-series data is difficult to use directly when the analysis aims to find factors contributing to SCEs, as well as for qualitative analysis. That is, comparison or correlation across SCEs is not possible using raw time-series data and when segment (or event) attributes are used. In the DriveWare setting with application of algorithms to segments of Records, a Segment attribute may sometimes have the same meaning as a performance indicator.

Examples of segment attributes are 1) descriptive information about driving conditions such the type of road, weather, traffic density and a driver's engagement in a secondary task (both measures based on DAS-data and from video annotation), and 2) mean speed and standard deviation of a baseline epoch, non-SCE or SCE.

Event attribute

When the segment attributes are related to an event they are sometimes referred to as event variables. It is an aspect of an SCE that does not change over the length of the SCE - e.g. over a 30 second segment around the SCE-trigger-time. The data can come from video annotation or from aggregation of time series data into a single event.

For event video annotation there are three types of event attributes.

- **Single value categorical event attributes**

A single value categorical event attribute is a categorical value "summarising" an entire event (e.g. SCE). That is, the SCE has one and only one value for this attribute. Examples are weather, road type and driver drowsiness state.

- **Multiple-value categorical event attribute**
  A multiple-value categorical event attribute is when an event has one or more categorical values describing an entire SCE (e.g. several secondary tasks being performed during the SCE).
- **Numerical event attributes**
  Numerical event attributes is one (or a few) quantitative value (numerical) associated to an event. The numerical event variable includes for example a single point in time (e.g. annotated driver reaction point or start of evasive manoeuvre). Additionally, more high level information can be extracted from time-series data using specific algorithms, i.e. start of evasive manoeuvre, start of overtaking, the presence of a secondary task activity, etc. For this data type, one (or a few) sample instance(s) (a "data line" in the database) represent X (e.g. 30) seconds of driving time, summarised as one of a few numerical values. This is the usual material used in the calculation of odds ratio (in risk calculations). Numerical event attributes are often the same as a performance indicator (algorithm) applied to Segments of Records.

Sequence

To study complex phenomena, there is sometimes a need to transform the data into a more complex and structured form. For example, driver actions or manoeuvres from several continuous and complex signals can be transformed into sequences. One can think about this transformation as a way to transform multiple complex time series for several parameters (typically from the CAN bus), into a sequence of identified events (not SCEs, just events). For example, a sequence of transformed data can be the following (Figure 1).

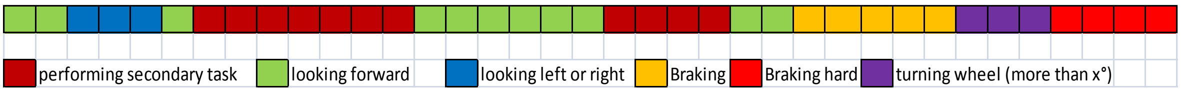

Figure 1: Schematic example for a simplified sequence of several events

This approach may be useful to analyse for example glance directions by categorizing the area focused by the driver. An example of such a description is provided at Figure 2. It is also possible to describe the epoch by defining non-SCE events from various continuous measures to automatically construct a sequence of "events" such as for example speeding followed by hard braking.

Naturally, if sequences are to be used for comparing baseline epochs and SCEs, the sequences must be extracted/created in the same way.

Functional data

Functional data analysis is a branch of statistics that analyses data by providing information about curves, surfaces or anything else varying over a continuum. Functional data are usually a parameterisation of time-series data into e.g. splines or other polynomial descriptions, but can also be other types of data fit (exponential etc.).

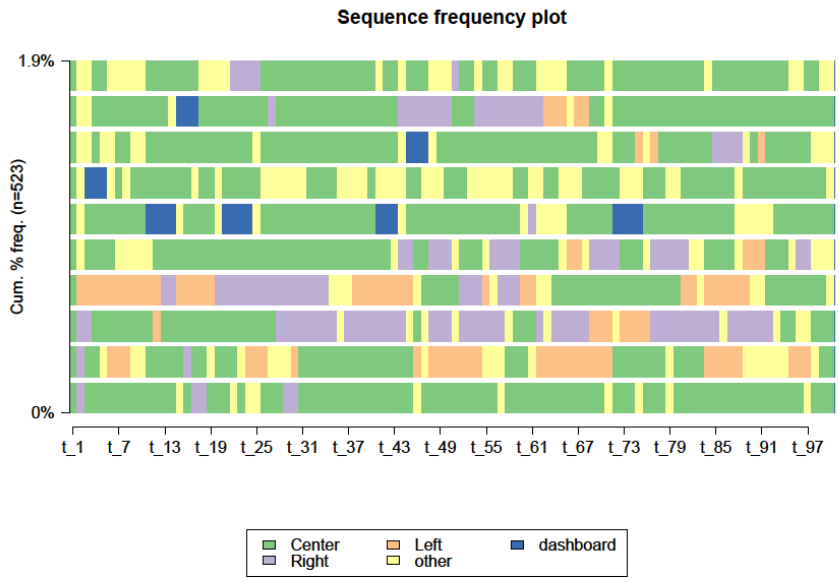

Figure 2: Example of glance fixation sequences for a 6 second period preceding a crossing

References

Dozza, M., Bärgman, J., & Lee, J. D. (2013). Chunking: A procedure to improve naturalistic data analysis. *Accident Analysis & Prevention, 58,* 309–317.

FOT-NET. (2011). *FESTA Handbook Version 4*. Retrieved from http://www.its.leeds.ac.uk/festa/

3 Data sources and variable types

To answer the questions in the five UDRIVE research topics of Risk Calculations, Everyday Driving, Distraction, Vulnerable Road Users (VRUs) and Eco Driving, it is necessary to describe the driving situation at a given point in time as detailed as possible. For example to describe the risk of driver distraction the driver activity and gaze direction is needed, possibly together with the distance to other road-users, own speed, steering activity and acceleration. The gaze direction and driver's actions can be utilised to infer distraction while the other measures can be used to indicate the driver and other road-user actions.

There are several ways to acquire the necessary information. Sensors like accelerometers, GPS and the vehicle's internal CAN (brake pedal, speed, engine RPM, etc.) provide continuous objective measures that are acquired automatically. On the other hand there are variables that cannot be acquired by sensor within the UDRIVE project. These include driver distraction, driver gaze direction, and visibility. To measure these variables a wide video coverage with subsequent video annotation by humans after the data acquisition is needed.

Additionally there is information in external databases that can be used to enrich the dataset after data acquisition. A prominent example is map matching which allows using the acquired GPS trails to derive road type, intersection presence, speed limits and more. UDRIVE utilizes a mix of installed sensors, a connection to the vehicle's CAN, broad video coverage with extensive annotation and map matching after the data acquisition to generate a wide set of variables that analysts can evaluate (Figure 3).

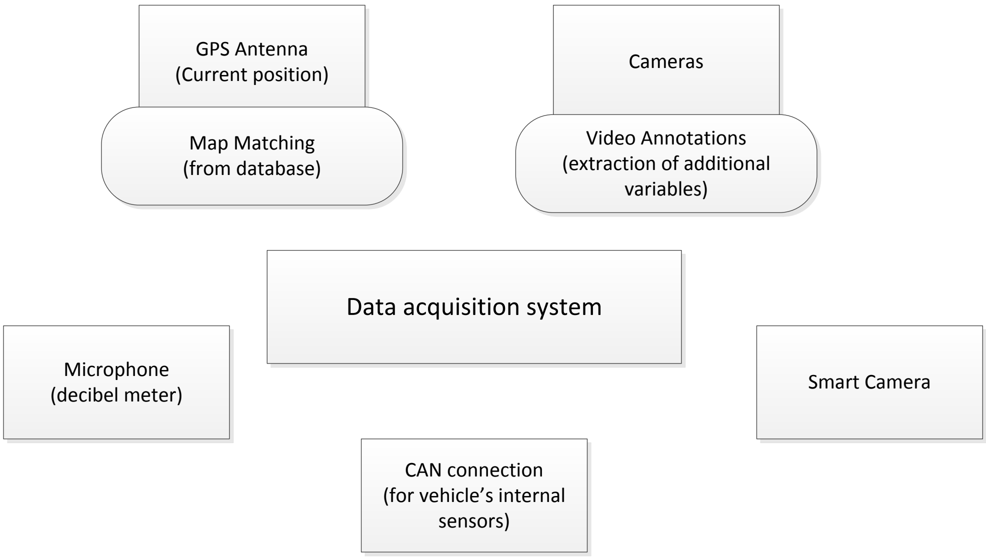

Figure 3: Overview of the Sensors and data sources that will be utilized in UDRIVE

These data sources generate different kinds of variable types. These variables can be grouped according to their functional relevance for the analysis. In UDRIVE there are twelve types of variables in total (Table 2). Together the data sources and variable types constitute the foundation of what will be possible in the analysis and are thus an important part of the preliminary analysis plan.

Table 2: Overview of variable types used in UDRIVE

Type	Description
Questionnaire	Item from questionnaires
Measure	A raw sensor output (e.g. speed), but it can be filtered and resampled etc.
Derived Measure	A variable calculated from one or several measures (not from DAS directly)
Non SCE event	An event at a point in time or over a period of time (e.g. braking, turning)

SCE trigger	Algorithms that are used to find SCEs
Video Annotation	Variable derived from video annotation
Map Matching	Variable that needs to be identified from map data or other geographical information
Location	A location type variable (e.g. a certain type of intersection that is crossed frequently by drivers). The description of how the locations are to be found is needed
Select Filter	A specific filter algorithm that will be used to extract certain parts of the data (e.g. a specific baseline or any other selection needed).
Video	Video from camera (only a collection of the video channels needed)

4 Video annotation process

One of the major challenges in UDRIVE data analysis is the sheer mass of video material that has to be processed. Dependent on vehicle type, 7-8 different video views are available. For example for cars there will be 8 different video views covering the driving situation from different perspectives (Figure 4). While UDRIVE utilizes a smart camera to measure number, type and distance to other road users in front of the equipped vehicle, some other variables cannot be measured automatically yet and need to be acquired via video annotation. Accordingly the cameras facing outside are intended to assess the presence, conspicuity and gaze direction of other road users, negotiation behaviour on intersections and visibility conditions. Additionally, the behaviour of the vehicle directly in front of the equipped vehicle (principle other vehicle = POV) can be assessed from the front cam. This includes the activity of the braking lights and looming of the POV rear (Figure 4-2). The inward facing cameras cover the activity inside the vehicle. The face camera allows the identification of gaze direction, reaction to specific events and drowsiness (Figure 4-4). The driver activity camera allows assessing the driver's activity like handling of objects or controls (Figure 4-6). The presence of passengers, their general activity and possible interaction with the driver can be identified from the cabin cam (Figure 4-7). Note that this image will have a reduced quality to protect the identity of the passengers. Finally the feet cam allows in combination with the pedal activity to identify if the driver is preparing for a braking reaction by hovering over the braking pedal (Figure 4-8).

Figure 4: Example shot of the eight camera views used in UDRIVE. From top left to bottom right the following camera views can be seen: An array of 3 front cameras (left, center, right) showing a nearly 180° view of the situation in front of the vehicle (1-3); A face camera showing the gaze direction and facial expression of the driver (4); A blind spot camera showing possible road users on the right side of the vehicle (5); A driver action camera, showing the activity of the driver's hands (6); A cabin camera, showing presence of other passengers (7); A feet camera, showing the driver's feet activity (8)

The described setup demonstrates the camera constellation for cars. At the time of the production of this deliverable, preliminary example camera views were only available for cars. Nonetheless the views for the trucks will be similar to those of the cars. A difference in the truck views will be an overlap of the cameras 1 and 3 to cover the blinds spot directly in front of the truck as well, while the front cam no. 2 will face ahead. Trucks differ from cars in that they have bigger blind spots and comparably less passenger activity. Thus instead of the cabin cam, trucks may have an additional blind spot camera for the left blind spot.

The constellation for the powered two wheelers (PTWs) will consist of 5 cameras covering the front view, the rider's head, the left and right side view and a rear view. This constellation resulted from the different situation of the PTW in traffic, and from technical reasons. For example PTW riders have to pay more attention to the following and side traffic since they are more easily overlooked.

The annotation of video material is organised according to the relevance of the respective annotations. Annotation that is vital for multiple partners and research questions is partially conducted at the central annotation site at TU Chemnitz, and partially at the respective UDRIVE WP4.X tasks. Annotation that is relevant for an individual partner and single research question is typically conducted "locally" (within the task) by the respective partner. Data will be hosted by SAFER, all annotators will access the data through a remote desktop environment (Hosted on VMWare).

One responsibility of central annotation is the identification of the driver for each single trip. For legal reasons, only the video material of consenting drivers can be stored and analysed. In addition, in case of multi user vehicles, it is necessary to identify the specific driver and label the data accordingly.

Another main aspect of central annotation is the classification of SCE-candidates into not-safety-relevant and safety-relevant categories (e.g. crashes and near-crashes). Based on SCE-triggers, annotators will review SCE-candidates in order to determine whether the candidate is indeed an SCE or not. In a second step, variables within a fixed time window (e.g. 30s) around the SCE (or a respective baseline epoch) will be annotated. This includes segment/event attributes as well as time-series annotation. The relevance classification and subsequent "base-annotation" is likely to be the most resource consuming activity of the central annotation process.

As the interaction with VRUs is an issue that can only be covered through video review, a portion of central annotation will be concerned with coding material that is required to address VRU research questions. This annotation is most likely to be location based, meaning that specific relevant locations (e.g. intersections) are identified through GPS data (coupled with map information), to then annotate the required variables. It is likely that we will use different annotation tiers. That is, passes through positions are first coded with context (e.g. presence of other road users), then a second level of more detailed annotation takes over. In the second level each individual video is watched with other available data to describe the event using a qualitative coding schema. The central annotation will likely focus on the second level. Ideally, the use of the MobilEye system will simplify this task.

All those annotation activities require extensive management and quality control. The coordination with analysis partners, the training of annotators and the regular meetings and quality checks are time consuming and should not be underestimated. Likewise, the initial setup of all annotation activity, including the iterations necessary to finalise the codebook, are expected to take a considerable amount of time.

As a basis for the annotation activity, a codebook is being developed that includes descriptions of all the required annotations. To achieve that, analysis partners that depend on the annotation are requested to contribute to the clear and unambiguous description of each individual variable and its categories (if applicable). They are expected to review the available material and, based on that, provide examples and guidelines for potentially ambiguous coding cases. Equally important is the description of the events that justify annotation. In some cases analysts will provide sets of events to annotate, that the central annotation management will have to aggregate; while in other cases the analysts are to describe the situations that shall be reviewed and coded in detail, and also how they should be extracted from the dataset. The contribution of all analysis partners in the development of the codebook is central to the success of the annotation.

In parallel, a set of procedures is under development that is required for a flawless operation of the central annotation site. This includes aspects of annotator recruitment, training, quality control, etc. These procedures can borrow heavily from past projects, given the elaborate descriptions that are available e.g. from SHRP2. While the procedures are developed mainly against the background of central annotation, local annotators (i.e. analysis partners conducting their own annotation) are strongly encouraged to follow the procedures as closely as possible.

5 Safety Critical Events

This Chapter describes SCEs and their use in the UDRIVE project. Since crashes are rare events in normal everyday driving, analysis of naturalistic road-user data often requires the use of crash surrogates (or proxies). In previous naturalistic driving studies (NDSs) examples of such surrogates are near-crashes and incidents (ref 100-car, SHRP2 etc.). In UDRIVE we use the term SCEs as a common term for all crash surrogates that have an assumed relationship with crashes. The relationship between crashes and SCEs has been shown multiple times in previous research i.e. conflict theory (Hydén, 1987; Svensson & Hydén, 2006) and recent NDS analysis (Guo & Fang, 2013; Guo, Klauer, McGill & Dingus, 2010).

In UDRIVE SCEs are typically SCE-candidates that have been classified as safety relevant through manual video review according to a pre-defined coding schema. It may also happen that SCEs are found by chance (and not by SCE-candidates), but as long as they then fulfil the strict SCE relevance-classification criteria, they may also be called SCEs.

The SCE-candidates are segments in data around a time (SCE-trigger-time) identified by applying SCE-triggers to time-series data. An SCE-candidate is a segment of time with a start and an end on either side of a SCE-trigger-time. How much time should be allotted before and after the SCE-trigger-time should be defined globally within the project. SCE-candidates are potential SCEs that require manual review of their relevance to traffic safety. For more information, read the Definition section (Section 2).

A SCE-trigger is the algorithm that is applied to time-series measures to identify SCE-candidates. That is, SCE-triggers describe some mechanism in kinematics of the ego-vehicle or interaction kinematics between the ego vehicle and other road-users or infrastructure components. Examples of the former are thresholds on longitudinal or lateral acceleration, possibly complemented with thresholds on derivatives of the same measures. For more information, see the Definition section (Section 2).

5.1 The process of development of SCEs in UDRIVE

SCEs will be an important part of the analysis in UDRIVE and thus the identification of SCE-candidates and the subsequent classification into not-safety-relevant and safety relevant (with sub-categories) is critical for the project. The SCE-trigger implementation has its own task in UDRIVE that will start in the summer of 2014 and will finish before the end of 2014. At the time of writing, a review of current literature as well as the forming of an international working group on SCE-triggers and definitions is on-going. Collaboration with FOT-net (http://www.fot-net.eu) activities on the subject are natural, as well as intensive collaboration with the SHRP2 project (Hallmark et al., 2013). In the same task, but together with the annotation codebook development task, the SCE-candidate classification schema will be developed. The schema will be defined by incorporating the experience from partners in the project, but also from studying literature and consulting a network of experts outside the project. The following two sections describe some aspects of SCE-triggers (to get to SCE-candidates) and SCE-candidate classification.

5.2 SCE-trigger examples

A SCE can be indicated by several means. The following list gives an overview of some potential candidates. While this list is not exhaustive, it demonstrates the kind of indicators that will be used. The exact threshold values will be different between cars and trucks and will be defined through experience from other studies and determined from pilot data in UDRIVE. All listed events are only candidates which have to be verified by video annotation for severity. Previous studies have shown that combining triggers as short head way and longitudinal jerk will significantly reduce the number of false positive candidates.

- **Hard braking by the driver**

The braking reaction can be identified from the brake pedal activity or through high longitudinal acceleration as a proxy metric. It is assumed that an unusually hard braking reaction could indicate a SCE. Most NDS studies use this in one way or another.

- **A hard steering reaction by the driver**
  The steering activity can be directly measured at the steering wheel or via lateral acceleration or yaw rate as a proxy. An unusually hard steering action of the driver may indicate a swerving manoeuvre which may have been initiated to avoid a crash. Most NDS studies use this in one way or another.
- **A high longitudinal acceleration of the vehicle**
  An extreme longitudinal acceleration is likely indicative of a crash. Most NDS studies use this in one way or another.
- **High vehicle longitudinal jerk**
  Vehicle jerk is the derivative of acceleration. When jerk is high it means that the rate of acceleration increases fast. Studies have shown some correlation with SCEs (Bagdadi & Várhelyi, 2013).
- **High brake pedal depression jerk**
  Brake pedal jerk is the derivative of the brake pedal acceleration. Ongoing studies show some promising results in the identification of SCEs with brake pedal jerk.
- **Small time-headway**
  The threshold of the time-headway to the lead vehicle (LC) or any other situation can be used as an SCE-trigger. A small time headway may be indicative of an SCE. To distinguish between intended and unintended small time-headways, the time spend at a constant time-headway can be utilized. If the time-headway is constant over a longer time (e.g. 5 s) this could indicate that the short time-headway was intended. To exclude parking and manoeuvring, events below a threshold could be excluded.
- **Time-to-collision**
  Time-to-collision is indicative of SCEs by proximity. That is, TTC is a measure that, when small, indicates small safety margins. Drivers have a range of safety margins they are comfortable with (comfort zones, e.g. Summala (2007)). If the TTC is less than what drivers normally accept, it may be indicative of an SCE. Also note that using TTC with a threshold is an SCE-trigger that does not require driver actions. That is, most kinematic SCE-triggers (accelerations, yaw rate, brake pedal movements etc.) require that the driver actually saw the hazard. Time-to-collision does not have this limitation.
- **Unintended Lane change**
  A slow lane change that is not accompanied by the use of the turn indicator signal and/or leaving the driving lanes is dangerous and could indicate inattention of the driver. Usually this does not happen if a driver is paying attention to the road. Previous studies have shown that this is difficult to use in SCE-triggers since it typically produces very many false positive SCE-candidates.
- **“Ooops!”-Reaction**
  Driver’s facial expression and even body language show signs of surprise or alarm. This is not an SCE-trigger per se, but if events are found by chance, it may be a filter criterion. Also, it will likely be used as part of the SCE-candidate validation.

5.3 SCE-candidate classification

There are several ways to approach the classification of SCE-candidates into not-safety-relevant and safety-relevant. Also, when an SCE-candidate has been classified as safety-relevant there may be several different categories of criticality. A rigorous development of a coding schema for the SCE-candidate classification is crucial for a successful project. The following are some considerations to be included, but to date no decisions have been made in the relevance classification strategy.

- **Subjective classification of criticality**
  By viewing the scene in front (and when possible around) the instrumented vehicle and studying the interaction between the instrumented vehicle and surrounding traffic and infrastructure, a subjective evaluation of the criticality of the situation is made by the annotator. Most previous studies of naturalistic driving data have employed this type of classification strategy.
  A drawback with this approach is the subjectivity of the interpretation of the unfolding of the SCE-candidate event as seen on video. Care should be taken to ensure that driver responses (e.g. Ooops! Reaction) is not used as an indicator of criticality (unless explicitly stated that it should be, see next bullet).

  Examples of categories from the SHRP2 data dictionary (coding schema) – (SHRP2, 2010):

  Crash: Any contact that the subject vehicle (SV) has with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated.

  Near crash: Any circumstance that requires a rapid, evasive manoeuvre by the SV, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash. A rapid, evasive manoeuvre is defined as a steering, braking, accelerating or any combination of control inputs that approaches the limits of the vehicle capabilities.

  Crash-relevant: Any circumstance that requires a crash avoidance response on the part of the SV, any other vehicle, pedestrian, cyclist, or animal that is less severe than a rapid evasive manoeuvre (as defined above), but greater in severity than a “normal manoeuvre” to avoid a crash. A crash avoidance response can include braking, steering, accelerating, or any combination of control inputs.

- **Only including SCE-candidates where there is a driver reaction**
  One way to define SCEs as being relevant is to only classify events at relevant SCEs where it is obvious that the driver felt some sort of discomfort. Discomfort may be identified by studying facial expressions and abrupt changes in body posture. Previous work includes attempts to extract posture change by means of image processing (Dozza & Gonzalez, 2013). This approach has some obvious drawbacks in that it will not include events where the driver did not see the hazard. Another limitation is that between-driver variability may be large and thus some drivers, just because of them easier showing signs of distress, are overrepresented in the SCEs selected. It is however believed that manual annotation of the Oops! Reaction is more consistent between annotators than the critically coding approach.

References

Bagdadi, O., & Várhelyi, A. (2013). Development of a method for detecting jerks in safety critical events. *Accident Analysis & Prevention, 50,* 83–91. doi:10.1016/j.aap.2012.03.032

Dozza, M., & González, N. P. (2013). Recognising safety critical events: Can automatic video processing improve naturalistic data analyses? *Accident Analysis & Prevention, 60,* 298–304. doi:10.1016/j.aap.2013.02.014

Guo, F., & Fang, Y. (2013). Individual driver risk assessment using naturalistic driving data. *Accident Analysis & Prevention, 62,* 3–9.

Guo, F., Klauer, S., McGill, M., & Dingus, T. (2010). *Evaluating the Relationship Between Near-Crashes and Crashes: Can Near-Crashes Serve as a Surrogate Safety Metric for Crashes?* Blacksburg, Virginia, US.

Hallmark, S., McGehee, D. V., Bauer, K. M., Hutton, J. M., Davis, G. A., Hourdos, J., . . . Ljung-Aust, M. (2013). *Initial Analyses from the SHRP 2 Naturalistic Driving Study: Addressing Driver Performance and Behavior in Traffic Safety* ((Keine Angabe)). Washington, DC.

Hydén, C. (1987). *The development of a method for traffic safety evaluation: The Swedish Traffic Conflicts Technique* (No. Bulletin 70). Lund, Sweden.

SHRP2. (2010). *Researcher Dictionary for Video Reduction Data, v2.1*. Washington DC.

Summala, H. (2007). Towards understanding motivational and emotional factors in driver behavior: Comfort through satisficing. In C. P. Cacciabue (Ed.), *Modelling driver behavior in automotive environments* (pp. 189–207). London: Springer.

Svensson, Å., & Hydén, C. (2006). Estimating the severity of safety related behavior. *Accident analysis and prevention, 38,* 379–385.

6 Research questions for crash causation and risk

A number of factors are taken into account in order to create a sample of participants needed for addressing the identified research questions (Pereira, Utesch, Baumann et al., 2013).

6.1 Research questions for risk calculation (T4.2.2)

This topic investigates the risk of several driver behaviour patterns in relation to the occurrence of SCEs. This analysis will focus on the driver's behaviour, but other risk factors will also be considered. If a driver fails to react this could be attributed to distraction (execution of secondary tasks), diminished driving ability (drowsiness) or even overconfidence in the situation leading to risky behaviour. Accordingly the investigated risk factors can be divided into these three groups which will be addressed by specific research questions respectively. A quantitative analysis will be performed to identify the respective risks of different driver behaviours. The analysis approach will be very similar for all topics. In a second step these risks will be compared for different factors like road type and country.

The risk calculation will preliminarily focus on the general research questions below. However, these may be further broken down into more detailed research questions (e.g., what is the risk of being involved in an SCE while engaged in auditory-vocal but non-visual secondary tasks). Moreover, further general research questions may be added later. Thus, the goal of this preliminary analysis plan is to describe the general approach that will be adopted for the risk calculations. Note that if time permits, more advanced methods may be applied as well.

Overview of research questions:

- RQN1.1 What are the risks of different driver behaviours?
- RQN1.2 Is there a difference in the driving related risks when stratified by road type, vehicle type and country?
- RQN1.3: What is the risk of disregarding safety precautions?

RQN1.1 What are the risks of different driver behaviours?

These research questions will quantify the risk of drivers engaging in a number of secondary tasks, looking away from the road and being drowsy.

Background of the analysis

While it is broadly assumed that using a cell phone while driving impacts driving safety, more recent research indicates that it is not the usage of the device itself that is problematic, but the visual-manual interaction with the device (Fitch et al., 2013). Only Naturalistic Driving allows for making accurate risk calculations on data directly from the field. Understanding the real risks related to the engagement in different types of secondary tasks is an important step in identifying unsafe road user behaviour. This analysis will perform the calculations on a number of potential risk factors.

Refining of research question

The risk calculations can be broken down to more specific research questions:

RQN1.1.1: What is the risk of being involved in an SCE (crash or near crash) while engaging in secondary tasks while driving?

RQN1.1.2: What is the risk of being involved in an SCE (crash or near crash) when looking away from the forward roadway?

RQN1.1.3: What is the risk of being involved in an SCE (crash or near crash) while driving in a drowsy state?

Which analysis will be performed?

This part of the analysis will calculate the risks of several potential risk factors. The basic idea is to select variables that may be related to the occurrence of SCEs, measure the frequency of these variables in SCEs and in controls (e.g. uncritical situations) and then compare the frequencies. For these means the calculation of odds ratios has been proven useful. They allow a statement about the relative risk change when a specific factor is present, like looking away from the road.

To calculate the risk, those situations have to be identified in which the driver was distracted. Driver distraction cannot be identified reliably by automatic methods, so this variable relies heavily on video annotation. Video annotation is very time consuming and cannot be done for all the data that will be acquired in UDRIVE. Thus a selection of situations that will be annotated for distraction has to be made. The SCEs will be a major source for information. Based on experience from the previous NDS it is expected that there will be few SCEs and even fewer crashes in the data (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005). To not lose valuable data it is imperative that at least all identified crashes and relevant SCEs are annotated. Thus all SCEs will be identified and annotated for the presence of the potential risk factors.

Kinematic triggers will be used to identify SCEs within this dataset and for comparison an appropriate control/baseline will be selected. The identified SCE candidates will be validated by video annotation.

Once the SCEs are identified from the pool of candidates, these will be video annotated with respect to several risk factors. In addition baseline epochs will be annotated with the same coding schema. The annotation will focus on secondary tasks that have been identified in similar projects such as the 100-car study (Neale et al., 2005) and SHRP2 (Hallmark et al., 2013).

When the SCE and baseline epochs are annotated, the odd's ratio and risk for secondary tasks like visual-manual interaction with nomadic devices can be calculated relatively easily by comparing the frequencies (Table 3).

Table 3: Overview of data needed for calculation of Odd's ratios

	Visual-manual interaction with nomadic device present	**Visual-manual interaction with nomadic device absent**
SCE (Trigger based)	A Number of SCEs with driver executing visual-manual task with nomadic device	B Number of SCEs without driver executing visual-manual task with nomadic device
Baseline (random sample or stratified)	C Number of events with driver executing visual-manual task with nomadic device	D Number of events without driver executing visual-manual task with nomadic device

The odd's ratio will be calculated from the table: Odds Ratio = (A x D)/(B x C). An odds ratio higher than 1.0 indicates that there is a higher than normal risk associated with the factor. An odds ratio smaller than 1.0 indicates that the risk associated with this factor is lower than normal.

If time allows, it is planned to perform logistic regression analyses with random effects (e.g. mixed effect models) to handle individual drivers being overrepresented as well as covariates when using matched baselines. Odds ratio calculation is derived from logistic regression and the use of the more elaborate modelling that logistic regression provide, may produce more robust and generalizable results.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?

Since this Naturalistic Driving does not include an experimental setup there is no treatment phase. Instead the co-occurrence of certain factors will be investigated. The relevant factors in this analysis are the driver's engagement in visual-manual interaction (yes/no, or possibly as specific time-series based indicators) and the presence of a SCE (yes/no). This leads to four relevant conditions (Table 3). Even though the type of interaction differs between the specific research questions, basic methods are the same.

The baseline selection process is the most important aspect of these risk calculations. Both matched and random baselines may be used for different interpretations. For matched baselines it is important to have structured matching criteria, for example using segmentation (Dozza et al., 2013).

Which SCEs are relevant for the research question? How long are the events?
Relevant SCEs can be extracted and selected in several different ways. The team in UDRIVE Task 4.2.1 will develop kinematic and proximity trigger algorithms for the SCE candidate extraction from time-series data, while the Task 4.2.1 team annotates these candidates with respect to defined safety relevance criteria. The work on SCE extraction and definition as part of addressing the research questions described here is only to provide support and give feedback to these teams. It is not foreseen that these research questions will have very specific needs in the definition of SCEs, compared with what is planned in T4.2.1.

Which non-SCE events are important for the research question?
If time permits and the number of SCEs allow for it, stratification of SCEs in e.g. over-taking events or passage through intersections may be a separate analysis.

Which Variables are relevant for this research question?
The following list gives an overview of the variables required for answering the mentioned research questions (Table 4). Specifically these are examples of measures and events that may be used as part of a matched baseline selection.

Table 4: Overview of relevant non-video variables

Variable	Description	Source	Type
DriverID	The ID of the driver	From DAS	Measure
TripID	The trip ID	From DAS	Measure
Time related to SCE	The baseline events should be selected before the SCE (e.g. within X-Ys before)	From DAS	Derived Measure
Ego vehicle speed	The speed of the vehicle	From CAN	Measure
Braking activity	The brake pedal position either in % or pressure	From CAN	Measure
Steering activity for cars	The current steering wheel angle	From car CAN	Measure
Longitudinal acceleration	The longitudinal acceleration of the vehicle. Possibility to match on drivers' deceleration/acceleration	From DAS accelerometer	Measure
Lateral acceleration	The lateral acceleration. Proxy for steering angle	From DAS accelerometer	Measure
Distance to lead-vehicle in m	The distance to the next vehicle in front of the driver in meter. Possibility to match on headway	From Smart Camera	Measure
Time headway to lead-vehicle in s	The distance to the next vehicle in front of the driver in seconds. Possibility to match on headway	From Smart Camera	Measure
Primary other vehicle deceleration	Longitudinal acceleration of the lead vehicle	From Smart Camera	Measure
Lane change	Indication of lane change	From Smart Camera	Non SCE event
Lead-vehicle overtaking	Information about if the lead-vehicle just entered the roadway	From Smart Camera	Non SCE event
Lane position	The lateral position in the lane	From Smart Camera	Measure
Curve radius	Possibility to make match on radii	From Map	Derived Measure
In intersection	Possibility to make match on intersection	From Map	Non SCE event

How will a sample be selected?
Two samples need to be selected for answering this research question. The analysis will focus on SCEs and baseline events. The sampling strategies are explained in the respective sections.

Which sample size is needed?
It is expected that there will be a relatively small number of SCEs in the data (around 200-400 events). Thus it is planned to annotate all SCEs and use them for analysis. If not enough SCEs are found, the events for at least cars and trucks may be pooled to increase the sample size. For the baseline a sample will be drawn. It should be as large as possible but due to annotation resource limitations it should be limited to about 2-3 times the number of SCEs (for each baseline type, i.e. matched and random).

How will the data be validated?
SCE candidates will be drawn automatically from information from kinematic triggers and other sensors in T4.2.1. It is not unusual to get a high number of false positives with this approach. To select only relevant events, SCE-candidates will be validated by video annotation. Annotators will check if the candidate event indeed was critical.

How will the baseline be selected?
The baseline consists of the part of the data where no SCE was present. The UDRIVE data will be too extensive to manually annotate all of it, and thus a sample must be taken. It is likely that some analysis will require random baseline epochs, while others will require matched baseline epochs. The random baseline epochs will likely still be matched within a driver (matched to the SCEs for this driver). The matched baseline will have a number of matching criteria which are to be prioritised and sequenced. That is, if there would be a selection on DriverID+Trip+SpeedRange and baseline epochs cannot be found with this selection, the baseline extraction algorithms need to choose if it should change trip and keep DriverID+SpeedRange or loosen the speed range condition but keep the same trip. This may be a complex algorithm that needs validation. Information about the selection strategy actually employed for each baseline epoch will be stored with the epoch for later analysis of covariates. There are on-going (recently started) projects on sampling strategies for naturalistic driving (Nerman, Rootzén, Selpi, Dozza & Bärgman, 2012), which will be used to make the best baseline selection decisions. Also note that for certain analyses it may be more relevant to compare high severity near-crashes with low severity near-crashes or non-relevant SCEs.

Which variables need to be video coded and how can the coders identify the states of them?
The following table gives an overview of some of the variables that need to be video annotated for answering the mentioned research questions (Table 5). To allow for comparability with other studies, the annotations in UDRIVE will be based on the 100-car data dictionary (Fitch et al., 2013), or the SHRP2 (2010) with some modifications and additions.

Table 5: Overview of annotation variables from the 100 car study (Fitch et al., 2013)

Cell phone use	Portable Hands-free (PHF)	Moving object in vehicle	Personal hygiene
Hand-Held: Dialing	Portable Hands--Free: Holding/Wearing Headset/Earpiece	Insect in vehicle	Driving-related inattention to forward roadway
Hand-Held: End task	Portable Hands--Free: Locate/Put-on Headset/Earpiece	Pet in vehicle	Other Secondary Task
Hand-Held: Holding	Portable Hands--Free: Push button to begin/answer	Object dropped by driver	Unknown
Hand-Held: Locate/Reach/ Answer	Portable Hands--Free: Push button to End	Reaching for object, other	Unable to Determine

Hand-Held: Talk/Listen/Voice Commands	Portable Hands-Free: Talk/Listen/Voice commands	Holding object, other	Neutral/No Emotion Shown
Hand-Held: Text messaging	Cognitive distraction	Object in vehicle, other	Happy
Hand-Held: Viewing/Browsing/Reading	Lost in thought	Operating other electronic device	Angry/Frustrated
Integrated Handsfree: Press button to begin/answer	Looked but did not see	Adjusting radio or HVAC	Sad
Integrated Hands-Free: Press button to end	Talking/singing/dancing (w/o passenger or cell)	Adjusting/monitoring other devices integral to vehicle	Surprised
Integrated Hands-Free: Talk/Listen/Voice commands	Reading/Writing	Looking at non-driving related external object/event	
Just driving	Cognitive, other	Eating/drinking	
Just talking	Interacting with Passenger	Smoking/tobacco	

What possible scientific publications can you foresee based on your analysis?
The findings are highly relevant for several journals concerned with traffic safety. A scientific paper could focus on the impact of visual-manual interaction with devices on the occurrence of SCEs by comparing these events with the non-visual (manual) phone conversations. Possibilities for publication include:

- (Journal) Transportation research part F: Traffic Psychology and Behaviour
- (Journal) Human Factors: The Journal of the Human Factors and Ergonomics Society
- (Journal) Accident Analysis and Prevention
- (Conference) International Conference on Driver Distraction and Inattention

RQN1.2 Is there a difference in the driving related risks under several conditions?

This research question will compare the risks identified in the section regarding the identification of different secondary tasks in relation to exposure, and will compare the risks between countries where possible.

Background of the analysis
The advantage of UDRIVE is that we will have data from real drivers in real vehicles while they are driving in everyday situations on the roads in Europe. Data will be collected at operation sites (OS) in seven different countries. These countries differ in culture and environment. For example in Germany there are sections on highways without a speed limit, and in the UK the traffic direction is different from the other OSs. Each country's drivers adapt to the local conditions and probably develop a unique driving style. Based on these conditions it can be assumed that drivers differ in the frequency and types of secondary tasks they engage in. This analysis will study the differences in risk factors between these conditions.

Refining of research question
These research questions are directly related to the risks identified in the previous section.

RQN1.2.1: Do these risks differ between road types?

RQN1.2.2: Do these risks differ between vehicle types?

RQN1.2.3: Do these risks differ between European regions?

Which analysis will be performed?
We will have data from trucks and cars and will thus be able to compare the risks of certain factors measured in different vehicle types (e.g. looking away from the road). The focus of this task will be on the

four OSs that collect data from cars. There is only one OS which collects truck data, and the PTW riders are unlikely to engage in secondary tasks while riding. Consequently the odds ratios from RQN1.1 will be recalculated separately for each road type (urban, rural, motorway), vehicle type (trucks and cars) and country (Poland, France, UK and Germany) respectively and then compared with each other.
Due to the close similarities to the previously mentioned research question, the possible publications mostly overlap with the ones mentioned in RQN1.1.

RQN1.3: What is the risk of disregarding safety precautions?

This research question will calculate the risks of failing to perform standard safety precautions that usually are supposed to help in avoiding SCEs.

Background of the analysis
Being distracted or drowsy are not the only causes of crashes. Every day we follow a complex set of rules that we learned in driving school to help us minimize the likelihood of a crash. Stopping at a red light, granting right of way on an intersection, using the turn indicator and looking over the shoulder before changing lanes are learned behaviours that are supposed to keep us safe. But abiding to these rules can be cumbersome, especially when there is no direct negative feedback after not following a rule. Drivers, who experience time and again that no car crosses after they slowed down on an intersection in a suburb with little traffic, may be less likely to slow down in the future. Other reasons could be overestimating their own abilities or underestimating the risks of not following these rules. Actually little is known about the prevalence of drivers engaging in safety traffic rules and safety precautions. On the other hand this information is highly desirable, because if we know about the prevalence and risk of disregarding safety precautions, appropriate counter actions can be prepared. It is highly unlikely to observe this kind of behaviour in a non-naturalistic setting. Only drivers who feel at ease and are driving in real traffic will show this behaviour. UDRIVE offers the opportunity to investigate the risk and prevalence of disregarding safety precautions in Europe.

Refining of research question

RQN1.3.1 What is the risk of not slowing down on non-signalled intersections?

RQN1.3.2 What is the risk of tailgating/close following (time headway < 1.5 s) a lead vehicle?

RQN1.3.3 What is the risk of driving significantly (+20%) above the speed limit?

RQN1.3.4 What is the risk of not using turn signals when changing lane or turning?

Which analysis will be performed?
This research question is similar to the analysis described in RQN1.1, with the difference being that the investigated risk factors are not related to a distracted driver. A driver who is forgetting to use the turn indicator or driving through an orange light can pay full attention to the road and may increase the chance of a crash nonetheless. However, the risk can be calculated the same way as the risk for using a mobile phone during the trip. In both occasions the presence (or in this case absence) of the activity is annotated as an SCE and, baseline events and the frequencies are compared between the conditions. Thus the same analysis will be performed as in section RQN1.1. Relevant factors like time of day (day/night) and surroundings (residential area/highway) will be accounted for in the analysis by calculating separate risks. The data needed to answer this research question will mostly consist of GPS, time and map matching data. Thus it may be possible to analyse PTW data as well, if time allows.

Which Variables are relevant for this research question?
The following list gives an overview of the variables required for answering the mentioned research questions (Table 6). Specifically, these are examples of measures and events that may be used as part of a matched baseline selection.

Table 6: Overview of relevant non-video variables for RQN1.3

Variable	Description	Source	Type
DriverID	The ID of the driver	From DAS	Measure
TripID	A unique ID of the trip	From DAS	Measure
Driving Speed	Current speed in kp/h	From CAN	Measure
Is in intersection	Current position is in intersection	From Map Matching	Derived Measure
Time Headway	Distance to next vehicle in front in seconds	From Smart Camera	Measure
Turn indicator signal	Activity of turn indicator	From CAN	Measure
Lane Change	Lane change is performed	From Smart Camera	Measure
Time of Day	The current time	From CAN	Measure
Urban Area	Current position inside or outside urban area	From Map Matching	Derived Measure
Type of Road	Kind of road (urban/rural/highway)	From Map Matching	Derived Measure

How will the baseline be selected?

The baseline will be a matched sample similar to the situations in which the behaviour of disregarding safety precautions was observed, but without the driver disregarding safety precautions.

References

Dozza, M., Bärgman, J., & Lee, J. D. (2013). Chunking: A procedure to improve naturalistic data analysis. *Accident Analysis & Prevention, 58,* 309–317. doi:10.1016/j.aap.2012.03.020

Fitch, G. M., Soccolich, S. A., Guo, F., McClafferty, J., Fang, Y., Olson, R. L., . . . Dingus, T. A. (2013). *The Impact of Hand-Held And Hands-Free Cell Phone Use on Driving Performance and Safety-Critical Event Risk* (No. DOT HS 811 757). Washington.

Hallmark, S., McGehee, D., Bauer, Karin, M, Hutton, Jessica, M., Davis, G., Hourdos, J., . . . Ljung-Aust, M. (2013). *Initial Analyses from the SHRP 2 Naturalistic Driving Study: Addressing Driver Performance and Behavior in Traffic Safety* (SHRP 2 Safety Project S08). Washington, D.C.

Neale, V. L., Dingus, T. A., Klauer, S. G., Sudweeks, J., & Goodman, M. (2005). *An overview of the 100-car naturalistic study and findings*. Paper presented at the Proceedings - 19th International Technical Conference on the Enhanced Safety of Vehicles, Washington, D.C., June 6-9, Washington D.C. http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv19/05-0400-W.pdf

Nerman, O., Rootzén, H., Selpi, Dozza, M., & Bärgman, J. (2012). *Project application: Statistical methods for study designs in traffic safety and driving behavior naturalistic driving studies.*

Pereira, M., Utesch, F., Baumann, M., Bärgman, J., Petzoldt, T., Lai, F., . . . Winkelbauer, M. (2013). *Research questions, performance indicators and functional requirements: Deliverable 11.1 of the EU FP7 Project UDRIVE*. Retrieved from www.udrive.eu

SHRP2. (2010). *Researcher Dictionary for Video Reduction Data, v2.1*. Washington DC.

6.2 Research questions for "holistic" crash causation (T4.2.3)

This task and its corresponding set of research questions aims to identify the patterns of particular behaviours in SCEs. For a part of the analysis (risk calculations) the prevalence of factors in SCEs compared to relevant baseline events, will be analysed as well. Risk calculations are performed in T4.2.2, but there will likely be significant interactions between task 4.2.3 (holistic) and T4.2.2 (risk) in performing the more advanced risk calculations.

Two different methods will be used to address the research questions related to crash causation (or, to not infer causality, "factors likely to contribute to the occurrence of crashes and near-crashes"). The first is a quantitative approach that uses and further develops existing methods to produce aggregated chains of such contributing factors. The chains of individual events are produced by experts' qualitative analysis of "all" available data for the individual SCEs. Hereafter we call this *Qualitative analysis*. Note that even if it is called qualitative analysis, it may still include simple statistics in the last phase of analysis. The second method uses mathematical data mining methods to identify chains and correlations across factors possibly contributing to crashes (and near-crashes), and their relationship. Hereafter we call this *Quantitative analysis*. Quantitative analysis uses mathematical techniques for the extraction and correlation of factors, while in the qualitative analysis the relationships are made by expert judgment based on a pre-defined coding schema.

Note that for all analyses it is expected that SCEs are provided by T4.1.3, with minor support from the researchers performing the research on crash causation and risk. Further, since several of the research questions have the same method base, descriptions in earlier research questions have the majority of the detailed information, while later discussed research questions (later in the document) will mostly refer to the earlier research questions.

In the following description the different research questions are divided into three parts, one common (here after called *Common*) for the two analytical approaches, and one for each approach *Qualitative analysis* and *Quantitative analysis* respectively when applicable.

RQN1.4: How can contributing-factor chain schemas be applied to naturalistic road user data?

This research question involves only *Qualitative analysis* and the aims are to: 1) further develop the method previously used in Engström, Werneke, Bärgman, Nguyen, and Cook (2013), and disseminate the updates, and 2) perform inter-rater reliability testing of the method with the aim to refine and disseminate the method.

The estimated time for this task is only one person month. The development of the method will partly be done in addressing other research questions, while this research question is for method aggregation, inter-rater reliability and dissemination.

Background of the analysis

The method to be used here has been used in previous research, but needs additional refinement with respect to the additional data being available in UDRIVE. The method uses only SCEs as delivered from task T4.1.3. Figure 5 shows an example of the qualitative coding schema previously used and presented at the driver distraction and inattention conference 2013 (Engström et al., 2013). Note that this figure only includes the part of the method relating to the factors that contributed to the driver's failure to avoid a near-crash or a crash in terms of reactive responses, while the fully developed method also includes a part dealing with reasons as to why the driver failed to pick up the predictive information needed to avoid the conflict in the first place. The method is a qualitative expert judgment evaluation of all available data for the individual events, with an aggregation of all coded events for a scenario to identify patterns. More details are included in following research questions.

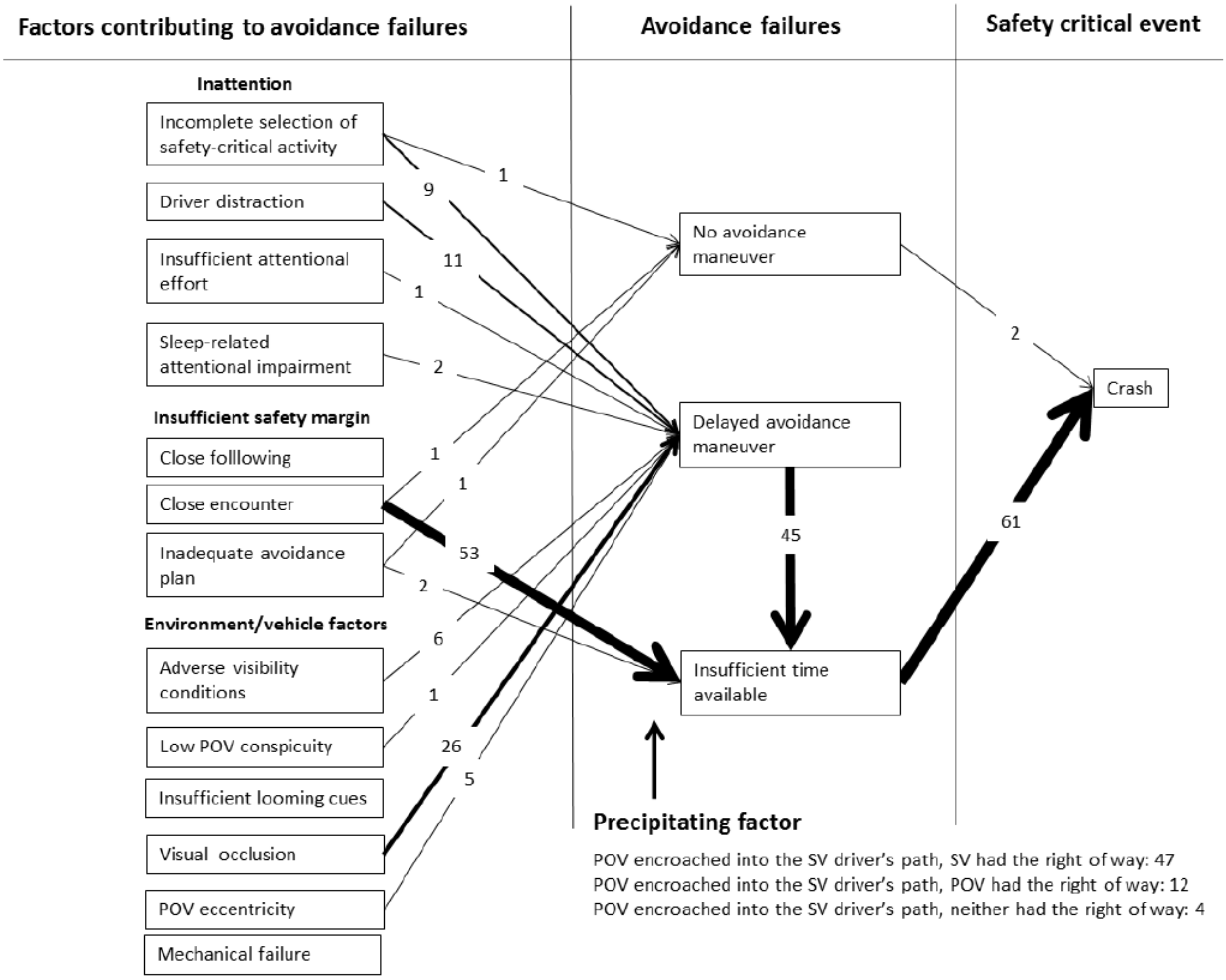

Figure 5: Example of qualitative coding scheme from Engström et al. (2013)

Which analysis will be performed?

To address this research question three tasks will be performed. The first is the evaluation of the method for the use of UDRIVE-data, followed by the refinement of the method by describing the use of the additionally available data and/or SCEs (compared with previous studies). This part also includes the categorisation of events into scenarios (possibly using classification performed in T4.1.1). The second task is the training of a few analysts in the method for one SCE scenario, followed by an inter-rater reliability evaluation. Finally, the analysis will be written up and disseminated.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?

Only SCEs will be used.

Which SCEs are relevant for the research question? How long are the events?

Focus for this research question will be passenger vehicle SCEs. For this research question several scenarios will be used in the evaluation and development of the method, but it is likely that only one (e.g. rear-end) will be used for inter-rater reliability testing.

Which variables are relevant for this research question?

All available information from the SCEs will be used in the expert judgment. This means that the list of variables would include almost all available measures. Therefore only some key variables are documented in the list below (Table 7).

Table 7: Overview of relevant non-video variables for RQN1.4

Variable	Description	Calculation	Type
SV Speed	Current ego speed	From CAN	Measure
POV speed	The speed of the principle other vehicle. Derived through own speed and relative SV/POV speed	From Smart Camera	Measure
SV lateral and longitudinal acceleration	The SV accelerations in lateral and longitudinal direction	From CAN and DAS sensor (preferably both)	Measure
SV yaw rate	The angular rate of the vehicle around the z-axis (how fast the SV turns)	From DAS sensor	Measure
Relative distance SV/POV	The distance between the SV and POV.	From Smart Camera	Measure
Relative velocity SV/POV	The relative velocity between the SV and the POV	From Smart Camera	Measure
Relative heading SV/POV	The heading of the POV in relation to the SV	From Smart Camera	Measure
Relative acceleration SV/POV	The relative acceleration of the SV and the POV	Derived from Smart Camera (will be noisy)	Derived Measure
Radial motion of POV relative SV	The angular rate of the centre of the POV in relation to the heading of the SV.	From Smart Camera	Measure
SV brake pedal position	The position of the brake pedal (could also be surrogates)	When available on CAN	Measure
Lane position	The position in the lane	From Smart Camera	Measure
SV distance travelled	The distance travelled by the SV from the start of the trip.	Integrated from SV speed	Derived Measure
Optical angle of POV	The angle of the POV as seen from the driver's perspective. Most relevant for rear-end scenarios	From Smart Camera	Measure
Optical expansion rate of POV	The derivative of the optical angle. Also called looming.	From Smart Camera	Derived Measure

How will a sample be selected?

The selection of SCEs will be made from the pool of SCEs delivered from T4.1.1. Since this is only the method development, this analysis will use SCEs in the order they arrive from the annotators.

Which sample size is needed?

In the order of 20-30 SCEs per scenario will be used in the method development. This will overlap with the following research questions.

How will the data be validated?

No selection bias evaluation will be performed for this research question.

Which variables need to be video coded and how can the coders identify the states of them?

The analysis for the research question will use primarily annotations from the main central annotation, together with the measures collected in the DAS. However, one key element to the expert judgment is the review of the individual videos. That is, the individual analyst (experts) will have to watch each individual video together with other available data, and using this all to describe each specific event using the qualitative coding schema. The following is a subset of variables that will need to be coded in the videos (Table 8). A complete list will be produced as part of the annotation codebook development. In the following table it is indicated whether the variables are time-series (to be coded for each video frame) or event based (only one value per event).

Table 8: Overview of relevant video annotated variables for RQN1.4

Variable	Description
SCE narrative	A description of the SCE as text. Should be structured.
Driver actions	Description of driver's actions according to coding schema (secondary tasks etc.). Possibly time-series data.
Driver visual behaviour	The direction of drivers gaze (categorised by region-of-interest). Time-series data.
POV visual occlusion	Coding of occlusion of POV. Time-series data.
Presence of other road users	Information about the presence of road-users other than the SV and POV. Event variable.
POV brake light onset	Moment of activation of POV braking lights.
Time of POV entering encroachment zone	The time when the POV enters the forward path of the SV (only applicable for some scenarios)

What possible scientific publications can you foresee based on your analysis?
Since this is method development with inter-rater reliability evaluation, scientific publications would, if separately published, likely be in the form of a conference article or poster. It is unlikely that there will be enough resources to write a scientific article based on the results.

RQN1.5: What are the factors that contribute to the occurrence of safety critical events for lead-vehicle and intersection conflict scenarios for cars and trucks?

This research question involves both Qualitative and Quantitative analysis, but the overall aim is the same: The aim of this research question is to identify factors that contribute to the occurrence of SCEs on European roads with respect to lead-vehicle and intersection scenarios for cars and trucks. The results are to be used for the identification of appropriate countermeasures with respect to the driver (e.g. training and driver assistance systems), the environment (e.g. infrastructure layout and road furniture), and the vehicle (e.g. brake performance).

The chain of events that leads to the occurrence of an event can be complex and the analysis will include various information types (vehicle kinetics, driver actions, infrastructure characteristics, etc.). The analysis will require the researchers to "mine" for knowledge inside these complex data; either qualitatively or quantitatively. The process to converge on an answer with a solid basis is the following:

1. Describe the information available in a relevant form (i.e. build sequences or make a coding schema for qualitative analysis that describes "chains" of contributing factors).
2. Perform a descriptive analysis of the quantitative sequences (extract main contributing factors) or qualitative chains (actually apply the coding to relevant SCEs).
3. Perform a classification of the sequences in order to extract relevant groups of different driving behaviour. For qualitative analysis, aggregate individual events per scenario (see RQN1.4)
4. Study how these groups/aggregations are made up with respect to e.g. scenario type, car type, driver characteristics, or regions of Europe.
5. If resources allow it, try to build a predictive algorithm to anticipate occurrences of an SCE.

Much interaction with RQN1.4 is expected in the qualitative analysis.

Background of the analysis

Qualitative analysis

See RQN1.4.

Quantitative analysis

There exist statistical methods for data mining, describing and visualizing sequences of states or events, and more generally discrete sequential data. Their primary use to-date has been to analyse biographical longitudinal data in the social sciences, such as data describing careers or family trajectories. Most of their features can be applied to qualitatively identified sequences. We plan to use such methods to extract patterns from the UDRIVE observations.

Refining of research question

Qualitative analysis

The aim is to address four slightly different specific research questions. However, depending on the progress of the research versus available resources, one or more of these may be excluded from the final analysis. These questions are:

RQN1.5.1: What are the factors that contribute to the occurrence of SCEs for lead-vehicle scenarios for cars?

RQN1.5.2: What are the factors that contribute to the occurrence of SCEs for lead-vehicle scenarios for trucks?

RQN1.5.3: What are the factors that contribute to the occurrence of SCEs for intersection scenarios for cars?

RQN1.5.4: What are the factors that contribute to the occurrence of SCEs for intersection scenarios for trucks?

Quantitative analysis

One or more of the specific research questions for qualitative analysis will also be addressed by quantitative analysis. However, for the quantitative analysis the initial scope of scenarios are broader and the separation into scenarios occur later in the process.

Which analysis will be performed?

Common

The following tasks are common between the quantitative and qualitative analysis and will be needed to address all research questions:

1. Interaction will task 4.1.1 to support in the specification of SCEs (triggers and description of manual classification of relevance for safety)
2. Interaction with task 4.1.2 to set up a procedure for accessing the SCEs and the data relevant for the expert analysts' review of the data (events). This includes the visualisation of video and data for expert judgement as well as the quantitative analysis and sequencing (see later in this description).

The following tasks are common between quantitative and qualitative analysis, but differ between research questions:

1. Extract the events relevant (scenario) for the specific research question
2. Calculate any additional derived measures or performance indicators identified as important for correct assessment of events of the specific scenario type (feed-back to other specific research questions as well). The identification of what is specifically needed will be a part of the research/work, but a first indication is given in the variable lists and video annotation descriptions.

The analysis will be performed in stages. First annotation preparations will be performed, then method development, and lastly, after all events are available, the actual analysis will be performed (see Figure 6).

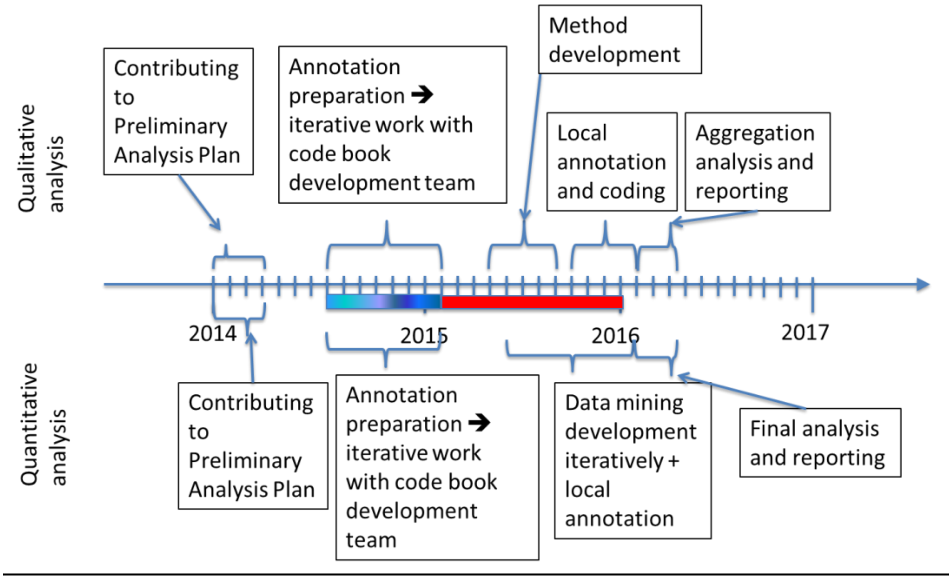

Figure 6: Planned execution of the qualitative and quantitative analysis

Qualitative analysis

The following are common within the qualitative analysis and in general also form the basis for all the research questions addressed by qualitative analysis.

1. Perform a qualitative analysis using both quantitative and qualitative data for each SCE. That is, by viewing time-series data together with event variables and video, the analyst (expert) will be judging what factors likely contributed to the outcome (near-crash or crash). This is documented in a per-event schema with additional notes on the interpretation of the event, and the mismatch identified between the driver and the actual unfolding of the event. Note that the occurrence of a factor does not mean its inclusion. There has to be a reason for including it and a check is that if it would be removed, would that have changed the outcome of the event? The analysis is focusing on making expert judgments of the mismatches between drivers' expectations and the actual unfolding of the events.
2. All events are aggregated by schema "boxes" (see example in Figure 6 in RQN1.4) and documenting on the box and link counts.
3. Interpretation of the aggregation charts are made and reports/publications written.

Quantitative analysis

There are two types of analysis planned for the quantitative analysis, but the method(s) used will depend on how many SCEs are found for the different scenarios.

There are different analyses needed for different data types (for data types, see Chapter 2). The following will describe a few different methods that are likely to be used in the UDRIVE data mining analysis. Note that several of these analysis methods are novel in their application on naturalistic driving data. This means that the efforts in addressing these research questions are basically research without a certain positive outcome of the analysis.

"Data mining" of event variable data

The event variable data used here are single values (categorical or numerical) that describe the event. These are extracted either from time-series data or are annotated manually from video.

A rough estimation indicated that if the number of relevant SCEs is more than 1000, usual statistical methods can be used to describe the data. Indeed, thousands of SCEs can provide sufficient information on many different accident causation mechanisms, and multivariate analysis methods can be useful. The idea is to summarize SCE description by using suitable indicators, treat them as numerical vectors, and then try to identify patterns and groups that could relate to a specific accident type or driving behaviour.

Available methods are well described in the literature, and it is planned to use the well-known Principal Component Analysis or Hierarchical Ascendant Classification methods. See for example the book "Applied Multivariate Statistical Analysis" (Härdle & Simar, 2012) for an overview of such methods.

Unfortunately, experience proves that it is unlikely to get a sufficient number of SCEs for the multivariate methods to be useful on event variables. Moreover, as this research question focuses on lead-vehicle and intersection scenarios, it is more likely to get hundreds of events (or even less than a hundred) rather than thousands. Researchers from LAB and IFSTTAR therefore searched for, and will evaluate, new approaches inspiring from epidemiology or social sciences.

"Data mining" using sequences

Sequences are defined in Chapter 2. However, this task includes the extraction and use of sequences in a particular way. The following outlines two approaches that may be used to define/extract sequences for further analysis:

1. **Identification of an a-priori defined sequence of non-SCE events and indicators**. Here experts perform the parameterisation of non-SCE events and indicators used to define the sequence. These experts also defined the sequence (order of components) that will be searched for in the SCEs (see Figure 7).

Figure 7: Example for an a-priori sequence.

2. **Automatic identification of sequences:** Here the sequences are identified by intelligent software working from a list of predefined criteria and rules. The idea is not to define a priori sequences but to have an iterative, automatic routine that identifies sequences step by step, until a set criterion is reached (converged upon). It may be that experts are defining the non-SCEs and indicators.

At the end of the process, a segment of X seconds (e.g. 30 s) of time preceding an SCE will be described by a sequence of different "states", each of which can be described by the starting and ending time of the sub-segments of data (events). The following characteristics of the sequence will depend on the technical approach described previously to build them:

An example of what can be done using simple sequences of real gearshifts is presented at Figure 8. It is planned to use specific analysis software packages to perform this analysis (see Gabadinho, Ritschard, Müller, and Studer, 2011), from the R software project (http://www.r-project.org/).The authors of this approach developed various features including the following:

- Visualise the sequence data set
- Explore the sequence data set by computing and visualizing descriptive statistics
- Build a typology of transitions
- Run discrepancy analyses to study how sequences are related to covariates
- Analyse event sequences.

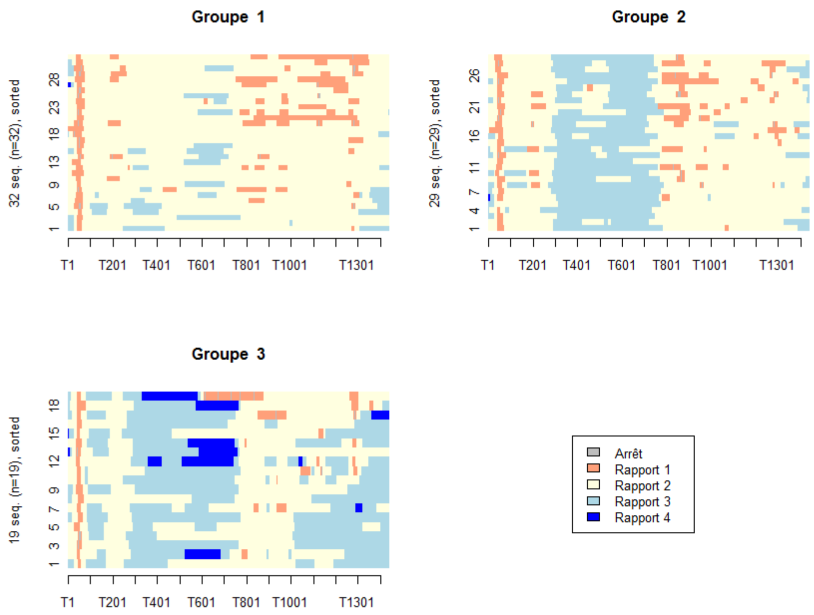

Figure 8: Example of a sequence pattern identification based on gear sequences while driving a 1km road with a roundabout.

Much previous work used these methods. The following are some relevant references (Gabadinho, Ritschard, Studer, & Müller, 2011; Ritschard, Bürgin, & Studer, 2013; Studer, G., Gabadinho, & Müller, 2010). For further information, please visit http://mephisto.unige.ch/traminer/

One issue is to find the best way to describe an SCE with sequences. This is true with respect to the research question itself and with respect to the type of analysis that will be performed, which could depend on the number of available SCEs.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?

Only SCEs will be used.

Which SCEs are relevant for the research question? How long are the events?

Qualitative analysis
For the different specific research questions there will be different foci of conflict scenarios and thus different SCE selections. The following combinations will be considered, but one or more may be excluded depending on how the available data and research progress during the analysis phase: 1) car/rear-end, 2) car/intersection, 3) truck/rear-end, and 4) truck/intersection. Also note that if research on these conflict scenarios is performed in other studies prior to the actual UDRIVE analysis (which is still 1.5 years in the future), the focus may be shifted to other conflict scenarios.

Quantitative analysis
The SCEs used for qualitative analysis will also be used in the quantitative analysis. However, SCEs from other scenarios may also be included.

Which non-SCE events are important for the research question?

Qualitative analysis
No non-SCEs will be included in this analysis.

Quantitative analysis
Part of the work on defining sequences includes the development of algorithms for extracting segments of data with certain properties, which are then called events. These events will include different forms of thresholds (e.g. speed over speed limit, acceleration over $5m/s^2$), as well as typical driving manoeuvres such as turn initiation. The detailed list of these events will be developed as part of the analysis.

Which Variables are relevant for this research question?

Qualitative analysis
See RQN1.4

Quantitative analysis
The analysis will be mostly the same as for qualitative analysis, with the following additions: additional variables will be added in the analysis phases.

How will a sample be selected?

Qualitative analysis
The selection of SCEs will be made from the pool of SCEs delivered from T4.1.1. For the method development (together with RQ 1.1.1) the first SCEs to arrive for each scenario will be used. The main analysis will not be performed until the data is “frozen” and all SCEs are identified. At this time a random sample of events will be used within a scenario selection if not all events within a scenario can be coded due to time constraints. The scenario selection will be based on Najm, Smith, and Yanagisawa (2007).

Quantitative analysis
Only SCEs for car following (lead vehicle) and intersection scenarios will be used. Splitting this data set according to car type (cars or trucks) may lead to too small data sets unsuitable for analysis. All SCEs for the selected scenarios will likely be used.

What sample size is needed?

Qualitative analysis
The aim is approximately 100 events per scenario (specific research question), but depending on the ease of compiling the necessary data there may be more or less. The resources will be allocated to rather code more events for a few scenarios (specific research questions) than few events for many scenarios.

Quantitative analysis
We need approximately 1000 events to perform Principal Component Analyses or Hierachical Ascendant Classification methods.

How will the data be validated?
The selection of SCEs will be analysed post-hoc with respect to selection bias on covariates. This task will also support T4.1.1 in selection bias discussions prior to the overall SCE selection.

How will the baseline be selected?
No baseline will be used

Which variables need to be video coded and how can the coders identify the states of them?

Qualitative analysis
See RQN1.4

Quantitative analysis
The analysis will require the same variables as for RQN1.4 (Table 8). Additional variables may be added in the code book for the development and analysis phase.

What possible scientific publications can you foresee based on your analysis?
At least one scientific publication should be possible, for example in Accident Analysis and Prevention.

RQN1.6: Are there driver/vehicle/environmental factors that frequently occur together in a safety critical event?

Background of the analysis
Note that this research question to a large extent overlaps with RQN1.5. Much of the analysis in RQN1.5 will also address this research question. However, the methods presented here have the primary purpose to address this specific research question. Also, this research question number is different from its original in deliverable D1.1.1.

This analysis uses event variables (attributes of an SCE, see details for RQN1.5). This means that X (e.g. 30) second segments of continuous data are summarised into a set of indicators (computed from continuous values) or attributes (type of road, type of car, weather, presence of a non-SCE event, etc.). For this research question every numerical value needs to be transformed into a categorical risk factor. For example, average speed across the 30 seconds can be aggregated as „normal speed“, “excessive speed“, or „low speed“. Viewing the SCE this way will allow the use of a well-known statistical method used to detect and represent underlying structures in a data set: Multiple Correspondence Analysis (MCA).

Refining of research question
No refinement is scheduled for this hypothesis, although choices among the relevant risk factors will be made. The most relevant ones and the most trusted ones (in terms of data quality) will be used for analysis.

Which analysis will be performed?
MCA is an extension of Correspondence Analysis (CA) which allows one to analyse the patterns of relationships of several categorical dependent variables. As such, it can also be seen as a generalisation of principal component analysis (PCA) when the variables to be analysed are categorical instead of quantitative. Because MCA has been (re)discovered many times, equivalent methods are known under several different names such as optimal scaling, optimal or appropriate scoring, dual scaling, homogeneity analysis, scalogram analysis and quantification method. MCA is used to analyse a set of observations described by a set of nominal variables.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?
Only SCEs are used here.

Which SCEs are relevant for the research question? How long are the events?
All SCEs for car-following and intersection scenarios will be used.

Which non-SCE events are important for the research question?
Events related to an identified risk could be incorporated through a binary variable being 1 if such an event is present, 0 if not. Events such as “excessive speeding” or “performing secondary tasks” or “Advanced driving system (ADAS) usage” for example can be included.

Which Variables are relevant for this research question?
Only categorical PI or categorical attributes will be used. This will defined as part of the analysis.

How will a sample be selected?
No selection will be made. All the available SCEs will be used.

Which sample size is needed?
More than 30 SCEs will be used.

How will the data be validated?
No specific validation will be performed here.

How will the baseline be selected?
No baseline is used.

Which variables need to be video coded and how can the coders identify the states of them?
The researches in this task will be part of defining the annotation variables as part of the annotation codebook development.

What possible scientific publications can you foresee based on your analysis?
This work can be included in the RQN1.5 analysis, and so, it will be part of the work to be published.

References

Engström, J., Werneke, J., Bärgman, J., Nguyen, N., & Cook, B. (2013). *Analysis of the role of inattention in road crashes based on naturalistic on-board safety monitoring data*. Paper presented at the Driver Distraction & Inattention, Göteborg.

Gabadinho, A., Ritschard, G., Müller, N. S., & Studer, M. (2011). Analyzing and visualizing state sequences in R with TraMineR. *Journal of Statistical Software, 40*(4), 1–37.

Härdle, W., & Simar, L. (2012). *Applied multivariate statistical analysis* (3rd ed). Berlin, New York: Springer.

Najm, W. G., Smith, J. D., & Yanagisawa, M. (2007). *Pre-Crash Scenario Typology for Crash Avoidance Research* (No. DOT HS 810 767). Washington DC.

Ritschard, G., Bürgin, R., & Studer, M. (2013). Exploratory Mining of Life Event Histories. In J. J. McArdle & G. Ritschard (Eds.), *Quantitative Methodology. Contemporary Issues in Exploratory Data Mining in the Behavioral Sciences* (pp. 221–253). New York: Routledge.

Studer, M., G, R., Gabadinho, A., & Müller, N. S. (2010). Discrepancy analysis of complex objects using dissimilarities. In F. Guillet, G. Ritschard, D. A. Zighed, & H. Briand (Eds.), *Studies in Computational Intelligence: Vol. 292. Advances in Knowledge Discovery and Management* (pp. 3–19). Berlin: Springer.

7 Research questions for Everyday Driving

7.1 Research questions for descriptive analysis of everyday driving (T4.2.4)

The research questions developed in D1.1.1 have been reviewed following ongoing discussion on the availability of data as well as resources. Of the initial set of research questions developed for D1.1.1., some are no longer viable due to the availability of data. The aim is that analysis for all the following research questions will be performed. However, if there are issues with data or if other critical issues arise, the list may have to be reduced.

RQN2.1: To what extent are driver factors associated with risky behaviour?

This research question consists of the following five sub-questions:

RQN2.1.1 Who engages in risky behaviour (definitions of risky driving behaviour? – excessive speeding, close following, excessive lateral g, etc.)?

RQN2.1.2 What driver characteristics (e.g. age, gender, annual mileage and personality factors) influence speed choice?

RQN2.1.3 What driver characteristics play a role in curve negotiation?

RQN2.1.4 What driver characteristics influence car following behaviour and reaction time to the lead vehicle?

RQN2.1.5 Does the presence of passengers (also their characteristics) affect risk taking?

RQN2.2: To what extent are environmental factors associated with risky behaviour?

This research question consists of the following three sub-questions:

RQN2.2.1 Who drives on what types of road?

RQN2.2.2 Are environmental factors influential on driver behaviour? E.g. if a specific type of driver always drives aggressively/recklessly regardless of time of day, type of road, or traffic density?

RQN2.2.3 Does infrastructure quality influence risk (e.g. cross-country comparisons)?

RQN2.3: To what extent are driver assistance systems used?

This research question consists of the following two sub-questions:

RQN2.3.1 Who uses ADAS (e.g. speed limiter, cruise control, lane departure warning, fuel efficiency advisors, portable sat nav unit, etc.)?

RQN2.3.2 Where do drivers use ADAS (e.g. urban, rural, motorway etc.)?

RQN2.4: To what extent are seatbelts used?

This research question consists of the following three sub-questions:

RQN2.4.1 What driver/passenger characteristics influence seatbelt usage?

RQN2.4.2 Is seatbelt usage influenced by environmental factors (e.g. urban/rural/motorway where implications of crash severity would be different)?

RQN2.4.3 Is seatbelt usage influenced by trip characteristics (e.g. short/long trips [and presence of passengers])?

RQN2.5: How does traffic culture influence driving behaviour?

This research question contains the following sub-question:

RQN2.5.1 What is the contribution of driver attitudes, traffic behaviour and road structure and conditions to driving risk? Are they standalone or do they interact with each other (e.g. cross border comparison)?

The aim of the above research questions is to investigate the relationship between a range of driving behaviours (objective data) and driver characteristics (subjective data).

Background of the analysis

The overall aim of the above research questions is to investigate the relationship between on the one hand driver characteristics, country (i.e. traffic culture), environmental and situational factors and in-vehicle conditions (i.e. passenger presence), and on the other hand driver risk-managing behaviours. Those risk-managing behaviours — speed choice, headway, belt-wearing – will constitute the major dependent variables (Carsten, Kircher and Jamson, 2013).

These research questions will facilitate a better understanding of what happens in everyday driving and identify who/when/where risky behaviours and potential conflicts occur. They are highly relevant to enhancing traffic safety. Many of them are also relevant for use as safety performance indicators, e.g. by country.

Which analysis will be performed?

The data used is of the form of single or multiple independent variables and a range of dependent variables, such as percentage of the time driven along a particular type of road when the vehicle was above the speed limit. The standard methodology to be used would be multivariate regression analysis or ANOVA (statistically equivalent) with the choice between the two depending on the nature of the variables being used (e.g. categorical, ordinal or interval). For belt-wearing (dichotomous dependent variable), logistic regression will be applied to identify the predictors of non-belt-wearing.

It can be predicted that the various dependent variables (speed, time headway, lateral g, non-belt-wearing) are correlated with each other in that high-risk drivers tend to adopt a general risky driving style. One means to confirm this for the participants would be check whether the factors (and models) predicting risk on one dependent variable are transferrable to others. A more sophisticated technique for looking at the relationship between several independent variables and several dependent variables (as is available here) is multivariate multiple regression analysis, which is a form of General Linear Model (GLM). Provided the data are suitable, this technique will be adopted.

Of course the data will have to be checked for normality and if there is substantial violation of the required normal distribution. If this is the case then non-parametric tests such as Wilcoxon signed rank tests will have to be used.

The project subjective data collection applies multiple questionnaires, each of which contains numerous items. Therefore factor and cluster analysis will be carried out to reveal the underlying patterns and to classify the participants into groups. This analysis will only be feasible for the car drivers.

The analysis will be performed via a number of tasks:

Task 1: Identification of risky driving behaviours in terms of excessive speeding, close following and curve negotiation in everyday driving; i.e. who/where/when.

The following variables will be used: speed, time headway, Time to Collision and lateral g. Segments of data from the continuous data stream will be identified via agreed-upon thresholds. For example:

- Speeding: speed limits
- Excessive speeding: speed over 10% of the speed limit + 2 km/h
- Time headway: time headway less than 1.5, 1.0 and 0.5 seconds.
- Lateral g: lateral g greater than 0.5

Segments will be tagged with driver identification as well as environment variables. The latter will include:

- Road types: single carriageway, dual carriageway and motorway (map data)
- Road geometry: link, bend, junction (map data)
- Locality: urban and rural (map data)
- Temporal factors: day/night, rush/non-rush hours (according to time stamps from the logged data)

Driver characteristics will be based on demographics and subjective data (e.g. DAQ, DBQ, DSQ, SS, hazard perception skills). Factor and cluster analysis will be applied to reveal underlying patterns and groupings among the participants.

Task 2: identification of presence of passengers and associated seat belt wearing.

The presence of passengers and their seat belt wearing will be identified from the video data. The output will be an annotated file containing the following columns: trip ID, presence of passenger (e.g. 0, 1, 2, 3, 4) and seat belt wearing (e.g. 0, 1 for each passenger seat). This analysis will be dependent on the video quality and will not be viable in night time situations.

Passengers will be tagged by gender and age bands where possible.

The presence of passengers will be used for the analysis of risky driving behaviour (Task 1).

Task 3: analysis of factors associated with risky behaviours.

This analysis will establish the correlation between the outcomes of Task 1 and candidate factors including presence of passengers (from Task 2) and driver demographics (from the subjective data).

Task 4: Driver seat belt wearing.

For drivers, patterns of driver seat belt wearing will be obtained via the data extracted from the CAN (SafetyBeltSwitch). The data will be analysed according to driver demographics, environment variables and presence of passengers; i.e. who/where/when.

Task 5: ADAS usage.

This analysis will establish patterns of ADAS usage among the car drivers via the data extracted from the CAN. The data will be analysed according to driver demographics, environment variables; i.e. who/where/when. The systems fitted to the selected vehicles are Speed Limiter and Cruise Control. The settings of each system in terms of speed and triggering of standby status are also available, thus allowing a link with the research questions on speed choice, since drivers may be using ADAS as a means to comply with speed limits.

The relationship between driver characteristics and type and frequency of ADAS use can be analysed using logistic regression or alternatively Probit models. Odds ratios can also be used to make comparisons between different users and different situations.

For the relationship between road characteristics and type and frequency of ADAS use, special attention will be given to selection bias: the samples must be chosen from periods when ADAS could have been used.

Time, in terms of night versus day will also be used as a factor. Again, logistic regression or Probit models are the likely analysis method with the initial activation location being the relevant event.

The overall outcome will be the identification of the most common scenarios for ADAS usage. Identifying non-users and circumstances of non-use will also be important,

Task 6: driver behaviour and the presence of pedestrians.

This analysis will focus on speed choice and precautionary driving on links (as opposed to intersections) in the presence/absence of pedestrians in the environment. It aims to establish driver awareness of potential hazard and associated adjustment. The dependent variables will be (1) reduction in speed (2) absolute speed, since cautious drivers may already be driving slowly. Locations where pedestrians are likely to be encountered will be based on map data as opposed to being extracted from video.

Task 7: cross border comparison.

This analysis will establish differences in risk taking patterns across countries. The potential association between risky behaviours and road quality (e.g. EuroRAP star rating) will also be explored.

Task 8: multivariate multiple regression analysis will be applied if feasible to reveal *overall* relationships between the independent variables and the various indicators of risky driving,

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?

Baseline data will be used for the aforementioned analyses. A range of driver and environment factors, as described in the analysis description above, will be used in the analysis. The data will have to be segmented into sections of driving in homogeneous conditions, according to speed limit, road type and, if available from the digital map, road geometry (straight or curvy). Some particular road segments such as sharp curves will be singled out for more detailed analysis of speed and lateral g (see e.g. LeBlanc et al., 2006, for an approach to analysing such segments).

Which SCEs are relevant for the research question? How long are the events?

The analysis of the aforementioned research questions will not focus on SCEs, but establish patterns of the interactions among driver and situational variables.

Which non-SCE events are important for the research question?

The analysis of the aforementioned research questions will not focus on SCEs, but establish patterns of the interactions among driver and situational variables.

Which Variables are relevant for this research question?

A range of driver and environment factors described in the analysis section above will be used in the analysis.

How will a sample be selected?

The analysis will make use of vehicle data, video data, as well as map data.

Speed: relevant segments will be identified from the continuous data stream based on speed over the speed limits for speeding as well as speed over specific thresholds for excessive speeding.

Car following: relevant segments will be identified from the continuous data stream based on time headway over specific thresholds for close following.

Lateral g: relevant segments will be identified from the continuous data stream based on curves as well as lateral g over specific thresholds.

Video data: a sampling strategy is being developed which will take a range of factors into account; for example:

- Time of day (day/night, rush/non-rush hours)
- Types of road (single carriageway, dual carriageway, motorway) and geometric characteristics (e.g. link, bend etc.)
- Locality (urban/rural)
- Trip length
- Exposure to traffic (e.g. accumulated mileage during the trial), taking road types and trip lengths into account.

Which sample size is needed?
The samples available for the analyses depend on the overall baseline samples. However the aim is to create a sub-set of samples from the baseline consisting of comparable situations in terms of a range of factors, as described above in the sample selection, for each participant. The main limiting factor for some of the analyses may be the number of participants in the study. Regarding ADAS usage, it is not known to what extent the drivers will be using the two systems.

How will the data be validated?
Not relevant to this analysis.

How will the baseline be selected?
Not relevant to this analysis.

Which variables need to be video coded and how can the coders identify the states of them?
Seatbelt wearing and the presence of passengers will require video coding. The baseline data will need to be examined soon after ignition-on and ideally at intervals subsequently.

What possible scientific publications can you foresee based on your analysis?
The analysis will lead to an understanding of the patterns of risky behaviours and the interactions between driver and environmental factors associated with these risky behaviours. It will also reveal the correlations among the risky behaviours, i.e. to what extent they are clustered by driver. It is expected that the findings will be of substantial scientific interest.

References

Carsten, O., Kircher, K. and Jamson, S. (2013). Vehicle-based studies of driving in the real world: the hard truth? Accident Analysis and Prevention, 58: 162-174.

LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, J. Mefford, M., Hagan, M., Bareket, Z., Goodsell, R. and Gordon, T. (2006). Road departure crash warning system field operational test: methodology and results. Report UMTRI-2006-9-1, University of Michigan Transportation Research Institute, Ann Arbor, Michigan.

8 Research questions for Distraction and Inattention

The research questions related to driver distraction and inattention will address two general topics: (1) attention selection mechanisms and (2) the willingness of drivers to engage in secondary tasks.

In addressing the first topic, a general distinction can be made between reactive and proactive attention selection. Reactive attention selection generally is unplanned and occurs automatically in response to unexpected events such as a lead vehicle suddenly braking. By contrast, proactive attention selection is based on knowledge and expectations of potential hazards and how a situation will unfold.

The second main research topic concerns the willingness of drivers to engage in secondary tasks such as phone dialling or texting, and how drivers adapt such secondary task activities to the evolving traffic situations. This analysis will look at secondary task engagement in normal driving situations. Both quantitative and qualitative analyses will be performed in order to identify the main factors that determine when and how drivers engage in secondary tasks while driving.

8.1 Research questions for Attention selection mechanisms (T4.3.2)

RQN3.1: Which perceptual cues reliably capture attention and trigger avoidance manoeuvres in SCEs?

This analysis will focus on which perceptual (mainly visual) cues capture attention and trigger avoidance reactions in truly critical situations.

Background of the analysis

Existing laboratory research has demonstrated that attention is mainly captured bottom-up by transient luminance and movement transients such as stimulus onsets, translational movement and looming, that is, the optical expansion of a closing object (e.g., Franconeri and Simons 2003). In the driving context, examples of such transients include brake light onsets, the appearance of an object behind an occluding object, a vehicle at an intersection that starts moving into the driver's path and the looming of a closing lead vehicle.

These types of stimuli could thus be expected to capture the driver's attention in a reflexive, automatized way in critical situations. Liebermann et al., (2007), in an experimentally controlled field study, found that both brake light onsets and looming triggered braking responses in lead-vehicle braking situations. However, in this study, the braking events were somewhat anticipated and it is still possible that different results are obtained in critical naturalistic situations, where the critical event is normally strongly unexpected. More specifically, it could thus be hypothesised that experienced drivers develop automatized responses to certain stimuli but not to others, and that the degree of automaticity is determined by the consistency of the mapping between stimulus and response in real-world driving situations (Schneider, Dumais and Shiffrin, 1984). Strong looming consistently signals the need for an immediate response, while brake lights do not (and thus they are more variably mapped to avoidance responses). Hence, it could be hypothesised that looming (and perhaps other types of stimuli such as appearance and vehicle movement onsets at intersections) capture attention and trigger automatic avoidance responses in driving. By contrast, brake light onsets may capture attention but not trigger automatic responses.

Refining of research question

RQN3.1.1: Which looming (optical expansion) cues reliably capture attention and/or trigger avoidance responses in critical situations (when eyes are on road)?

RQN3.1.2: Do brake light onsets reliably capture attention and/or trigger avoidance responses in critical situations (when eyes are on road)?

RQN3.1.3: To what extent do looming response thresholds depend on visibility conditions?

RQN3.1.4: How do drivers select their avoidance manoeuvre (braking and/or steering) in different types of critical situations? How is this related to the visual cues that are available?

Which analysis will be performed?

For the analysis of responses to looming (RQN3.1.1), SCEs where the driver looked forward at the onset of looming will be selected. The physical reaction onset, the accelerator release, the brake reaction onset and the steering reaction onset will be identified and the values of optical angle (θ) and angular velocity (θ-dot) measured (either manually or by means of the MobilEye system). This will also involve signal processing, image rectification and camera calibration based on the methodology described in Bärgman et al. (2013). The values of θ and θ-dot at the different response onsets will be calculated. Based on this data, different types of looming detection models will be evaluated, including estimated linear and non-linear functions relating θ-dot to θ (see Flach et al., 2004) but also models based on the accumulation of looming over time (Purcell et al., 2011; Markkula, submitted). Different combinations of θ and θ-dot, such as tau (τ=θ/θ-dot) and its reciprocal (inverse tau) will be investigated.

A similar analysis will be done for brake light onsets (RQN3.1.2). However, since these signals have a defined onset (unlike looming), the analysis will be based on response times, i.e., the time durations between the brake light onset and the different response onsets (physical reaction onset, the accelerator release, the brake reaction onset and the steering reaction onset). The analysis will examine to what extent these response times are consistent across events. If a response consistently occurs within a certain time relative to the brake light onset, this indicates that it was automatically triggered by the brake light onset. Differences between the different types of response onsets will be investigated. Depending on the data (number of SCEs) available, a similar analysis can be made for other types of discrete cues in different scenarios.

As suggested by Lee (1976), looming detection is slower in situations with limited visibility, in particular in darkness where looming is mainly provided by the two rear-end lights. This topic is address by RQN3.1.3. The key analysis will involve comparing looming responses (for the different response variables), for different visibility conditions. A similar analysis will be done for discrete cues such as brake light onsets. The analysis will focus on darkness versus daylight conditions. However, depending on the availability of safety-critical events, other visibility conditions may be investigated as well.

A further issue to be investigated is how do drivers select their avoidance manoeuvre (braking and/or steering) in different types of critical situations, and how this is related to the visual cues available (RQN3.1.4). Avoidance responses will be classified into a set of pre-defined categories (no response, braking only, braked and then steered, steered and then braked, braked and steered simultaneously) and it will be investigated to what extent these response categories can be predicted based on the visual cues available. Logistic regression or other classification techniques will be applied for this analysis.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?

This is described in the previous section.

Which SCEs are relevant for the research question? How long are the events?

This analysis will focus on rear-end crashes and near crashes where the monitored driver is in the following vehicle. The main motivation for this is that (1), based on existing crash statistics, this is expected to be the most common SCE type (accounting for about 30% of all crashes) and (2) rear-end scenarios typically allow for “clean” measurement of looming and brake light onsets. However, depending on the number of available SCEs, other types of scenarios (e.g., intersections) may be addressed as well.

The data segment needs to include at least 15s of data prior to the crash or the point of minimum distance.

Which non-SCE events are important for the research question?

This analysis will only use SCEs.

Which Variables are relevant for this research question?

The following list gives an overview of the variables required for answering the mentioned research questions (Table 9Table 4).

Table 9: Key variables in the analysis of RQN3.1 and RQN3.2

Variable	Description	Source	Type
Theta	The visual angle subtended by the collision object (e.g., the closing lead vehicle)	Depending on the output from MobilEye. If calculated manually, the methodology in Bärgman et al. (2013) will be used.	Derived
Theta-dot	The rate of change of theta.	See above	Derived
Tau	Theta/theta-dot		Derived
Brake light onset	The onset of the lead vehicle's brake light.	Manually annotated	Video Annotation
Appearance behind object	The moment the collision object appears behind an occluding object.	Manually annotated	Video Annotation
Driver reaction	The onset of the first visible reaction of the SV driver to the POV. This can involve any physiological reaction including body movement, a change in face expression etc.	Manually annotated	Video Annotation
Accelerator release	The point where the accelerator pedal is fully released.	Calculated based on CAN data (exact algorithm TBD).	Derived
Brake onset	The onset of the brake application (based on brake pedal position)	Calculated based on CAN data (exact algorithm TBD).	Derived
Steering avoidance onset	The onset of the steering avoidance manoeuvre	Calculated based on CAN data (exact algorithm TBD).	Derived
Onset of the evasive manoeuvre	The onset of the actual evasive manoeuvre	Combining brake pedal, steering wheel angle and acceleration signals to determine the onset of the avoidance manoeuvre (exact algorithm TBD).	Derived
Visibility conditions	Focus on lighting conditions (daylight, dusk/dawn, dark but lighted, darkness), but other factors (e.g., adverse weather) may be considered as well.	Manually annotated	Video Annotation
Gaze eccentricity	The visual angle of the SV-driver's gaze direction relative to the forward roadway.	Manually coded	Video Annotation

How will the data be validated?

The analysis will be conducted on SCEs that will be validated as part of the video annotation process.

Which variables need to be video coded and how can the coders identify the states of them?

See Table 9.

What possible scientific publications can you foresee based on your analysis?
Results from RQN3.1.1 and 3.1.2 are likely to be published together in one or more papers. Possible target journals include Human Factors, Accident Analysis and Prevention, Transportation Research Part B, Injury Prevention etc.

RQN3.2: Why do the reactive attention capture mechanisms, identified in RQN3.1, sometimes fail and lead to crashes?

This analysis will focus on understanding why the mechanisms underlying reactive attention capture and avoidance manoeuvre triggering, studied under RQN3.1, sometimes fail and lead to crashes.

Background of the analysis
A large body of experimental as well as naturalistic driving research has identified different forms of inattention, in particular visual diversion from the forward roadway and fatigue/sleepiness (Dingus et al., 2006; Horrey, Wickens and Consalus, 2006; Klauer et al., 2006; Engström et al., 2013), as key factors behind response failures in critical situations.

It may be hypothesised that a key mechanism behind reactive avoidance failures is the co-occurrence of inattention and a sudden critical event (Dingus et al, 2006). The general aim of this analysis is to investigate in detail how different aspects of inattention (e.g., gaze diversion, micro sleeps, cognitive load, etc.) affect the ability to react to critical visual cues (e.g. looming).

Refining of research question
RQN3.2.1: To what extent do eyes off road co-occurring with visual cue onsets explain reactive attention failures and SCE involvement?

RQN3.2.2: To what extent do long eye closures co-occurring with visual cue onsets explain reactive attention failures and SCE involvement?

RQN3.2.3: To what extent do drivers fail to react to critical stimuli even if their eyes are open and directed towards the road? If so, what are the critical attentional mechanisms?

Which analysis will be performed?
The first main part of the analysis addresses the impact of off-road glances and long eye closures on reactions to visual cues (RQN3.2.1 and 3.2.2). The visual cues and response variables of interest are the same as in RQN3.1.

In a first step, time-series plots where events are aggregated and time-aligned relative to the onset of the visual cue of interest will be created (e.g., where t=0 corresponds to the brake light onset or a threshold on θ-dot). The time series will be divided into segments and the total eyes-off-road time (TEORT) will be calculated for each bin. If the overlap of off-road glances and the visual cue onset is critical for SCE involvement, there should be a dip in TEORT around the onset of the visual cue. The more critical the cue, the deeper the dip should be. Moreover, the dip should increase with the severity of the event (i.e., it should be larger for crashes than near crashes, and larger for near crashes than for incidents). For the continuous optical variables (e.g., looming), a further analysis could investigate areas of overlap rather than just overlap at a certain threshold.

Second, SCEs where the visual cue overlaps with eyes off road (off road glances or eye closures) will be selected. The response onsets for these events will be compared to those obtained in the RQN3.1.1 analysis (for events where the driver looks towards the forward roadway). These response distributions will also be compared between crashes, near crashes and incidents, in order to investigate to what extent eyes-off-road overlapping with looming cues predicts event severity. For discrete cues, such as brake light onsets, a similar analysis will be conducted based on response times. In addition this analysis will address to what extent different visual cues are able to attract the gaze back to the road. Here, the response onsets will be related to (manually coded) gaze eccentricity.

These analyses will be conducted for off-road glances and eye closures respectively, as well as for their combination (eyes off road).

The second main part of the analysis addresses to what extent drivers fail to react to critical stimuli even if their eyes are open and directed towards the road (RQN3.2.3). One situation where this may occur is when the driver directs his gaze back to the road while engaged in visual time sharing between the forward roadway and a secondary task. This could be investigated by selecting events where the driver glances off-road at least twice and calculate the looming cues (e.g., θ-dot or 1/τ) that occur when the driver looks back. If looming cues that occur between glances are strong enough to normally capture attention and trigger a response (as determined under RQN3.1), but the driver does not respond and looks away again, this indicates that visual inattention *per se* (irrespectively of gaze eccentricity) may impair responses to looming. The same analysis can be done for discrete cues such as brake light onsets. It could also be investigated if missing the brake light onset (or other discrete cues) due to an off-road glance impairs detection of the cue when looking back (this can be regarded as a form of change blindness; Rensink, 2002).

Second, a similar analysis could be conducted for events which contain long eye closures due to sleepiness, but where the critical visual stimulus occurs when the driver's eyes are open. Thus, response thresholds and response times could be compared to SCEs where there are no visible signs of sleepiness.

A third issue concerns the extent to which cognitive (or working memory) load affects reactive responses to SCEs. This can be addressed by selecting events where the driver is engaged in a secondary task (e.g., conversation) while gaze is still directed towards the forward roadway. Response thresholds (for continuous optical variables) and response times (for discrete variables) for cognitively loaded drivers could then be compared to events where there are no visible signs of cognitive load. This analysis could be aided further by more detailed annotation of the cognitive task, such as the timing of speech utterances and emotional content.

The feasibility of the second and third analysis depends on the prevalence of sleepiness and cognitive load in the available SCEs.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?
This is described in the previous section.

Which SCEs are relevant for the research question? How long are the events?
As for RQN3.1, this analysis will focus on rear-end crashes and near crashes where the monitored driver is in the following vehicle.

Which non-SCE events are important for the research question?
This analysis will only use SCEs.

Which Variables are relevant for this research question?
See Table 9.

How will the data be validated?
The analysis will be conducted on SCEs that will be validated as part of the video annotation process.

Which variables need to be video coded and how can the coders identify the states of them?
See Table 9.

What possible scientific publications can you foresee based on your analysis?
Results from RQN3.1.1 and 3.1.2 are likely to be published together in one or more papers. Possible target journals include Human Factors, Accident Analysis and Prevention, Transportation Research Part B, Injury Prevention etc.

RQN3.3: What factors determine how drivers proactively allocate their attention in anticipation of how a driving situation will unfold and why do these proactive selection mechanisms sometimes fail?

The analysis of proactive selection mechanisms will focus on the identification of key factors that determine how drivers allocate their attention in anticipation of how a driving situation will unfold, and why this sometimes fails to match the actual scenario, thus leading to critical situations.

Background of the analysis
These research questions address issues such as "why did the driver have his eyes off road at the particular moment when the lead vehicle braked"? There is relatively little research on this topic in the driver behaviour literature and thus an important part of the work is to identify and define key factors underlying proactive attention allocation. A starting assumption will be that proactive attention allocation is generally determined by (1) the driver's situational understanding and (2) extra motives.

The driver's situational understanding is based on experience with similar situations as well as predictive information specific for the situation. Such predictive information includes events or objects that are visible ahead (e.g., the brake light onset of a lead vehicle slowing down ahead, a traffic queue building up, an intersection) as well as the behaviour of other road users.

Extra motives refer to motivational factors such as achievement of task goals (the driver has a strong desire to achieve certain trip-related goals, for example, is in a hurry to reach the destination in time, or may feel a strong urge to send a text message), behavioural norms (the driver uses the behaviour of other road users as normative model for his/her own behaviour), need to prove ones driving skills (the driver feels a need to prove driving skills to other road users or peers), hedonistic objectives (the "pleasure to drive" motivates the driver towards certain behaviours, e.g. speeding), aggression (the driver is in an emotional state of aggression) and social group pressure (e.g. the driver is under social pressure towards certain behaviour by peers) (see Näätänen and Summala, 1976).

Failures in proactive selection may thus be generally related to an erroneous situational understanding as well as extra motives that push the driver to take more risks. Failures in situational understanding may, in turn, be induced by failures to pick up relevant predictive information (for example, a failure to detect a traffic queue ahead). Furthermore, failures to pick up predictive information may be due to inattention, limited visibility, occlusion, etc. Extra motives, in particular an urge to complete a secondary task, may drive people towards taking their eyes off the road in situations where they are not normally willing to do it.

Refining of research question
RQN3.3.1: What are the main factors that guide driver's proactive attention allocation?

RQN3.3.2: What are the key mechanisms behind an erroneous situational understanding?

RQN3.3.3: What are the key mechanisms behind failures to pick up predictive environmental cues?

RQN3.3.4: To what extent do extra motives induce proactive attention selection failures in critical situations?

Which analysis will be performed?
The analysis will mainly involve qualitative analysis of video recordings from selected SCEs. The analysis will also be aided by plots of key signals (e.g. speed, acceleration, visual behaviour, looming, brake light onsets, etc.) A methodology for coding and aggregating those factors relevant for proactive attention allocation will be developed based on existing work (e.g., Habibovic et al., 2013; Engström et al., 2013). Such factors may

include different categories of erroneous situational understanding, different forms of extra motives, missed predictive cues and different forms of inattention. The categorisation of inattention will be based on the inattention taxonomy recently developed by a US-EU expert group (Engström, Monk et al., 2013). An important part of this work will be to achieve sufficient inter-rater reliability of the coding scheme.

In addition, interviews will be conducted with a subset of the drivers involved in SCEs based on a pre-defined interview guide. The aim of the interviews is to obtain information of the driver's subjective experience of the event, in particular the presence of extra motives. Naturally this is very difficult to analyse based on videos alone. The interviews will be conducted as part of the debriefing session, will be conducted in the driver's native language and will be aided by the video recording of the event (to aid the driver's memory of the event). Since the number of interviews will be limited due to resource constrains, the selection will focus on the most severe events.

The end result of the analysis will be tree-charts for each SCE that link contributing factors in the proactive (normal driving) phase with their consequences in the reactive (crash avoidance) phase (i.e., the mechanisms studied under RQN3.1 and 3.2). The charts for each SCE will then be aggregated in order to elicit common patterns of contributing factors.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?
The analysis will be purely qualitative; no statistical analysis will be conducted.

Which SCEs are relevant for the research question? How long are the events?
In order to link this analysis to the analysis of reactive attention selection in RQN3.1 and 3.2, the analysis will focus on rear-end events. However, it is likely that other scenarios are addressed as well, in particular intersection scenarios. The video clips used for analysis should contain data of at least 30 seconds prior to the crash/near crash.

Which non-SCEs are important for the research question?
This analysis will only use SCEs.

How will the data be validated?
The analysis will be conducted on SCEs that will be validated as part of the video annotation process.

Which variables need to be video coded and how can the coders identify the states of them?
See Table 9.

What possible scientific publications can you foresee based on your analysis?
Possible target journals include Human Factors, Accident Analysis and Prevention, Transportation Research Part B, Injury Prevention etc.

8.2 Research questions for Involvement in secondary tasks (T4.3.3)

The research questions developed in D1.1.1 have been reviewed following ongoing discussion on availability of data as well as resources. Analysis for the following research questions will be performed.

RQN3.4: What are the key factors influencing the willingness of drivers to deliberately engage in secondary tasks such as phone conversation, dialling or texting?

RQN3.5: How do drivers adapt ongoing secondary task activities to the evolving driving situation?

RQN3.6: To what extent can an individual's willingness to engage in secondary tasks, and its effects on risk and driving performance, be predicted from psychological tests?

Background of the analysis

The aim of the above research questions is to investigate uptake of secondary tasks during the course of driving. RQN3.4 focuses on when/where/who, which will provide understanding of patterns of secondary task uptake in relation to the driver and environmental factors (Carsten et al., 2012; Carsten et al., 2013). RQN3.5 focuses on the process of carrying out secondary tasks; i.e. the interactions between the progress of driving and secondary tasks once a secondary task has been initiated. RQ 3.7 investigates the relationship between the results of the aforementioned two analyses (objective data) and driver's risk-taking tendency (subjective data).

Refining of research question

The following refined research questions will be considered in the analysis. However, depending on the time constraints in the analysis phase, some questions may be left for subsequent projects to address.

RQN3.4.1: What is the prevalence of secondary task activity in normal driving? What specific types of secondary tasks do drivers typically engage in?

RQN3.4.2: To what extent do driving task complexity and secondary task complexity influence the decision to engage in secondary tasks while driving?

RQN3.4.3: To what extent is the willingness to engage in secondary tasks while driving dependent on age, gender and cultural factors?

RQN3.5.1: To what extent do drivers adapt their safety margins while performing secondary tasks?

RQN3.5.2: How do drivers schedule secondary tasks activities according to current and anticipated driving demands, and to what extent do motivational factors influence this scheduling behaviour? To what extent is this adaptation effective in increasing driving safety?

RQN3.5.3: What are the key psychological mechanisms underlying extremely long off-road glances?

RQN3.6.1: To what extent can the general willingness to engage in secondary tasks and specific scheduling characteristics (e.g. extreme glances) be predicted from psychological tests?

RQN3.6.2: Which personality dimensions have the strongest predictive value?

Which analysis will be performed?

A set of preparatory tasks will be carried out. A sampling strategy will be developed for identifying the occurrence of secondary tasks from the video stream. Of course only a subset of all video will be used in the extraction of secondary tasks. However, if appropriate sampling is performed, analysis results should be generalizable. Here, time based sampling will be used instead of distance based sampling.

A range of factors may affect uptake of secondary tasks or specific types of secondary tasks, for example:

- Time of day (day/night, rush/non-rush hours)
- Types of road (single carriageway, dual carriageway, motorway) and geometric characteristics (e.g. link, bend etc.)
- Locality (urban/rural)
- Trip length
- Time on trip, with phone calls arguably being more likely towards the end of a trip

Surrogate approaches to the identification of secondary tasks may also include button activation records from the Multi-Media CAN (MM CAN) or the scrambled audio recording. There are some limitations on the samples these surrogate approach might produce. For the MM CAN, the tasks will be limited to tasks involved with pushing a button in the vehicle. A large range of secondary tasks will most likely be missed. For example, phoning will not be registered unless the phone is connected to the built-in Bluetooth. Secondary tasks associated with nomadic devices (e.g. smartphone) will also not be captured. As for the scrambled audio recording, background noise (e.g. radio/music) may prevent conversations from being identified.

In addition to sampling strategy, the following two tasks will be carried out during the preparation phase:

- Defining a hierarchical scheme for classifying secondary tasks (e.g. Hierarchical Task Analysis methodologies and task taxonomies)
- Defining the difficulty of the secondary tasks based on complexity and attentional demand.

Sample secondary tasks may include:

- Phone related tasks (dialling, answering, texting; either handheld or hands-free)
- Entertainment related tasks (radio, CD, MP3 player, etc.)
- Comfort-related tasks (adjusting air conditioning temperature or fan speeds, etc.)
- Eating, drinking, smoking, move an object, etc.
- Interaction with passengers
- Other nomadic device related tasks (e.g. navigation settings)

The distinction between received phone calls and messages and self-initiated ones is fundamental, as only self-initiated activities are fully subject to self-regulation. However, it is not known at this stage whether this distinction will always be clearly identifiable.

These preparational tasks will be followed by several sets of analyses:

The relations among task uptake, types of tasks, complexity of tasks, temporal factors, environmental factors and driver factors will be examined, in order to establish an understanding of what/when/who in terms of secondary task uptake during every day driving. For example, stop-and-go situations in an urban environment or monotonous motorway situations might encourage drivers to undertake secondary tasks in comparison with when the driving task is more demanding. The driver typology created by the factor and cluster analysis discussed in section 7.1 can be exploited here. Dependent variables will be both task engagement and task duration (i.e. frequency of secondary task engagement and proportion of time allotted for task engagement). Both personal and situational variables will be used in the analysis. The major analysis tools will be multivariate regression and/or ANOVA (which are statistically equivalent). For task engagement, which is a dichotomous variable per specific task, logistic regression will be applied. Using standard approaches from the literature, a hierarchy of task complexity will be created and applied. This will allow investigation of whether there are systematic differences between engagements in easier as opposed to more demanding tasks. Task types — auditory, visual, visual-manual — will also be distinguished.

The outcomes of the above analysis will lead to a selection of sample tasks for a more elaborated analysis focusing on the progress of these tasks. Video data will be examined across the whole length of selected tasks in order to establish interactions among task progress, environmental factors and driver factors; i.e. safety margins, and how this varies before, during and potentially after secondary task completion (Figure 9). For example, the same type of secondary tasks might be interrupted more often in certain traffic situations, or certain driver characteristics may be associated with different patterns of glancing behaviours (e.g. a series of short glances or a few long glances away from the forward view during the completion of a secondary task). The Hierarchical Task Analysis methodologies will be employed again in this analysis.

A separate analysis will be carried out on the pre-task period (see below) to identify whether drivers adapt before task initiation by increasing their safety margins. The initial plan is to perform a regression analysis with change in speed, change in time headway and change in lane as the dependent variables. More sophisticated time series analysis will also be considered.

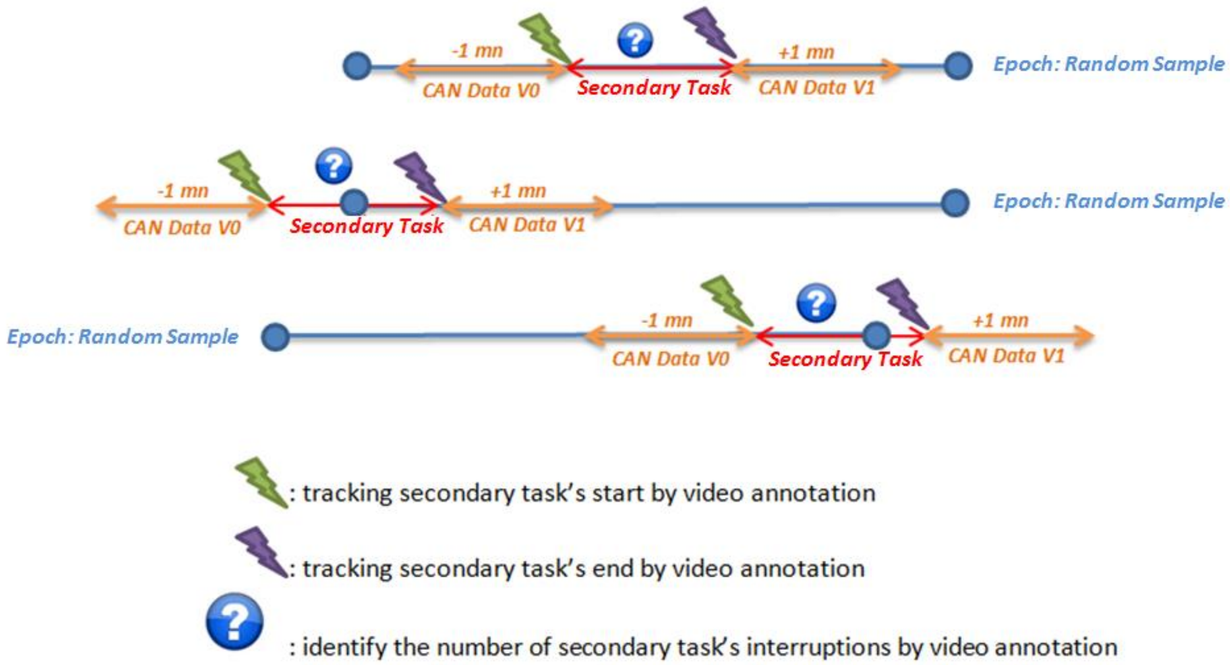

Figure 9: A possible example for analysis is a descriptive analysis of whole safety margins' included indicators, according to three states. Three states can be defined "before secondary task", "during secondary task" and "after secondary task".

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?
Comparisons will be made among types of secondary tasks (e.g. visually and non-visually dominant tasks), types of road environment (e.g. urban, rural, motorway) and driver characteristics (demographic variables as well as risk-taking tendency).

Which SCEs are relevant for the research question? How long are the events?
The analysis of the aforementioned research questions will not focus on SCEs, but establish patterns of the interactions among task types, environmental factors and driver characteristics.

Which non-SCE events are important for the research question?
The analysis of the aforementioned research questions will not focus on SCEs, but establish patterns of the interactions among task types, environmental factors and driver characteristics.

Which Variables are relevant for this research question?

The following list gives an overview of the variables required for answering the mentioned research questions (Table 10Table 4).

Table 10: Key variables in the analysis of RQN3.4 - RQN3.6

Variable	Description	Source	Type
Time of day	The time of day (day/night, rush/non-rush hours)	From DAS	Derived Measure
Type of road	The type of road (single carriageway, dual carriageway, motorway/mountain)	From Map	Map Matching
Locality	Type of location (urban/rural)	From Map	Derived Measure
Trip length	Duration of current trip	From DAS	Derived Measure
Exposure to traffic	e.g. accumulated mileage during the trial	From Video	Video annotation
Phone related tasks	Tasks like dialling, answering, texting; either handheld or hands-free	From Video	Video annotation
Entertainment related tasks	Tasks like the operation of radio, CD, MP3 player etc.	From Video	Video annotation
Comfort related tasks	Tasks like adjusting air con temperature or fan speeds etc.	From Video	Video annotation
Consume related tasks	Secondary tasks like eating, drinking, smoking, moving objects, etc.	From Video	Video annotation
Other nomadic device related tasks	E.g. operation of navigational aid	From Video	Video annotation
Gaze direction	Direction of eye glances	From Video annotation	Video annotation
Speed	Current speed in kp/h	From DAS	Measure
Headway	Time in seconds until the driven vehicle is in the position where the vehicle in front is currently at	From Smart Camera	Measure
Brake	Braking activity	From CAN	Measure
Throttle position	Throttle activity	From DAS	Measure
Time stamps		From DAS	Measure
Road geometrics	Type of road segment (link, bend, junction)	From Map	Measure
Steering wheel angle	The steering wheel angle	From CAN	Measure
Lateral acceleration	The lateral acceleration	From DAS	Measure
Longitudinal acceleration	The longitudinal acceleration	From DAS	Measure
Position in the lane	The lateral position in the lane	From Smart Camera	Measure
Variation of position in the lane	Variance of lane position for a certain interval	From Smart Camera	Derived Measure
Driver foot position	Describes if driver's foot is over brake or accelerator pedal	From Video	Video Annotation
ADAS use	Activity of assistance systems	From CAN	Measure

How will a sample be selected?

It is vital that the sample provide an unbiased selection of secondary task engagement. This means that we need to consider the need to capture information from all trip types. There is a risk that if (for example) a time interval of selecting video at 5-minute intervals is implemented, short-trips will be totally omitted. Therefore the initial time stamp after trip start should be relatively short. In refining the sampling strategy, we will consult the appropriate survey data to help reveal the distribution of trip length. This means the present proposal is preliminary.

The proposed sampling procedure is as follows:

- Initial sample: 3 minutes after trip start (first vehicle motion)
- Subsequent interval: 10 minutes
- Process at each sampling point:
    1. Identify task (if any) and record time stamp
    2. Scroll back to task initiation and record time stamp. For phone calls identify if self-initiated.
    3. Scroll back 1 minute and time stamp
    4. Scroll forward to task end and time stamp

This process gives:

- Task type
- Task duration
- A pre-task time so that pre-task adaptation can be investigated (e.g. slowing down or increasing headway in advance of task engagement)

Situational variables will be identified via the time stamps.

Which sample size is needed?
Sample size will largely be dependent on resources available for video coding. The proposed time interval of 10 minutes may need to be increased, depending on the available resource and the time required for the video coding of each instance.

How will the data be validated?
The sampling methodology for the identification of secondary task occurrence as described above will be validated by examining a small set of video samples in detail, in order to confirm the efficiency of sampling. This can for be achieved example, by comparing the sampling results of different time intervals, 30 seconds, 1 minute, 1.5 minutes, etc. Secondary task occurrence identified via the surrogate data sources (i.e. MM CAN and scrambled audio recording) will need to be confirmed by video analysis.

How will the baseline be selected?
Not relevant for this analysis.

Which variables need to be video coded and how can the coders identify the states of them?
A coding protocol will be developed, which will identify the occurrence of secondary tasks as well as progress of secondary tasks. Gaze direction will be one of the relevant variables. The Hierarchical Task Analysis methodologies will be used for task breakdown.

What possible scientific publications can you foresee based on your analysis?
The analysis will lead to an understanding of the patterns of secondary task uptake and interactions between driver and environmental factors associated with driver distraction. Publication will be at conferences such as the Driver Distraction and Inattention Conference and in scientific journals — Accident Analysis and Prevention and Transportation Research Part F being the most likely targets.

References

Bärgman, J., Werneke, J., Boda, C.-N., Engström, J. and Smith, K. 2013. Using manual measurements on event recorder video and image processing algorithms to extract optical parameters and range. *Proceedings of the 7th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Bolton Landing, New York, June 17-20, 2013.

Carsten, O., Kircher, K. and Jamson, S. (2013). Vehicle-based studies of driving in the real world: the hard truth? *Accident Analysis and Prevention*, 58: 162-174.

Carsten, O.M.J., Lai, F.C.H., Barnard, Y., Jamson, A.H. and Merat, N. (2012). Control task substitution in semi-automated driving: does it matter what aspects are automated? *Human Factors*, 54 (5): 747-761.

Dingus, T. A., Klauer, S.G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., Perez, M. A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., Jermeland, J., & Knipling, R.R. (2006). *The 100-Car Naturalistic Driving Study Phase II – Results of the 100-Car Field Experiment*. HNTSA DOT, Report No: HS 810 593

Engström, J., Werneke, J., Bärgman, J., Nguyen, N. and Cook, B. 2013. Analysis of the role of inattention in road crashes based on naturalistic on-board safety monitoring data. In *Proceedings of the 3rd International Conference on Driver Distraction and Inattention*, Gothenburg, Sweden.

Engström, J., Monk, C.A., Hanowski, R.J., Horrey, W.J., Lee, J.D., McGehee, D.V., Regan, M., Stevens, A., Traube, E., Tuukkanen, M., Victor, T. and Yang, D. 2013. *A conceptual framework and taxonomy for understanding and categorizing driver inattention*. US-EU ITS Cooperation, Driver Distraction and HMI Working Group. Available at http://ec.europa.eu/digital-agenda/en/international-transport-cooperation

Habibovic, A., Tivesten, E., Uchida, N., Bärgman, J. and Ljung Aust, M. 2013. Driver behavior in car-to-pedestrian incidents: An application of the Driving Reliability and Error Analysis Method (DREAM). *Accident Analysis and Prevention*, 50, 554-65.

Flach, J.M, Smith, M. R.H., Stanard, T. and Dittman, S.M. 2004. Collisions: Getting them under control. In G.J.P Savelsbergh (Ed.) *Time to contact*, Elsevier.

Franconeri, S.L., and Simons, D.J. 2003. Moving and looming stimuli capture attention. *Perception and Psychophysics*, 65, 999-1010

Horrey, W.J., Wickens, C.D. & Consalus. K.P. 2006. Modeling Drivers' Visual Attention Allocation While Interacting With In-Vehicle Technologies. *Journal of Experimental Psychology: Applied*, 12(2), 67–78

Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D.J. 2006. *The impact of driver inattention on near-crash/crash risk: An analysis using the 100-Car naturalistic driving study data*. US Department of Transportation.report No. DOT HS 810 59

Liebermann, D.G, Ben David, G., Schweitzer, N., Apter, Y., Parush, A. 2007. A field study on braking responses during driving. I. Triggering and modulation. *Ergonomics*, 38:9. 1894-1902

Markkula, G. submitted. Modeling driver control behavior in both routine and near-accident driving. Submitted to the 2014 Human Factors and Ergonomics Society Annual Meeting.

Lee, D. N. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception, 5,* 437–459

Näätänen, R. & Summala, H. 1976. *Road User Behavior and Traffic Accidents*. Amsterdam: North Holland.

Purcell, B. A., Heitz, R. P., Cohen, J. Y., Schall, J. D., Logan, G. D., & Palmeri, T. J. 2010. Neurally constrained modeling of perceptual decision making. *Psychological Review*, *117*(4), 1113–1143.

Rensink, R.A. (2002). Change Detection. *Annual Review of Psychology,* 53, 245-77

Schneider, W., Dumais, S.T. and Shiffrin, R.M. 1984. Automatic and control processing and attention, in R. Parasuraman and D. R. Davies (eds), V*arieties of Attention.* London: Academic

9 Research questions for Vulnerable Road users

9.1 Research questions for the analysis of drivers interacting with cyclists and pedestrians (T4.4.2)

Background of the analysis

Cyclists and pedestrians are active but also VRUs. Active in the sense that they use their muscles to transport themselves, and vulnerable as they are physically unprotected. Because of the latter, they have a high risk of becoming seriously injured when involved in a crash, in particular when colliding with a (much heavier) car, van or truck (ETSC, 2012). Whereas in the last decades the safety of car occupants has substantially been improved, the safety of pedestrians and cyclists has seen far less improvement (ETSC, 2012). As a result, the share of pedestrians and cyclists in the total number of road casualties is growing (Reurings et al., 2012; Steriu, 2012). For example, in the Netherlands, cyclists now account for about a quarter of all road fatalities and for more than half of all severe injuries. Most pedestrians and cyclists are killed in urban areas at intersections, often in collisions with motorised traffic (Reurings et al., 2012). Although in-depth crash investigations provide information about the actual crash itself (e.g., Otte et al., 2012), these studies provide little information about the safety critical interactions between cyclists and car drivers that precede these events. These safety critical interactions contain information about how these interactions differ from 'safe interactions', why some actions evolve into a crash and finally which factors prevent near-crash situations from turning into a crash. That type of information is a precondition for the design, selection and implementation of effective countermeasures.

RQN4.1: What characterizes Safety Critical events (SCEs) involving motorised traffic and cyclists at intersections?

Which analysis will be performed?

This research question describes the characteristics of SCEs of involving motorised traffic and cyclists at intersections. At the moment it is uncertain how much SCEs in this category will be collected. If the database will contain a low number of SCEs for this specific situation, a descriptive analysis will be performed. If a high number of SCEs for this specific situation will be collected, a more structured analysis will be performed focussing on the contributing factors the led to the SCE.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?

The design for RQN4.1 will be developed based on the number of SCEs available in the naturalistic driving database at a later stage.

Which SCEs are relevant for the research question? How long are the events?

RQN4.1 will analyse SCEs derived from two different sources:

1. SCEs from WP 4.2.1 involving cyclists ('involving' needs to be defined further)
2. VRU warnings generated by the Mobile Eye system

Which variables are relevant for this research question?

The following list gives an overview of the variables required for answering the mentioned research questions (Table 11Table 4).

Table 11: Key variables in the analysis of RQN4.1

Variable	Description	Source	Type
DriverID	The ID of the driver	Directly from DAS	Measure
TripID	The trip ID	Directly from DAS	Derived Measure

Time of day	The rough time of day (morning, noon, afternoon, evening, night)	DAS	Derived Measure
Weather condition	The rough category of weather (Sunny, rain, fog, snow)	From Video	Video Annotation
Speed	Continuous measure of the speed of the vehicle (km/h)	Directly from CAN	Measure
Distance	To determine position on intersection (begin and end position on intersection will be derived from video annotation)	Directly from CAN	Measure
At Intersection	When driver passes an intersection. Needed to query intersection passes.	Map Matching	Derived Measure
Speed limit	In order to categorise urban intersections by speed limits (50 km/h or 30 km/h or other)	MobilEye, Map Matching	Derived Measure
Urban Area	Indicates if current position lies inside or outside of urban area	Map Matching	Map Matching
Intersection characteristics	All available data from GIS. Those intersection characteristics (including type: T, X, roundabout; traffic control; pedestrian facilities) that are not available from GIS data need to be annotated from video.	Map Matching	Map Matching
Pedestrian presence	Partly from Mobile Eye (to facilitate sample selection for video annotation)	Partly from Mobile Eye (to facilitate sample selection for video annotation)	Derived Measure
Country	In order to filter data by country (France, Germany, Poland)	Directly from DAS	Measure
Vehicle manoeuvre at intersection	In order to filter data by type of manoeuvre at intersection (straight, left, right)	DAS and GPS	Derived Measure
Secondary tasks	Involvement of the driver in secondary task	Video	Video Annotation

How will a sample be selected?

1. SCEs from WP 4.2.1 involving cyclist ('involving' needs to be defined further)
2. VRU warnings generated by the Mobile Eye system

Which sample size is needed?

It is expected that there will be a relatively small number of SCEs in the data, therefore all identified crashes and SCEs between motorised traffic and pedestrians will be included and annotated in order to use them for the analysis. For the baseline a random sample will be drawn. It should be as large as possible but due to annotation resource limitations it should be at least 2-3 times the number of SCEs (for each baseline type, i.e. matched and random).

How will the data be validated?

The SCEs that will be identified by MobilEye and/or by G-forces can then be validated manually by video annotation. Annotators will check if the candidate event indeed was critical. Baseline cases for SCEs with pedestrians will be encountered based on matching cases of intersections and other factors that will be selected. Matching criteria will include: type of intersection (i.e: T, X, roundabout), type of control and priority (signalized, unsignalized, law of the country), speed limit and type of vehicle manoeuvre. The baseline cases will also be video annotated. Video coders will verify that the baseline cases match the cases of the SCEs on the specified selection criteria.

How will the baseline be selected?
For comparison purposes and possible risk calculation, the baseline rate of SCEs of cyclist and motorised vehicle interactions is needed. To make the baseline comparable, baseline cases for SCEs with cyclists will be identified based on matching cases of intersections. Matching criteria will include:

- Type of intersection (i.e: T, X, roundabout)
- Type of intersection control and priority (signalized, unsignalized, law of the country)
- Speed limit (50 km/h or lower)
- Type of vehicle manoeuvre (straight, right turn, left turn).

These criteria will be identified using the variables: "Type Of Road", "Urban Area", "Intersection", "Speed Limit". They can be identified using map matching.

Which variables need to be video coded and how can the coders identify the states of them?
The video annotations for this research question will be decided at a later stage depending on the number of SCEs collected in the dataset.

What possible scientific publications can you foresee based on your analysis?
Scientific publications can focus on the SCEs of cyclists in urban areas, driver behaviour and reaction to conflicting cyclists, and the potential contribution of collision avoidance technologies to the VRUs' safety. The findings from these investigations can be relevant to the following scientific journals:

- (Journal) Accident Analysis and Prevention
- (Journal) Transportation Research Part F: Traffic Psychology and Behaviour
- (Journal) Transportation Research Part C: Emerging Technologies.

RQN4.2: How do car drivers behave at intersections in urban areas where they might encounter cyclist? Which 'external' factors (e.g. intersection design) modify those behaviours?

This research question will study the 'normal' driving behaviour of drivers that might encounter cyclists at intersections in urban areas when making a specific manoeuvre (e.g. driver is making a left turn and the cyclist coming from ahead is travelling straight).

Background of the analysis
See the beginning of section 9.1.

Refining of research question
Driver behaviour will be studied in terms of gaze behaviour and speed behaviour. The interaction between motorists and cyclists intersections will be studied. In particular, the driver's left hand turn in relation to an oncoming crossing bicyclist will be the main point of interest. Different intersection characteristics and their effects on driver glance and speed behaviour will be compared, and a comparison of situations with and without VRUs will be made.

Regarding the intersection situation in which the car driver turns left and may be confronted with an oncoming VRU, the most task-relevant information arises from the forward roadway. VRUs may approach from this direction, in response to which the driver may have to yield in order to avoid a collision. Therefore, the expectation is that we will find more and longer glances to the forward traffic scene in situations with a VRU, as well as a shorter Intersection Gaze Release Time (IGRT) when compared to situations without a VRU.

IGRT is basically an indicator of attention allocated to possible threats ahead, with low IGRT values indicating more attention to possible threats ahead.

We also expect to find an effect on glance behaviour by comparing situations in which the car driver has the right of way to the VRU and vice versa. The reasoning behind this is that expectations elicited by certain cues in the road infrastructure (e.g. yield lines such as "shark's teeth", a series of white triangles indicating traffic priority) play an important role in influencing a driver's behaviour. Therefore, when a car driver is confronted with situations in which it is made clear that he or she does not have precedence, it is to be expected that more attention will be allocated to traffic coming from the direction that does have the right of way. Situations in which the VRU has the right of way are thus expected to lead to a longer total duration of forward glances and a shorter IGRT than situations in which the car driver has precedence.

A distinction between several levels of VRU facilities is also made, where we distinguish between situations with no VRU facilities, situations with bicycle lanes and situations with separate bicycle tracks (uni- and bidirectional). Previous (naturalistic driving) research done by Twisk et al. (2012) and Haupt et al. (2013), show that the presence of crossings for VRUs may lead to slower vehicle speeds and higher glance frequencies. Intersections with VRU facilities may, from a driver's perspective, be judged as more probable to contain potential hazards to the driver than intersections with no VRU facilities. Drivers making a left turn on an intersection containing a VRU facility are expected to adapt their glance behaviour and actively search for these potential hazards and may direct their gaze to the location with the highest task-relevant information, being potential hazards on the forward roadway. We expect that situations with separate VRU facilities will result in more glances forward and a shorter IGRT, compared to situations with no VRU facilities.

Finally, we hypothesise that intersection priority situation has an effect on the driver's visual behaviour. Intersections that have no signals or signage usually have clear sight lines and may cause the driver to form a relatively quick judgment on the presence of threats from oncoming traffic. Traffic light regulated intersections will usually be busier, drivers will therefore have a worse line of sight and may spend more time looking at and evaluating the possibility of danger on the oncoming roadway. We therefore expect to find a positive relationship between the degree of intersection priority control and the amount and duration of glances to the forward traffic scene. Situations with highly controlled intersections are also expected to be coupled with a shorter IGRT, compared to cases with uncontrolled intersections.

Which analysis will be performed?

RQN4.2 will study the interaction between motorists and cyclists on intersections. In particular, the driver's left hand turn in relation to an oncoming crossing bicyclist will be the main point of interest. Different intersection characteristics and their effects on driver glance and speed behaviour will be compared and a comparison of situations with and without VRUs will be made. Please refer to the previous section "Refining of research question" for a more detailed description.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)

A multilevel regression analysis will be performed on the following dependent and independent variables:

Dependent:

- IGRT/Distance
- Glance frequency on intersection
- Glance durations on intersection
- Average speed on intersection

Independent:

- Cyclist presence

    - Present/not present
- Intersection VRU facilities
    - No VRU facilities
    - Bicycle lane
    - One way bicycle track
    - Two way bicycle track
- Priority situation
    - Regulated by law only
    - Traffic signs and road markings
    - Traffic lights allowing partial conflicts
    - Traffic lights not allowing partial conflicts
- Number of intersection arms
- Number of lanes per intersection arm

Which non-SCE events are important for the research question?
Drivers passing intersections in urban areas (speed limit = 50km/h).

Which variables are relevant for this research question?
See Table 11 above.

How will a sample be selected?
All 'events' where drivers pass an intersection in urban areas will be selected using speed limit and intersection information from GIS data. Indicator use will be used to filter out left turn manoeuvres on intersections. If feasible, Mobile Eye data will be used to identify cyclist presence at the intersection. All (or a random sample) the events where the Mobile Eye indicates the presence of a cyclist at the intersection will be manually checked for the manoeuvre the cyclist makes at the intersection. Only oncoming cyclists that pass the intersection straight will be included in the analysis, see Figure 10 for an illustration.

These steps split all events where drivers are making a left turn manoeuvre on intersections into two groups:

- No cyclist present
- Cyclist (going straight on) present

The 'cyclist present' events will be further reviewed for relevance in the analysis. If for example the cyclist has already passed the intersection before our SV enters the intersection, the event might be less relevant for the analysis. A definition for *relevant* interactions of SV and cyclist will be developed.

In addition, a definition for 'no cyclist present' will have to be defined; this definition will describe how to deal with other road users (including VRU's) that interact with the SV in the 'no cyclist present' condition.

For these two groups, all the other independent variables will be video annotated or retrieved from GIS data (e.g. intersection VRU facilities, priority situation etcetera).

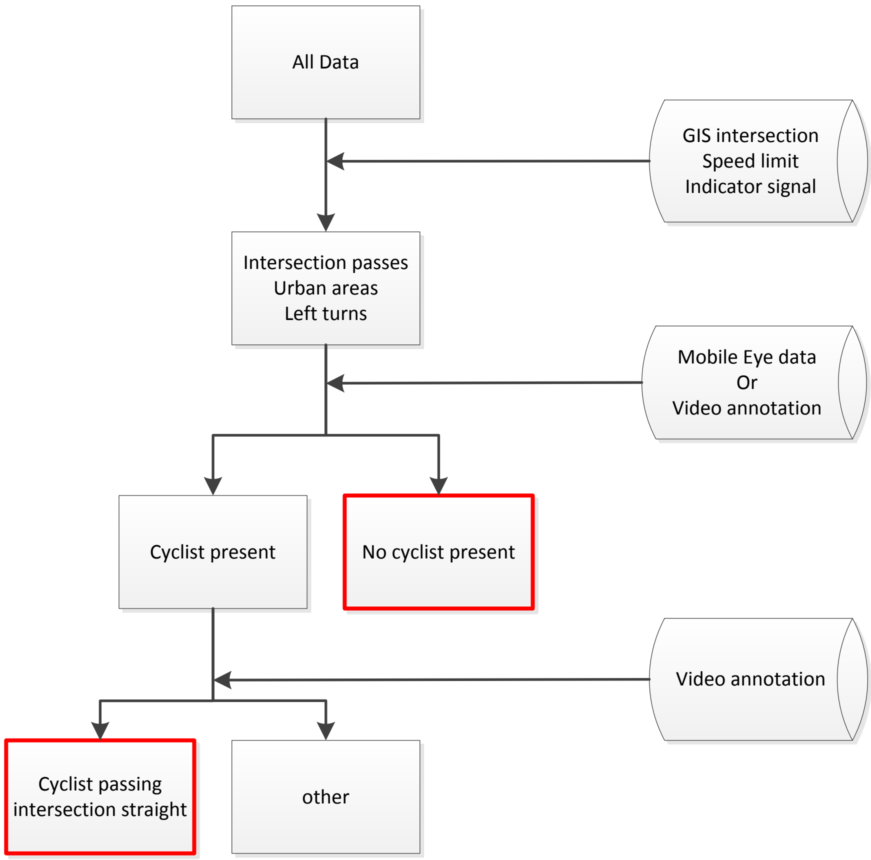

Figure 10: Illustration of sample selection process

Which sample size is needed?

A power analysis will be performed to determine how many cases are needed, per driver, for each of the independent variables in order to perform statistical analysis. In order to analyse all possible interactions between the independent variables, sufficient data for each of the combinations of independent variables would be needed. With the number of independent variables in the current design, this would have a major impact on sampling complexity. Therefore only relevant interaction effects between independent variables will be identified and included in the sampling strategy to ensure sufficient data for analysis.

How will the data be validated?

See this section of RQN4.1.

How will the baseline be selected?

See this section of RQN4.1.

Which variables need to be video coded and how can the coders identify the states of them?

Video annotation for this research question will be a multi-step process:

1. Sampling of relevant events for the analysis (Central annotation)
2. Annotation of intersection characteristics and driver/cyclist interaction on the intersection (Central annotation)
3. Annotation of driver glance behaviour (SWOV annotation)

Please refer to Figure 10 for a description of video annotations in Step 1. In Step 2, the following variables will be annotated:

- Time driver entering/exiting intersection

- Intersection VRU facilities
  - No VRU facilities
  - Bicycle lane
  - One way bicycle track
  - Two way bicycle track
- Priority situation
  - Regulated by law only
  - Traffic signs and road markings
  - Traffic lights allowing partial conflicts
  - Traffic lights not allowing partial conflicts
- Number of intersection arms
- Number of lanes per intersection arm

Video annotation for Step 3 will be performed by SWOV and involves the following variables:

- Glance behaviour of driver
  - Glance to arm *n* of intersection
  - Other glance direction

What possible scientific publications can you foresee based on your analysis?
See this section of RQN4.1.

RQN4.3: What characterizes Safety Critical events (SCEs) involving motorised traffic and pedestrians at intersections?

This research question describes the characteristics of SCEs involving motorised traffic and pedestrians at intersections. At the time of writing it is uncertain how much SCEs in this category will be collected. If the database will contain a low number of SCEs for this specific situation, a detailed descriptive analysis will be performed. If a high number of SCEs for this specific situation will be collected, a more structured analysis will be performed focussing on the contributing factors that led to the SCE.

Background of the analysis
See above at the beginning of section 9.1.

Which analysis will be performed?
The analysis performed for this research question is dependent on the number of collected SCEs involving pedestrians at intersections. If too little SCEs of this particular type are available, a detailed descriptive analysis will be performed. The identification of the SCEs will be determined by the ME identification and/or kinematics thresholds, and the location, i.e. at intersections, will be determined by map matching. Then, manual annotation of video data will be conducted to decide whether the events individuated by the ME are actually safety-critical. The main purpose of analysing the SCEs is to identify the contributing factors and causation patterns that might explain the process that lead to the critical event. For example in the study by Habibovic et al. (2013) by analysing critical events between pedestrians and motorists, it was found that at intersections drivers failed to recognize the presence of the conflict pedestrian due to visual obstructions, and/or because their attention was allocated towards something other than the conflicting pedestrian. The identified SCE candidates will be validated by video annotation. For comparison an appropriate

control/baseline will be selected. In addition, baseline cases will be annotated using the same coding schema.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?
The analysis of this question depends on the number of SCEs involving pedestrians that will be identified. If few SCEs will be identified, statistical modelling would not be feasible. In this case detailed analysis of the conditions that lead to the SCE will be examined, focussing on the exact behaviour of the driver and the pedestrian. However, in case the number of identified SCEs will be reasonable for a statistical modelling, then beside the detailed analysis of the conditions that lead to the SCE, statistical analysis and modelling (such as logistic regression with random effects) will be performed by comparing SCEs to appropriate control/baseline cases. These control/baseline cases will be selected with respect to different variables that may be related to the occurrence of SCEs. A comparison will be conducted in terms of driver behaviour when approaching the intersection.

Which SCEs are relevant for the research question?
RQN4.3 will analyse SCEs derived from two different sources:

1. SCEs involving pedestrians based on G-force kinematics which will be developed as part of Task 4.2.1.
2. VRU warnings generated by the MobilEye system

Which variables are relevant for this research question?
The variables relevant for answering this research question are the same as for RQN4.1 (see Table 11Table 4).

How will a sample be selected?
Our analysis of the interactions of the VRUs will be limited to the following conditions:

- Interactions at urban intersections (identified by “Type Of Road”, “Urban Area”, “Intersection”);
- Day time only (identified by the variable “Time Of Day”);
- Private cars only (identified by driver ID);
- Data from the following countries will be included: France, Germany, Poland (UK will not be included).

SCEs between motorised traffic and pedestrians at intersections will be identified by MobilEye and/or by driver response (G-forces), for example by driver braking and steering thresholds that will be set in advance.

Three samples need to be selected for answering our research questions. The analysis will focus on SCEs, baseline events, and normal interactions between motorised vehicles and pedestrians.

Which sample size is needed?
It is expected that there will be a relatively small number of SCEs in the data, therefore, all identified SCEs between motorised traffic and pedestrians will be included and annotated in order to use them for analysis. For the baseline a sample will be drawn. It should be as large as possible, but due to annotation resource limitations it should be about 2-3 times the number of SCEs (for each baseline type, i.e. matched and random).

For normal interactions between motorised traffic and pedestrians, power analysis will be conducted to determine the needed sample size per cell. A cell contains the following features:

- Type of intersection (i.e: T, X, roundabout)

- Type of intersection control and priority (signalized, unsignalized, law of the country)
- Speed limit (50 km/h or less)
- Type of vehicle manoeuvre (straight, turning right, turning left)
- Crossing direction of pedestrian.

How will the data be validated?
See similar section of RQN4.1.

How will the baseline be selected?
See similar section of RQN4.1.

Which variables need to be video coded and how can the coders identify the states of them?
Video annotations related to the specific interactions between pedestrians and the motorised traffic will be conducted. Some of the variables that need to be video annotated are related to: Pedestrian characteristics such as gender (female, male), age group (for example: child, adult, elderly), and number of pedestrians (1, 2, 3 or more); Pedestrian activity such as the use of nomadic devices (yes/no), walking direction (Entering/ leaving intersection), looking behaviour, yielding behaviour. Also, the behaviour of the driver such as looking behaviour and yielding. The inclusion of these variables and others are dependent on the quality of the videos. Therefore, further refinement and specification of the variables to be annotated will be determined after viewing some of the video samples.

What possible scientific publications can you foresee based on your analysis?
Scientific publications can focus on the SCEs of pedestrians in urban areas, driver behaviour and reaction to conflicting pedestrians, and the potential contribution of collision avoidance technologies to VRUs' safety.
The findings from these investigations can be relevant to the following scientific journals:

- (Journal) Accident Analysis and Prevention
- (Journal) Transportation Research Part F: Traffic Psychology and Behaviour
- (Journal) Transportation Research Part C: Emerging Technologies.

RQN4.4: How do car drivers behave at intersections in urban areas where they encounter pedestrians (normal conditions, i.e. not SCE). Which 'external' factors (e.g., intersection design) modify those behaviours?

This research question will study 'normal' driver behaviour of drivers that might encounter pedestrians at intersections in urban areas when making a specific manoeuvre (e.g. driver is making a left turn and pedestrian is coming from ahead is going straight on). Driver behaviour will be studied in terms speed behaviour and yielding behaviour.

Background of the analysis
See the beginning of section 9.1.

Refining of research question
This question is further divided into two more specific sub-questions:

- When (distance, TTC) and how (steering, braking/accelerating) does the driver first respond to a pedestrian? And how do these characteristics vary as a function of the:
  - (1) Roadway (crossing w/without signals, roundabouts)?
  - (2) Ambient conditions (weather, visibility, glare, traffic, environment type)?

(3) Driver type (age/gender), and condition (hours behind wheel, Passengers presence (their age, gender))?

(4) Direction of the driving (straight, turning right/left)?

(5) Pedestrian type (child, adult, older person) and conspicuity?

- What are the conditions that determine whether the driver will yield to the pedestrian or the pedestrian to the driver in terms of:

  (1) Who gave way to whom (stop/no-stop)?

  (2) Distance and Time-distance of a vehicle from a crossing point (when pedestrian is first detected by the ME)?

  (3) Type of pedestrian (age, gender)/ number of pedestrians (individual/ group and size of group), pedestrian conspicuity, pedestrian condition (disabled, distracted)?

  (4) Driver state (distraction) and behaviour (crossing an intersection, turning at an intersection)?

  (5) Country of driver (ITERATE demonstrated that driving style varies greatly among drivers from different countries)?

  (6) Type of roadway and the characteristics of the built environment?

At this moment it is not clear whether all of these variables would be available in order to be included in the analysis, for example the characteristics of the built environment. Therefore, the questions that will be investigated will depend on the data that will be available.

Which analysis will be performed?

Under this question the focus will be on understanding the driver's behaviour (i.e. accelerating/decelerating, turning, etc.) and reaction (yielding or not yielding) to a conflicting pedestrian. This will be considered in our analysis as the dependent variable. The independent variables will include driver manoeuvre, intersection geometric design, characteristics of the built environment, ambient conditions, driver and pedestrian characteristics, etc. However, at this moment it is still not clear if all of this data will be available. ANOVA analysis and regression models can be assumed to be an appropriate method to analyse the data. However, further investigation into appropriate and more sophisticated analysis methods is still needed.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?

Statistical analysis will be performed taking into account the following dependent and independent variables described in the previous section.

Dependent variables:

- TTC when first driver reacts to a pedestrian and type of action (steering, braking/accelerating)
- Average speed on intersection
- Yielding (who yielded to whom?).

Independent variables:

- Pedestrian presence
  - Present/not present.
- Type of intersection
  - T intersection
  - X intersection

  - Roundabout.
- Priority situation
  - Regulated by law only
  - Traffic signs and road markings
  - Traffic lights allowing partial conflicts
  - Traffic lights not allowing partial conflicts.
- Pedestrian characteristics (age, gender, number of pedestrians, conspicuity)
- Ambient conditions (weather, visibility, glare, traffic, environment type)
- Driver type (age/gender), and condition (hours behind wheel, Passengers presence (their age, gender))
- Type of driving manoeuvre (straight, turning right/left).

Which non-SCE's are important for the research question?
Drivers passing intersections in urban areas (speed limit = 50km/h or lower). Each intersection will be identified by a unique ID so that matching baselines (i.e. when the driver passes the intersection and no pedestrians are present).

Which variables are relevant for this research question?
See similar section of RQN4.1 (see Table 11Table 4).

How will a sample be selected?
See similar section of RQN4.3.

Which sample size is needed?
See similar section of RQN4.3.

How will the data be validated?
See similar section of RQN4.1.

How will the baseline be selected?
See similar section of RQN4.1.

Which variables need to be video coded and how can the coders identify the states of them?
See similar section of RQN4.3.

What possible scientific publications can you foresee based on your analysis?
See similar section of RQN4.3.

RQN4.5: Are the VRU related SCEs identified by the MobilEye (ME) system (ME warnings) correct, relevant, reliable and properly timed?

Background of the analysis
This question will focus on analysing the benefit to the safety of drivers using support/warning systems such as the ME system. Although the ME system is installed in the UDRIVE vehicle instrumentation, the drivers will not receive the actual warnings generated by the system. These warnings however, are logged by the DAS.

This research question could be examined by looking at two measures of reliability: (1) the percentage of the system false positives; (2) system timing advantage, i.e., the time lag between the warning of the ME and the time the driver reacted to the VRU presence. Whenever both of these measures are minimized the system reliability will increase.

For this question, probability analysis and type I error calculation can be considered as an appropriate method for analysis.

Refining of research question
If time and resources allow, the warnings related to pedestrians that are logged from the Mobile Eye will be studied in terms of correctness, relevance, reliability and timing. Most importantly, in terms of contribution to the safety of VRU's, the following two questions will be investigated:

- What are the percentages of the system false positive?
- What is the time lag between the warning of the ME and the time the driver reacted to the VRU presence (system timing advantage)?

9.2 Research questions for Analysis of PTWs behaviour and interactions with other vehicles (T4.4.3)

Background of the analysis
Powered two-wheeler users today account for almost one fifth of the deaths on European roads. While the numbers of killed car drivers and passengers have continuously been decreasing for 40 years, there was no positive trend for PTW. A turn-around started in the 2010s, but accident reduction still lags far behind of what is achieved for other road user groups. At the same time, PTW registrations in Europe strongly increase, which, to some extent, can help explain the development of accident numbers. But it is also an indication for the further deployment of PTW throughout Europe, increasingly as an alternative means of transport used to overcome the problem of urban congestion, a relatively cheap vehicle with low fuel consumption and a fair solution to parking problems.

Research on the field of PTW safety lags far behind research for other road user groups. To a certain extent, this is due to the relatively small share in the accident records (which is about to change significantly). But it is also due to the fact that traditional methods of road safety research did not and still do not offer opportunities to identify the underlying problems as well as they do for other road user groups. PTWs are, hence, a road user group perfectly qualified for being subject to naturalistic research.

UDRIVE's task 4.4.3 tries to focus on the problems, which, by most of the experts on the field are considered most striking in terms of PTW safety; and which other research methods are most unlikely to provide solution for.

RQN4.6: How do drivers and riders differ in speed choice?

This research aims at detecting difference in speed choice between PTW riders and other motorised road users within a collection of specific traffic situations.

Which analysis will be performed?
This activity aims at normal driving; hence there will be intensive cooperation and mutual exchange with the colleagues concerned with task T4.2.4. The first step will be to identify a selection of relevant scenarios, e.g.:

- Full stop
- Left turn, right turn
- Left and right corner at certain radius

- Straight section of predefined length.

These episodes will be identified by the use of GPS data. That is the only practical solution, since GPS data is comparable and available for all three modes (car, truck and PTW). The selection may be done by either comparing GPS position to exiting map data or by looking at trajectories calculated from series of GPS recordings. Further, the relevant part of the episodes have to be identified, e.g. five seconds before, during and five seconds after a left turn manoeuvre.

The second step will be to compare driving speed within these episodes. In addition, the speed can be compared to speed limits where available from map data. As far as the time devoted to this allows, other parameters like acceleration and lateral acceleration (as a function of speed) will be also be analysed.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?
For this research question, the question directly provides the information required here: The different modes (car/truck/PTW) will be compared. Situations will be defined as described above and speed is going to be the relevant parameter.

Which SCEs are relevant for the research question?
This question is not relevant for T4.4.3. To a certain extent, the task will work on the development of triggers for SCEs.

Which non-SCE are important for the research question?
Relevant events will be determined by GPS data. This can either be done by matching map data or by characteristic trajectories of the vehicles. The details will be developed during the analysis.

Which variables are relevant for this research question?
This work will mainly use the variables coming from the GPS, since they are (mostly) comparable between the different modes. Whatever is available and useful in terms of map data and annotation of particular situations will be used as well.

How will a sample be selected?
As indicated above, this research will select samples based on either map data, by trajectories of GPS data or by analysis of dynamic data (e.g. constant speed for xx seconds).

Which sample size is needed?
As explained above.

How will the data be validated?
Validation can be done by variations of the selection criteria, e.g. if an episode is of a designated length or remains within a certain interval of speed that is selected, the width of the interval and the duration of the event can be varied in order to check upon the stability of the result.

Further, external effects on speed choice have to be controlled for: For trucks, the typical “speed limiter speed” (88 to 90 km/h) has to be excluded for some purposes, for others it could be considered. Samples of car and PTW speed events have to checked for whether other vehicles ahead have influenced speed choice. Finally, checks for a reasonable distribution of the events with respect to other variables (e.g. trip duration, location, road type) will be executed.

How will the baseline be selected?
No baseline is needed for this kind of analysis.

Which variables need to be video coded and how can the coders identify the states of them?
It was agreed that there will be no particular video annotation with respect to PTW being present on the scene. This would require full time video annotation, which is most unreasonable compared to the importance of the issue. It currently remains unclear whether Mobileye will also detect PTW riders, besides pedestrians and bicyclists. If this is the case, this would probably result in a large number of encounters. If not, video annotators will flag any presence of a PTW rider in the car- and truck-videos.

What possible scientific publications can you foresee based on your analysis?
For presentation of PTW research results there are two scientific conferences, both held biannually: The ifz[1] Motorcycle Conference in Cologne and the MSF Motorcycle Safety Conference in Orlando (in the uneven years). For RQN4.6, some results could be interesting for accident reconstruction, e.g. having default estimates for typical behaviour of PTW riders in particular situations. Those could be published in the German "Verkehrsunfall und Fahrzeugtechnik", which is a Journal particularly addressing expert witnesses. SCE triggers are most interesting to the PTW research community and should be published in Accident Analysis and Prevention.

RQN4.7: What characterises looking behaviour of PTW riders in left turn manoeuvres?

Left turn manoeuvres serve as an example of manoeuvres with particularly demanding perceptional processes. These are chosen to learn more about how PTW riders organise their perception processes.

Which analysis will be performed?
Building upon the successful identification of left turn manoeuvres, this activity will assess additional aspects. The main task will be done as a 'case by case video-based assessment'. A categorization of glance behaviour has to be developed in advance. The observations are mainly based on head rotation as seen by rotation of the helmet. As previous experience shows, it is unlikely to estimate eye position on the videos due to glare and reflections in the visor. As a second task, a categorisation of left turn manoeuvres will be developed. After annotation, it will be assessed how PTW riders scan for other vehicles present on the scene. Furthermore, dynamic data and looking behaviour will be analysed versus other road users being present. For conclusions, the findings for car drivers and their interaction with pedestrians and cyclists in WP4.4.2 and previous work done by simulator studies with a particular focus on gap acceptance will be considered.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?
There will be less statistical analysis because of the descriptive nature of the research, looking at the videos and trying to identify particular behaviours by PTW riders. Statistical analysis can be done for gap acceptance. There is relevant data from simulator studies within the 2 BE SAFE project to be compared with.

Which SCEs are relevant for the research question?
This question is not relevant for T4.4.3. To a certain extent, the task will work on the development of triggers for SCEs.

Which non-SCE events are important for the research question?
Left turn manoeuvres have to be identified. This can be done by GPS data and map matching.

[1] Institut für Zweiradsicherheit, see www.ifz.de

Which variables are relevant for this research question?
This work will probably develop its own variables; however, those variables will not feed back into the general database. As an input, GPS data and some basic variables of vehicle dynamics will be used. For assessment, behaviours by the rider, behaviours by other road users, some variables to describe the infrastructural context and particularly variables describing the looking behaviour of riders will have to be set up and used during assessment on the basis of rider videos.

How will a sample be selected?
Left turn manoeuvres will either be selected by the general video annotation process, by map data in combination with trajectories or by trajectories alone. In case a number of events too large for full analysis is found, representative samples of the identified episodes will be selected for analysis.

Which sample size is needed?
As explained above.

How will the data be validated?
The key problem is correct identification of left turn manoeuvres. This can be validated by looking at a sample of rides and see whether left turn manoeuvres flagged as subject to analysis are correctly identified.

How will the baseline be selected?
No baseline is needed for this kind of analysis.

Which variables need to be video coded and how can the coders identify the states of them?
It would be very helpful if left turn manoeuvres were identified by the general annotation process. If this is not done, left turns have to be identified later by calculation of trajectories.

RQN4.8: Which circumstances related to rider, infrastructure and trip have an impact on SCE occurrence?

Probably the most difficult task in this research will be identification of SCEs for PTW. Relations to the rider himself, the infrastructure and the trip are most likely to occur and also most likely to facilitate development of a new type of countermeasures.

Which analysis will be performed?
It is most unlikely that the SCE triggers, which will be applied to trucks and cars, have any relevance to PTW. Due to the fact that a PTW is relatively short and relatively high compared to a passenger car, there is a significant pitch angle during braking manoeuvres, which impairs using longitudinal acceleration as a trigger variable. On the other hand, pitch rotation is hardly relevant to cars but may be very relevant for motorcycles.

PTW lean into corners, lateral acceleration is, hence, not useful as a trigger where sudden changes of the lean angle would be interesting information.

This task aims at developing useful triggers, most likely based on individual driving style, which is even more diverse for PTW than for cars. Validation of triggers will be done by video assessment.

Once an SCE definition is successfully developed, the issues currently under suspect of having the strongest impact to PTW (un)safety will be investigated. It is most likely that this will be done by a more qualitative assessment, since the results for SCE triggers will come too late to allow for the setting up of a set of baseline events within the duration of UDRIVE. It has to be considered that the starting point for PTW research is far away from what has already been achieved for cars.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?

There are a lot of indications for how SCEs for PTW can be identified by data on driving dynamics. This is even more difficult, since a lot of relevant sensor data will not be available for PTW, e.g. MobilEye data on the presence of other road users and time headway. There will be no CAN data telling us about actual values of braking, steering, throttle position, etc. Hence, there will be a mutual process of defining triggers for SCEs and validating them by video observation.

Which SCEs are relevant for the research question?

This question is not relevant for T4.4.3. To a certain extent, the task will work on the development of triggers for SCEs.

Which non-SCE events are important for the research question?

Not applicable for this research question.

Which variables are relevant for this research question?

This is probably the most striking problem with PTW. It is still unclear which of the variables or which combination of variables will deliver useful to trigger SCEs. It will probably be a combination of brake use, speed reduction, pitch rate, roll rate and deceleration.

One of the core questions within this work is whether the variables coming from the accelerometers and gyroscopes can be used directly or must be transferred to another coordinate system either parallel to the vehicle or parallel to the road. In that respect, it has to be considered that PTW have one additional degree of freedom in their dynamics, which is the roll angle. On the one hand, the roll angle is probably 10 to 20 times larger than for passenger cars, on the other hand, there is a clear mathematical relation between the roll angle, speed and curve radius.

$$\lambda = \arctan\left(\frac{v^2}{g \times R}\right)$$

wherein: $\boldsymbol{\lambda}$ = roll angle (rad)
v = riding speed (m/s)
g = 9,80665 m/s²
R = instantaneous radius (m)

It will be one of the key questions to which extent these circumstances aggravate analysis and to which extent SCE definitions used for cars can be applied for PTW data analysis.

How will a sample be selected?

This is mainly an exercise in how samples can be selected.

Which sample size is needed?

As explained above.

How will the data be validated?

This is an exercise of validating the accuracy of SCE triggers per se.

How will the baseline be selected?

No baseline is needed for this kind of analysis.

Which variables need to be video coded and how can the coders identify the states of them?

No need for any general video coding here. Identification of triggers will be a mutual process of selecting by certain triggers and validating by video analysis.

RQN4.9: What is the role of timely perception of a rider by drivers?

This is to investigate potential explanations for the most frequent accident type in urban areas involving PTW.

Which analysis will be performed?
This activity is based on driver data. The standard video annotation procedure will flag all episodes where a PTW rider is present on the scene. Video assessment will be done by looking at the glance behaviour of drivers and the general behaviour of the riders.

As a first step, the task will develop a categorisation of driver glance behaviour. The second step will be a categorisation of the rider behaviour and as a third step, a categorisation of riders' appearance with respect to conspicuity, e.g. colours and brightness of their vehicles, clothes and helmets will be made.

The primary goal of the activity is to use the rich information available from naturalistic data to conclude on patterns of perception, i.e. the parameters that ensure whether the riders are perceived by drivers or not depending on the appearance and behaviour.

The episodes identified by the general annotation procedure will be included either fully or to a reasonable share.

In case only a few episodes are identified, this identification will be done by a qualitative instead of a quantitative analysis.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?
"SMIDSY" is the most common accident type involving PTW in urban areas. "Sorry mate, I did not see you", or more scientifically, "looked, but failed to see" (which actually is wrong and should be "looked and saw, but failed to perceive, decide or react properly"). With this background, the analysts will look at the videos out of cars. The general annotation process will deliver any scene where a PTW is present. These scenes will be categorised in a first step, in particular if they are relevant for the analysis of the SMIDSY phenomenon. Typical behaviours of drivers and riders will be analysed. If a reasonable number of such scenes will be available, some quantitative analysis can be executed in order to identify contributing factors to unsafe behaviour of both riders and drivers.

Hence a baseline is not required for any of the analyses to be done within 4.4.3. The analyses will be qualitative, and in some cases descriptive.

Which SCEs are relevant for the research question?
This question is not relevant for T4.4.3. To a certain extent, the task will work on development of triggers for SCEs.

Which non-SCE events are important for the research question?
As described above, this task will focus on scenes where the presence of a PTW was found during the standard video annotation process.

Which variables are relevant for this research question?
This research will look into driver data where the focus is on watching the driver videos for those episodes where PTW riders are present on the scene. Some of the contextual parameters might be considered for the analysis, e.g. driving speed or, if available, map layers indicating intersections, roundabouts, road categories, etc. However, most of the variables used will be solely produced for this task and without any interest to other tasks.

How will a sample be selected?
It is unclear how many episodes in which PTW riders are present will be identified by the general annotation process. Hence there is a clear strategy: See how many episodes are identified. Then either look at all of them or design a selection process. An easy choice for selection process would be simple random sampling. However, it appears to be more useful trying to select the most interesting episodes. That - in case - will require identifying selection criteria, which do not exist now. Such criteria can be developed by starting with a small random sample, looking at commonalities and differences, setting up hypotheses and testing them with another small sample. As an example for a combination of selection criteria, among all episodes with riders present, the most interesting ones could be a) in urban area, b) within 100 m around an intersection c) at daylight d) with the car moving at less than 10 km/h.

Which sample size is needed?
As explained above.

How will the data be validated?
For this analysis a bias is less critical as there is no quantitative analysis which could be biased by the selection of episodes. It could occur that particular categories of relevant events are not at all or in a low number identified by the annotators, however, this will remain a weakness of the analysis since it could only be overcome by full time annotation.

How will the baseline be selected?
No baseline is needed for this kind of analysis.

Which variables need to be video coded and how can the coders identify the states of them?
As indicated above, it is required that presence of PTW on the scene is coded. It would also be helpful if more details are annotated, e.g. if there was a direct encounter between the PTW and the car or truck.

What possible scientific publications can you foresee based on your analysis?
For the presentation of PTW research results there are two scientific conferences, both held biannually: The ifz[2] Motorcycle Conference in Cologne and the MSF Motorcycle Safety Conference in Orlando (in the uneven years). Concerning RQN4.9, it strongly depends on the findings. Infrastructure, driver training, licensing, campaigning, this could all be measures relevant for the results that can be expected out of RQN4.9 and dissemination has to be tailored according to that.

References

ETSC (2012). Bikepal ranking European Traffic Safety Council (ETSC), Bruxelles

Habibovic, A., Tivesten, E., Uchida, N., Bärgman, J. and Ljung Aust, M. 2013. Driver behavior in car-to-pedestrian incidents: An application of the Driving Reliability and Error Analysis Method (DREAM). *Accident Analysis and Prevention*, 50, 554-65.

Otte, D., Jänsch, M., Haasper, C., (2012). Injury protection and accident causation parameters for vulnerable road users based on German In-Depth Accident Study GIDAS. Accident Analysis & Prevention 44 (1), 149-153

Reurings, M.C.B., Dijkstra, A., Twisk, D., Vlakveld, W.P., (2012). Van fietsongeval tot maatregel; kennis en hiaten. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV), Leidschendam

Steriu, M. (2012). Raising the bar: Review of Cycling Safety Policies in the European Union European Transport Safety Council (ETSC), Brussles

[2] Institut für Zweiradsicherheit, see www.ifz.de

Twisk, D. A. M., van Nes, N., Haupt, J. (2012). Understanding safety critical interactions between bicycles and motor vehicles in Europe by means of Naturalistic Driving techniques. Paper presented at the 2012 International Cycling Safety Conference, Helmond, The Netherlands.

Haupt, J., van Nes, N., Risser, R. (2013). Expect the expected. A field driving study on infrastructure systems. Manuscript in preparation.

10 Research questions for Eco Driving

10.1 Research questions for Driving Styles (T4.5.2)

10.2 Research questions for effects of driving styles on eco driving (T4.5.3)

RQN5.1: Does the vehicle power-to-mass ratio affect the driving style?

RQN5.2: How much do drivers deviate from the speed limit in free flow situations, and why?

RQN5.3: Is eco-driving and safe driving correlated, through increased anticipation of road infrastructure and traffic situations?

10.3 Research questions for potential effect of eco-driving (T4.5.4)

RQN5.4: When do driver brake and is it necessary to brake in each instance?

RQN5.5: Is eco-driving an observable characteristic of certain drivers?

RQN5.6: Do drivers shift gear to avoid high engine speeds and high fuel consumption?

Background of the analysis
In eco-driving research the relationship between driving behaviour and fuel consumption is to be analysed. This concerns all the continuous data, not that of specific events, hence the annotation is less relevant for the eco-driving research questions. The availability and quality of the continuous data, on the other hand, is of crucial importance to the research. Annotation, like start-and-end of congestion could be useful, however is not considered at the moment.

Central to eco-driving is the separation of personal driving style from infrastructure and from congestion while driving. The bandwidth of personal driving style is the bandwidth of the eco-driving. The infrastructure and congestion will be the main influence on the fuel consumption during a trip. In the analysis the difficult task is to uncover the remainder, which can be improved by a fuel economic driving style.

The number of continuous signals available in the project is limited. From these signals the forces affecting the driving style must be distilled. The relationship between driving behaviour and congestion is well known, but the degree of congestion is difficult to recover from the signals at hand. Headway is an important signal to be used in combination with the velocity and velocity variations. For infrastructure; bends, junctions, traffic lights, speed limits and lane width are important aspects to be retrieved from the map-data. These affect the driving behaviour, forcing the driver to slow down or even stop.

Refining of research question
The aspects of driving style important for fuel consumption are selected for the analyses. They include: braking, free-flow velocities and gear shifting. All of these are affected by the three forces underlying driving behaviour: infrastructure, interaction with other road users (e.g. congestion) and personal style. The aspects can be studied independently. However, in the analysis the underlying causes must be investigated

conjunctively. For example, if a driver brakes does he (or she) do so because of a traffic light, a vehicle ahead, or because the driver remembered he (or she) left the stove on. Whether the stove was left on cannot be determined, hence personal style is the remainder when all external causes are excluded.

Fuel consumption will vary a lot from driver to driver. Typically there is a 40% difference between the fuel bill per kilometre of the best and the worst. In part this is driving behaviour with the underlying three causes. However, tyre pressure, passengers, luggage, parasitic braking, temperature, road surface, etc. will all play a role. The large variation and the multitude of underlying causes strains the analysis. A lot of data is needed to allow for significant and discriminating results. Therefore all the data is to be used and the data must be as uniform as possible as well as independent of the aspects not covered in this analysis. Furthermore, it must be direct data, not derived, in order not to uncover processing artefacts rather than aspects of the driving itself.

The braking, gear shifting and free flow velocity all have an important impact on the fuel consumption. The total energy lost by braking is affected by congestion and infrastructure first of all, however, the personal style, having limited headway or late braking for bends and junctions can be investigated.

It is uncommon for drivers to shift gears as quickly as prescribed. The delay of gear shifting may occur during firm accelerations or congestion with limited headway. Once personal variations in gear shifting with velocities are established, the correlations with circumstances can be investigated further.

The free flow velocity, in particular at higher speeds on the motorway, is the most important determining factor for high-velocity fuel consumption. Personal style, lane width, etc. in combination with the speed limit at the location will affect the actual velocity driving. Also, the capabilities of the vehicle can affect the chosen velocity.

Some key quantities which will play a role in the investigation:

- Power at the wheels (positive or propulsion, and negative or braking): The safe avoidance of braking is a key part in reducing fuel consumption at low velocities. Hence restricting the power at the wheels is an important part of the investigation
- Engine speed: High engine speeds (not associated with high vehicle speed in the highest gear) is the second most important reason for unnecessary energy loss during driving.
- Degree of congestion: some driving is dictated by other road users. The best available signal is the amount of headway. This signal will be used as a proxy for the degree of congestion. However, headway is also a matter of personal style. These two aspects must be separated.
- The infrastructure: speed limits, traffic lights and bends are basically boundary conditions for driving behaviour. In the case of speed limits of 50 km/h it is not possible to achieve the same fuel efficiency as with an 80 km/h speed limit (Unless driving an electric vehicle or hybrid).

Which analysis will be performed?

The research will mainly consist of correlation studies in multi-regression analysis. All of the data can be included, if uniform. Functional relations between, for example, free-flow velocity, speed limit, lane width and head way can be uncovered. On the basis of these generic relations, the deviations for drivers and circumstances, such as road types, can be uncovered. These are the bandwidths within the data.

The expectation is that the statistical noise will be substantial. There is a need for many proper signals, long time series, and a variety of drivers. Only then can statistical significance be achieved. Hence the research plan consists of four phases:

1. Make the time-series data suitable for a general statistical evaluation of the averages, deviations, and correlations.
2. Make a model for the general prediction based on the analysis in 1

3. Study the residuals of each driver, road type, vehicle category, etc. of the general model prediction of the averages.
4. Determine the significance of the deviation of the residuals and match with observations.

The data determines the remaining analysis, which will lead to the final results.

In order to disentangle the different aspects affecting the driving behavior, much of the analysis will be meta-analysis on as much of the continuous data as possible. Only in this manner can the personal style, which can be described as eco-driving, be separated from parts of driving behavior dictated by the circumstances. With respect to the different research questions the following details will be studied:

RQN5.1: Does the vehicle power-to-mass ratio affect the driving style?
Eventually, only a compact car and a mid-range car model are available in the study. A higher power-to-mass ratio can yield more and more aggressive accelerations. These are not necessarily related to a higher fuel consumption. It is the subsequent braking which causes the increase in fuel consumption. Hence in the analysis the correlation between acceleration and a close-following deceleration is investigated. In principle, this could also be linked to the headway. A short headway and an impatient style may lead to quick successions of accelerations and braking. In some way the bandwidth car-following models and their relation to power-to-mass ratio is investigated. Car-following models explain the manner in which drivers keep a safe distance. It is the core of micro-simulation models. Such models can be derived from present data, with headway available in combination with vehicle velocity.

RQN5.2: How much do drivers deviate from the speed limit in free flow situations, and why?
The correlation between local speed limits and free-flow velocity is central in this research question. The free-flow situation is derived from headway and limited infrastructure like bends, junctions and traffic lights. Some drivers will have a personal speed limit, others may fluctuate with time of day, routine, or distractions. This will follow from the velocity in combination with speed limits, once the free-flow conditions are determined from other signals. All these effects are to be investigated.

RQN5.3: Are eco-driving and safe driving correlated through increased anticipation of road infrastructure and traffic situations?
The scoring of drivers on eco-driving styles and safety driving styles is the basis to establish a correlation between the two. However, the scoring on eco-driving styles can only be done once external influences are corrected for. These can be established by filtering out average velocity and necessary slowing down and stopping for bends and traffic lights. The remainder is then analysed for additional fuel consumption for braking, driving in a low gear and driving at a high velocity. The amount of coasting (i.e. slowing down without braking) is another good measure for eco-driving. If this is combined with a reduced amount of hard braking, it is a clear signal for a combination of safe driving and eco-driving.

RQN5.4: When do drivers brake, and is it necessary to brake in each instance?
In many cases braking is necessary and dictated by circumstances. Only a smaller amount of braking, in particular in congested traffic, can be avoided. The avoidable braking is braking while there is enough headway, no obstruction, no bends or no traffic signals. The filtering of the remaining braking behaviour is the basis for the study of variation in personal style. Another aspect of personal style is the headway kept at each velocity, and its association with braking. Shorter headway, which in many cases may turn out to be unnecessary, will probably lead to more braking. This is part of the investigation on braking behavior.

RQN5.5: Is eco-driving an observable characteristic of certain drivers?
Apart from linking safe driving with eco-driving, the scoring of different drivers on eco-driving, consistently or intermittently, is at the core of understanding naturalistic driving behavior. The braking, the engine speed or up-shifting and the velocity are key data. However, drivers should be compensated for circumstances such as heavy congestion, bendy roads and traffic lights. A general correlation with headway, bends and infrastructure allows one to compensate for, or at least separate into, different circumstances.

RQN5.6: Do drivers shift gear to avoid high engine speeds and high fuel consumption?

The part of the driving style which is most clearly distinguishable as personal is gear shifting. It is less influenced by circumstances, however may be affected by the power-to-mass ratio of the driven vehicle. With a higher power-to-mass ratio it is easier to follow traffic in a higher gear. The most persistent eco-driver will always shift gear below a certain engine speed. The subsequent acceleration may be limited by the lack of vehicle driveability. This may not necessarily be a bad thing, as it smoothens the traffic flow. The correlation between engine speed, velocity and transient driving are most easily studied with the signals available, especially after the other research questions already laid the groundwork of separating out the most important external circumstances affecting the driving style.

What conditions are you planning to compare or include in your model (basis for statistical analysis/model)?

The principle is to include as many relevant continuous signals as possible in the first stages of the analysis. If the signal turns out to be uncorrelated to other signals or faulty, biased, or not uniform, it will either be repaired or removed.

Which events are important for the research question? How long are the events?

Unlike in many other parts of the UDRIVE project, no event data is used in the eco-driving part. The relevant fuel consumption is taken over the whole trip. This means all data is relevant. The selection of data will be on the basis of braking, free-flow velocities and gear shifts. The baseline is therefore the average behaviour, and the research focusses on the deviations from the averages and the correlation with other available aspects.

For each measure relevant to your analysis describe how necessary performance indicators will be calculated.

The signals (1 Hz or higher sampling for speed and response time) relevant for eco driving include:

1. Pedal positions (accelerator, brake, clutch)
2. Headway
3. Gear position
4. Engine speed
5. Vehicle speed
6. (Lateral) accelerations
7. Lane width
8. Speed limit
9. Road type, urban
10. Degree of congestion
11. Infrastructure: junctions, roundabouts, traffic lights
12. Road gradient and road curvature
13. Cabin noise levels, view obstruction, or other distractions which are continuously monitored

Other continuous signals, which are available, will be considered for an initial correlation study.

How will the data be validated?

Statistical evaluation: averages, variances, covariances, auto- and cross-correlations are central to the analysis. The statistical analysis determines the significance, as this is the main validation of the data. Secondarily, from experience it is known that part of the data will have invalid values for certain signals. In many cases this data is removed, possibly for later use in partial studies once the overall baseline and correlations are established.

How will the baseline be selected?
All valid continuous data together is considered the baseline for the eco-driving research questions.

What possible scientific publications can you foresee based on your analysis?
In Europe, in particular with upcoming emission and CO2 legislation, the actual normal driving on the European roads is of utmost important to determine the boundaries of legislation and the effectiveness of policy measures. It is expected that the outcome of the UDRIVE eco-driving study can play an important role to set the new baseline for the effectiveness of policies and technological measures. The results will be made available via reporting through the appropriate forums.

11 Conclusions

The preliminary analysis plan builds upon the work done in the D11.1 about the initial research question and functional requirements. A set of prioritized research questions were developed by taking into account the new information about the available measures and the available resources. Partners from SP1 and SP4 where involved in writing this deliverable. By describing the planned analysis on the SP4 task level for each research question, this represents a bridge from SP1 to SP4 activity. The contents of this document will allow the analysts to reach a better understanding of the planned activities and identify possibilities for harmonisation.

While the first outline of the analysis is described in this report, the actual analysis may still be subject to change in further development of the project. The final analysis will depend heavily on the quality and amount of data that will be available in the end. This means the content of this document will be refined in the upcoming analysis plan later in the project.

12 List of abbreviations

ADAS	Advanced driving assistance system
DAS	Data acquisition system
DOW	Description of work
POV	Principal other vehicle
PTW	Powered two wheelers
IGRT	Intersection gaze release time
ME	Mobile Eye Camera
MCA	Multiple correspondence analysis
NDS	Naturalistic driving study
SCE	Safety critical event
SV	Subject vehicle
TEORT	Total eyes-off-road time
TTC	Time-To-Collision
VRU	Vulnerable road user

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