Final framework specification for

Evaluation Framework for Commercial Vehicle Safety Systems and Services (EFrame)

Authors: Johan Engström (Volvo) and Claudia Wege (Volvo)

Project within 2013-01306 FFI

Introduction

The objective of the EFrame FFI project was to develop a structured framework for traffic safety evaluation in an industrial (commercial vehicle manufacturer) context. The resulting framework facilitates more efficient development of crash/injury countermeasures by identifying and focusing on the most important safety (crash) problems, providing a toolset for analyzing crashes and estimating the potential and actual effectiveness of safety systems and services and, finally, identifying the data sources needed to perform these analyses. A general overview of the project and its results can be found in the Final Report (Engström and Wege, 2016)

The project started with identification of the general types of safety evaluation needed from an industrial development perspective (the Evaluation Use Cases, EUCs). The EUCs helped to keep the project focused, in spite of its broad general scope, and constituted the basis for all remaining work in the project. The following EUCs were defined:

EUC 1a: Following up the safety performance of Volvo Group trucks over time: The key goal of this type of evaluation is to be able to follow up the safety performance of Volvo's products already on the market (i.e., retrospective analysis). A specific example would be to compare the general safety performance (e.g., the risk for occupant injury) in Volvo trucks compared to competitors. Another would be to estimate the retrospective safety benefits of new safety features (e.g., the reduced crash risk offered by Advanced Emergency Braking, AEB)

EUC 1b: Understand which safety system or service has the highest potential benefit for heavy goods vehicles on specific markets: The main goal here is to be able to identify the key safety problems relevant for Volvo products on a specific market using available safety data for (e.g., national crash statistics), and use this analysis to identify which safety features offer the highest potential safety benefits on that market.

EUC 2: Definition of target scenarios and use cases for passive and active safety systems (as a basis for functional requirements): The aim here is to clearly identify and define the problems (injuries, crashes and their contributing factors) that safety systems and services are supposed to address (i.e., target scenarios defining crash statistics and crash/injury causation mechanisms), and to specify *how* the crash scenarios should be addressed (i.e., use case: how crashes and/or injuries are intended to be prevented by the safety system/service). This analysis should then form the basis for functional requirement specification in system development as well as the starting point for predictive (prospective) safety/cost benefit evaluation (EUC3).

EUC 3: Predictive (prospective) safety/cost benefit assessment: The aim of this type of analysis is to predict safety and/or cost benefits (e.g., crash reduction potential) of products and services not yet on the market as a key input to product planning.

EUC 4: Iterative evaluation during development: This represents the need to evaluate a system/service effectiveness during development, for example, in order to select between candidate system designs or to tune parameters (e.g., in a warning algorithm).

EUC 5: Evaluating the safety performance of a customer fleet or specific systems/services: The aim here is to be able to evaluate the safety performance of a customer fleet (e.g., in terms of crash rate or in terms of costs) and the potential for specific improvements (for the customer, e.g., in terms crash and associated cost reductions) offered by safety systems and services. This should also account for non-traffic crashes (e.g. at a customer site or in a closed logistical area like goods distribution at harbors).

Figure 1 maps the EFrame Evaluation Use Cases to the general Volvo safety development process (the “circle of life”).

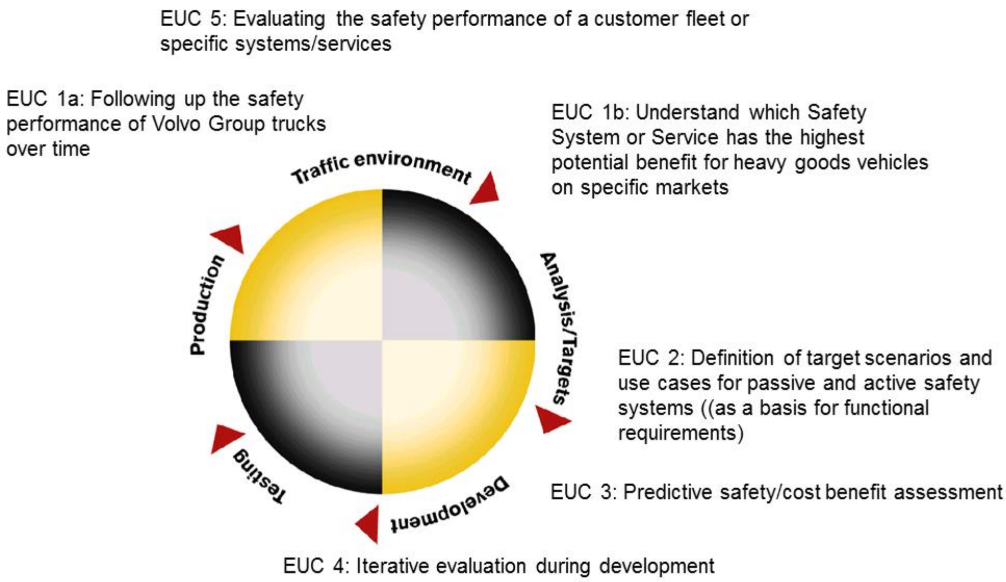

Figure 1 Illustration of the EFrame EUCs within the general Volvo safety development process (the “circle of life”)

Based on the Evaluation Use Cases, an initial sketch of the evaluation framework was developed in WP1. This was followed by a comprehensive state-of-the-art review of existing data sources and road safety analysis methodologies that could potentially be used as components in the framework (WP2). Based on this, existing methods were adapted, or novel methods developed, to address the Evaluation Use Cases (WP3). Finally, the methods adapted/developed in WP3 were applied to a set of concrete evaluation test cases in order to demonstrate the framework and identify needs for further improvement (WP4). Based on this, the final framework was defined. The objective of the present report is to describe the final version of the framework.

The report starts with a general overview of the framework. Next the methodology for defining target scenarios and use cases, which can be considered the “heart” of the framework, is outlined. This is followed by descriptions of methods for crash- and safety effectiveness analysis respectively. Finally, the types of data sources required for supporting the framework are outlined.

Framework overview

Figure 2 provides a high-level illustration of the evaluation framework and its four general components. *Data sources* refer to all sources of data (e.g., crash, behavior, exposure) that is needed to address the evaluation use cases. *Analysis* refers to the extraction of different types of information from the data. This may, for example, involve high-level analysis of crash statistics, detailed investigation of crash and/or injury causation mechanisms or the investigation of safety problems at a specific customer. The analysis result can sometimes be an independent output in its own right, but is generally conducted with the goal to define *target scenarios and use cases*.

The definition of target scenarios and use cases can be seen as the heart of the framework and is proposed to underlie all future safety feature development and evaluation at Volvo. Target scenarios refer to definitions of the problems that safety features are supposed to address (e.g., injuries, crashes or certain behaviors leading to crashes) and use cases describe *how* these problems are supposed to be addressed by safety features. The use cases should then serve as input to the specification of functional requirement at the beginning of the development process, but also as the basis for *effectiveness analysis*. Effectiveness analysis here refers to the prospective or retrospective analysis of the (potential or actual) effectiveness of different safety systems or services, for example, in terms of the proportion of target crashes prevented. This may involve counterfactual (”what-if”) simulation for re-playing the target scenarios with an active safety function and/or analytic methods (e.g., dose-response functions) for estimating potential reductions in injury risk. Finally, the results from the effectiveness evaluation can be scaled up to national crash statistics to obtain estimates of safety benefits on the national scale (e.g., number or severe injuries prevented per year). The results from the effectiveness analysis are envisioned as a key input to prioritization between safety features, for example in product planning.

The framework can thus be regarded as a toolbox for safety evaluation at Volvo, but also as a guide for how to use the data sources and analysis tools in a structured and efficient way. In the following sections, the framework components (tools and data sources) are described in further detail, with pointers to the project reports providing more detailed descriptions. We will begin with the definition of target scenarios and use cases as this is the “heart” of the framework, as the main target for crash analysis and the starting point for effectiveness analysis.

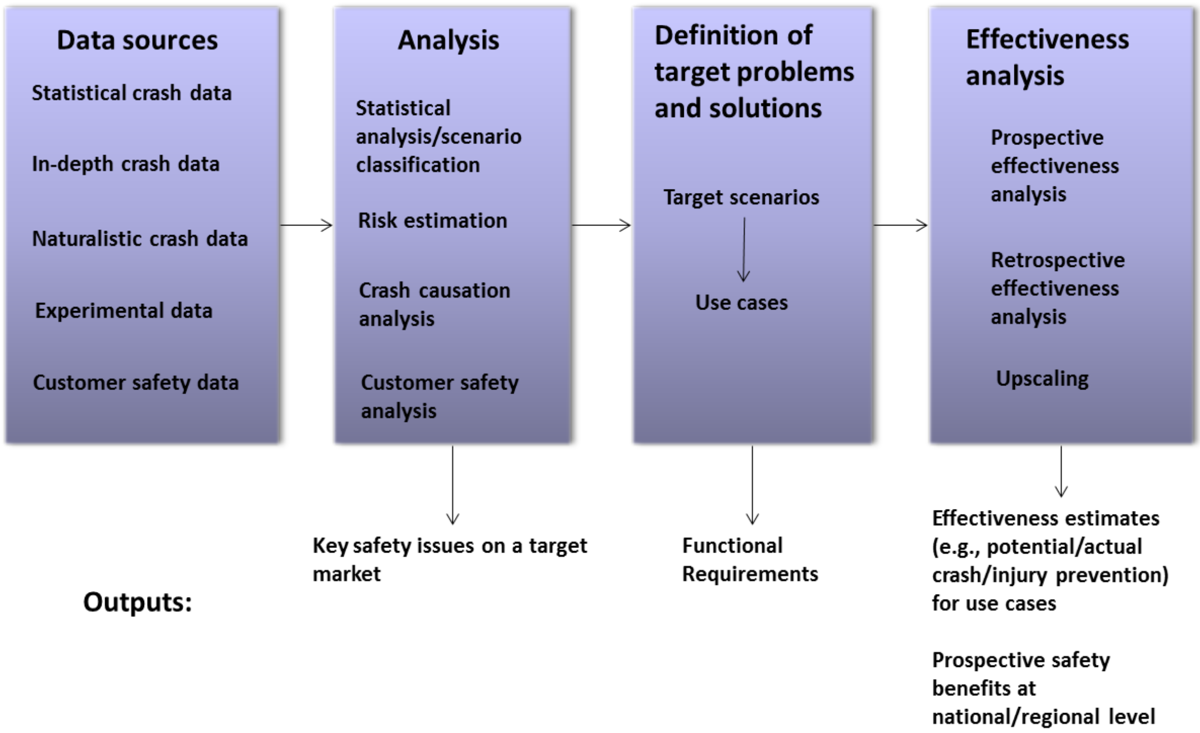

Figure 2 High-level representation of the safety evaluation framework

Definition of target scenarios and use cases

As stated above, the definition of target scenarios and use cases is intended as the logical starting point for any safety development and evaluation at Volvo. The general intended role of target scenarios and use cases in safety system development is schematically illustrated in Figure 3.

When envisioning a new safety feature, it is critical to be clear about the safety problem that the feature is supposed to address, that is, the target scenario. The definition of the target scenario should thus be based on available data and knowledge on, for example, the prevalence of crash types and their underlying causal mechanisms. Based on this, the next step is to define precisely *how* the safety feature is intended to address the safety problem (the use case). Here, it is also critical to consider enabling technologies and legal requirements which may impose further constraints on the possibilities to realize the use case. The use cases then provide the starting point for technological development (in terms of functional requirements), all testing activities as well as (prospective and retrospective) effectiveness evaluation. The present methodology for target scenario and use case development was based on the method previously developed in the InteractIVe EU-funded project (Engström, 2010a, b). See also the relevant state-of-the-art review performed within the present project (Engström, 2014).

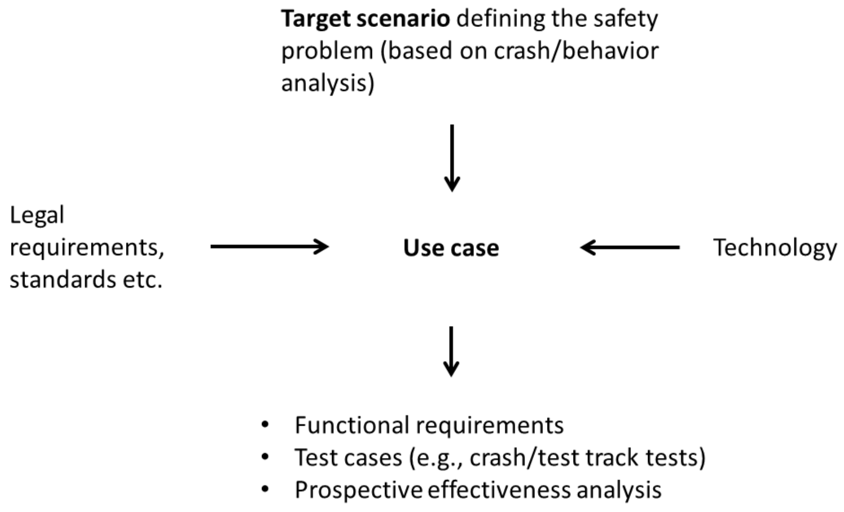

Figure 3 Schematic illustration of the general role of target scenarios and use cases in safety feature development and evaluation

While the principles outlined in Figure 3 are adhered to within AB Volvo (and probably most other vehicle manufacturers) in a general sense, what is proposed here is a more structured way of working based on clear cut definitions of target safety problems and solutions as the basis for development, ensuring (1) that development of safety features focuses on real safety problems and (2), that the proposed solutions are effective in addressing these problems.

The general proposed logic for defining target scenarios and use cases is illustrated in Figure 4 (this represents a slightly modified version compared to the original scheme proposed in the Task 3.4 report; Engström, Piccinini and Törnvall, 2015). At the highest level, each target scenario and use case is associated with a *general crash type*, which corresponds to the general crash typologies found in national crash databases, or in the Volvo ART Report (e.g., rear-end, run-off-road etc.). Target scenarios are then defined separately for the three main crash development phases: (1) crash, (2) conflict and (3) non-conflict, using pre-defined templates. For a further definition of these three phases, see (Engström, Piccinini and Törnvall, 2015).

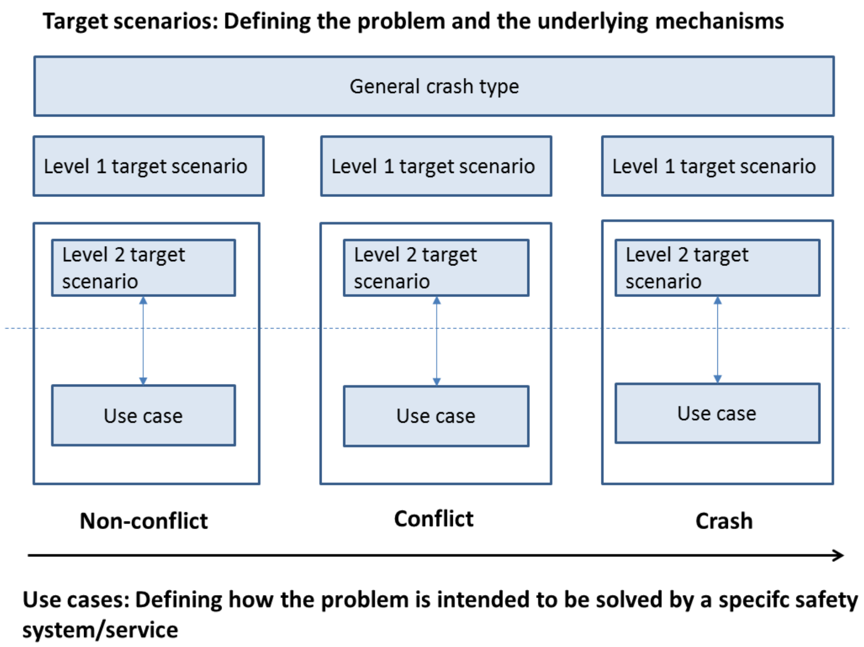

Figure 4 General logic behind target scenario and use case definition

The Level 1 target scenarios represent high-level crash types, within the general crash type (e.g. , rear-end & lead vehicle stationary). Level 1 target scenarios are typically derived from national crash data (e.g., STRADA in Sweden or NASS-GES in the US) or statistically representative in-depth crash data (e.g., GIDAS). An example of a Level 1 target scenario specification for the conflict phase is given in Figure 5 (adopted from the Task 4.3 report, Engström, Bärgman and Lodin, 2016).

<table>
<tr><td rowspan="2">Level 1 target scenario</td><td colspan="3">Name</td><td colspan="3">Definition</td></tr>
<tr><td colspan="3">Co1.1 SV following LV</td><td colspan="3">LV stopped + LV decelerating in Woodrooffe et al. (2012)</td></tr>
<tr><td>General crash type</td><td colspan="6">1. Rear-end striking truck</td></tr>
<tr><td rowspan="2">Source</td><td colspan="2">Databases used</td><td colspan="2">Region covered</td><td colspan="2">Time period</td></tr>
<tr><td colspan="2">GES, TIFA, LTCSS, State reports from NC and CA (Woodroofe et al., 2012)</td><td colspan="2">USA</td><td colspan="2">2003-2008</td></tr>
<tr><td>Typology</td><td colspan="6">Based on Woodrooffe et al. (2012). Performance Characterization and Safety Effectiveness Estimates of Forward Collision Avoidance and Mitigation Systems for Medium/Heavy Commercial Vehicles. US DOT. UMTRI-2011-36. LV stopped excludes cases where the vehicle was stopped already 100 m prior to impact which are categorized as LV fixed; see Woodroofe et al., 2012).</td></tr>
<tr><td rowspan="6">Statistics</td><td colspan="2" rowspan="2">Prevalence</td><td>Frequency per year</td><td>% of crashes in L1 target scenario</td><td>% of crashes in general crash type</td><td>% of all truck crashes</td></tr>
<tr><td>20234</td><td>100%</td><td>63%</td><td>5%</td></tr>
<tr><td rowspan="4">Injury distr.</td><td>No injuries (property damage only)</td><td>13391</td><td>66%</td><td>42%</td><td>3%</td></tr>
<tr><td>Slight injuries (AIS1+)</td><td rowspan="2">6196</td><td rowspan="2">31%</td><td rowspan="2">19%</td><td rowspan="2">1%</td></tr>
<tr><td>Severe injuries (AIS2+)</td></tr>
<tr><td>Fatalities</td><td>47</td><td>0.2%</td><td>0.2%</td><td>0.01%</td></tr>
<tr><td>Description of typical scenario</td><td colspan="6">A truck is going straight on a freeway with a posted speed limit of 70-90kph following a lead vehicle. There is daylight and the road is dry. The driver temporarily looks away from the road at the moment when a lead vehicle initiates braking due to a traffic queue ahead. Due to the inattention, the driver reacts late to the closing lead vehicle. Alternatively, the FV driver is following with a short headway (relative to the vehicle's braking capacity) with the eyes on the road when the LV brakes suddenly.</td></tr>
<tr><td>Key crash causation factors</td><td colspan="6">Inattention (mainly driver distraction but also drowsiness to some extent); close following; high speed in fatalities and severe injuries.</td></tr>
<tr><td>Key injury types</td><td colspan="6">Head/chest trauma, whiplash</td></tr>
</table>

Figure 5 Example of a Level 1 target scenario for the conflict phase

Each Level 1 target scenario may be associated with several Level 2 target scenarios. The Level 2 target scenarios define specific causal mechanisms behind the general crashes and/or injuries defined at Level 1. This is typically based on in-depth crash/injury data for the crash phase, naturalistic crash analysis for the conflict phase and naturalistic driving behavior analysis for the non-conflict phase. Examples of Level 2 target scenarios for the crash, conflict and non-conflict phases are shown in Figure 6, Figure 7 and Figure 8. As is seen in these examples, the Level 2 target scenarios are defined in terms of narratives describing causal mechanisms, although the exact formats (defined by the templates) differ between the three phases. For the crash phase, the focus is on injury mechanisms, for the conflict phase on crash causation mechanisms and for the non-conflict phase more distal (e.g., behavioral or organizational) causes for crashes. The narratives may be complemented by other types of representations (e.g., sketches and interaction diagrams; see e.g. Engström et al., 2010a) but, to keep things as simple as possible, it was agreed to use the narrative format as the basis for Level 2 descriptions in the present framework.

TSCr1.1.3 (48%): Non-intrusion based injury mechanisms

A heavy duty truck collides with the front in a small angle, 0–±30° towards another vehicle or an obstacle. The impact is covering the driver area but without large intrusions into cab in front of driver. This causes deceleration of the driver who moves forward until the seat belt couples the driver to the seat (if belted). The forward motion of the driver causes contact between the steering wheel and the chest of the driver. The chest will be compressed and thereby be exposed to an injury risk.

Figure 6 Example of a Level 2 scenario for the crash phase (from the Task 4.4 report; Thorn, Törnvall and Thomson, 2016)

TS Co1.1.1 Impaired reaction due to eyes off road while following	
1. Conflict development	
a. The pre-conflict behavior/state of the collision partners	The SV driver follows the LV at a relatively constant speed and time headway. The speed varies over a wide range with an average of about 40 km/h. The headway is typically in the range of 1.5-3 seconds (shorter headways are uncommon).
b. The critical action (if any) that induces the conflict	An obstacle suddenly appears ahead of the POV which then brakes unexpectedly with a deceleration rate typically in the range of 3-7 m/s^2. Alternatively, the SV brakes with no obstacle ahead, for example to exit the road or yield at a traffic light.
2. Corrective action	
a. The nature and timing of the involved road-users' corrective actions	The SV driver's response to the conflict is delayed due to the driver looking away from the road (typically between 1-3 seconds) at the moment looming cues, indicating that the LV is closing, starts to appear (angular expansion rate ~>0.01 rad/s in good visibility conditions). The SV driver initiates an avoidance maneuver (typically braking) within 1 second after looking back to the road (with an average of about 0.5 seconds), given that looming cues are present. Steering avoidance may occur later if there is sufficient time and space to allow for it. If the SV driver does not look back in time, no avoidance maneuver is initiated
b. The effect of the corrective action (e.g., in terms of lost traction or vehicle stability)	The driver decelerates with maximum deceleration, which ranges between 5-8 m/s^2 depending on vehicle's braking capacity. Unusually weak maximum deceleration (below 5 m/s^2; e.g. due to skidding or sub-standard brakes) is not common in this scenario.
c. Any pre-conflict factors that influences (a) or (b)	For various reasons (missing/misleading contextual cues, LV driver behavior, etc.), the driver does not expect that the LV was about to brake and thus feels that it is safe to look away. The SV driver may also be strongly motivated to finish a secondary task, which may override the inhibitory motive to maintain the eyes on the road to keep track of the LV.
3. Crash impact	
a. Location	The SV hits the LV in the rear center or to the sides if attempting steering avoidance.
b. Severity	Usually result in significant material damage (level S3), but can result in higher-severity outcomes for high initial speeds and a long off road glance, where the driver reacts late or not at all.

Figure 7 Example of Level 2 target scenario for the conflict phase (from the Task 4.3 report; Engström, Bärgman and Lodin, 2016)

L2 Target NCo target scenario: Tailgating

Actors: Driver, Drivers, Principal Other Vehicle (POV), Fleet

Sharp-end mechanisms

Describe the situation immediately preceding the conflict onset and how it either influences the development or nature of the conflict or influences one or more road-user's ability to handle a potential conflict.

A commercial vehicle Driver follows behind a POV and adopt a very short headway. If a conflict suddenly develops (e.g., the lead vehicle brakes unexpectedly), the driver will not have sufficient time to avoid a rear-end crash.

Blunt-end mechanisms

Describe how mechanisms operating the past (e.g., organisational factors) have played a likely role in generating the sharp end mechanisms identified above.

The Fleet that the driver works for is lacking safety culture and Drivers in the Fleet are thus not motivated to change their unsafe behaviours. As a result, several of the Drivers in the Fleet habitually exhibit very short headways.

Figure 8 Example of Level 2 target scenario for the non-conflict phase (from the Task 3.4 report; Engström, Piccinini and Törnvall, 2015)

As explained above, the use cases define how certain safety features are intended to address the safety problems defined by the target scenarios. In the present framework, each use case is associated with one or more Level 2 target scenarios (see Figure 4). In the crash phase, relevant safety features typically include passive (injury-preventing, protective) features such as restraint systems and protective vehicle structures. Use cases for the conflict phase typically involve active safety systems such as collision warnings or automatic braking/steering. Finally, safety features operating in the non-conflict phase may involve driving support systems operating in non-conflict situations such as Adaptive Cruise Control or Driver Alert Systems, but also behavior-based safety services such as driver coaching and more general safety management services. Examples of use cases for the three phases are given in Figure 9, Figure 10 and Figure 11.

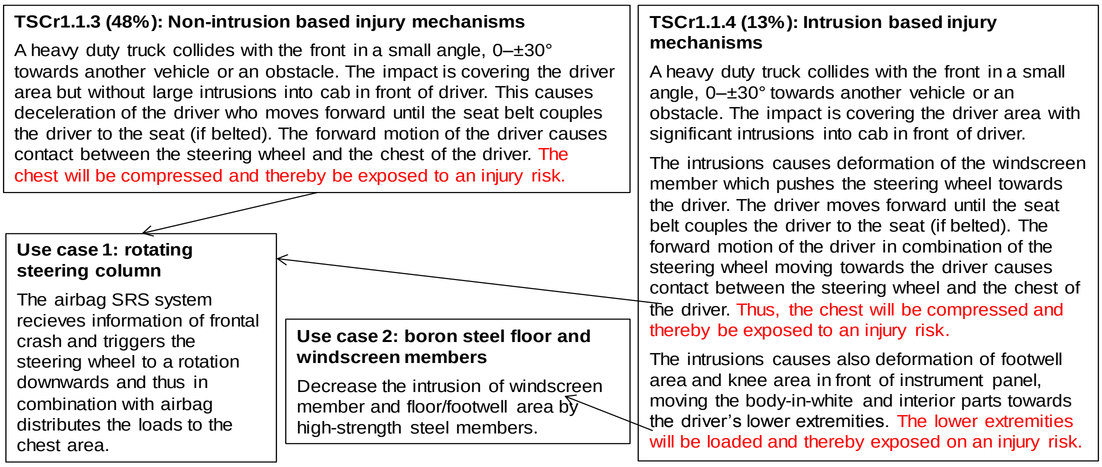

Figure 9 Examples of use cases for the crash phase and their associated target scenarios (from Thorn, Törnvall and Thomson, 2016)

AEBS UC Co1.1.1 Re-direction of gaze and automatic braking during eyes off road while following	
1. Conflict development...from TS	
2. Corrective action... from TS	
3. Safety interventions	
Intervention 1	The AEBS system detects the impending conflict by means of forward-looking sensors (e.g., radar, lidar and/or camera) and issues a warning to the SV driver.
Expected effect of intervention 1	The DV driver's gaze is redirected towards the forward roadway within 0.5-1 s after warning onset. If looming cues are visible, the driver reacts by braking and/or steering within about 0.5 seconds after gaze is back on the road. If looming cues are not visible (angular expansion rate ~>0.01 rad/s in good visibility conditions), the driver reacts when looming cues become visible.
Intervention 2	In case the driver's braking action is initiated too late to avoid the crash, the AEBS system detects this and automatically initiates braking.
Expected effect of intervention 2	The SV stops short of the LV or the impact speed is reduced. The effectiveness of the system in preventing the crash or reducing speed will depend on the on the maximum deceleration level of the AEBS system and the situation kinematics (i.e., initial headway, initial speed, LV deceleration rate).

Figure 10 Example of a use case for the conflict phase: Advanced Emergency Braking System with Forward Collision Warning addressing the target scenario in Figure 7 (from Engström, Bärgman and Lodin, 2016)

Use case for Tailgating NCo target scenario : Behaviour Change Management (BCM) program based on real-time and back-office driver coaching

Actors: Fleet, Drivers, Driver, POV, Consultant, Coach, Onboard System, Back-office System, Smartphone App

Describe the flow of events that is expected to result the safety intervention is implemented

1. The Consultant performs a diagnosis of the tailgating behaviour of the Drivers for the Fleet
2. The Fleet is supported by the Consultant to establish a policy against tailgating and to agree this goal with the Drivers.
3. The Drivers are incentivized by the Fleet in order to be motivated towards the agreed performance goal.
4. During driving, short headways are detected by an onboard sensor and real-time visual feedback is provided to the Drivers, indicating the the headway to the POV should be increased. When the driver increases headway above a certain level (say 2 s), the feedback is turned off.
5. Given that the Drivers are motivated towards the agreed goal by the incentives, they will obey to the feedback and increase headway
6. A safe following performance index is calculated by the Onboard System, based on the measured headway data, and sent to the Back Office System (with an interval of about 1h)
7. The Back Office System distributes this performance index to Drivers and the Coach via the Smart Phone App. Each Driver can thus see his own performance over different time intervals and compare it with the other Drivers.
8. If the average performance index (calculated over several days) drops below a certain level, the Smartphone App issues an alert to the Driver.
9. If no improvement is shown over time for this Driver, the Coach obtains a notification on the need for F2F coaching in his Smartphone App.
10. The Driver is then being coached face-to-face by the Coach, which increases his/her motivation to change behaviour.

Explain how the safety intervention will addresses the mechanism(s) defined in the target scenario (sharp-end and/or blunt-end)

The regular performance feedback coupled with a motivation (driven by incentives) to work towards the agreed performance goal (keeping safe headways), will lead to most Drivers adopting safe headways, thus increasing the safety margin in case of a sudden rear end conflict. The BCM program will also have a general effect on the safety culture in the Fleet, meaning that unsafe driving behaviors like tailgating become less socially accepted. This will further reinforce the behavioral change towards safe headways.

Figure 11 Example use case for the non-conflict phase: Behavior Change Management Program addressing the tailgating target scenario in Figure 8 (from Engström, Piccinini and Törnvall, 2015)

While the three use cases exemplified in Figure 9, Figure 10 and Figure 11 address quite different problems (occupant injuries, late reactions due to driver distraction and tailgating respectively) and by different means (protective vehicle structures, warnings/automatic braking and behavior change management), the general way of working is based on the same basic logic: The proposed solutions defined by the use cases are based on detailed definitions of the problems to be solved (the target scenarios), in turn supported by various forms of crash analysis (as further discussed in the following section).

Analysis methods

"Analysis" in the present framework refers to all types of information extraction from data, including, for example, analysis of crash statistics, crash/injury causation analysis, risk estimation but also the more general analyses of safety problem at specific customers. As stated above, the main goal of the analysis efforts within the present framework is to support the definition of target scenarios.

In the beginning of the project a comprehensive state-of-the-art review was performed on existing analysis methods and data sources that could potentially be used to realize the Eframe Evaluation Use Cases. This was documented in a set of review reports, listed in Table 1 (the review reports related to data sources are listed below).

Table 1 List of state-of-the-art review reports on existing analysis methods

Document name	Author
EFrame_WP2_SoA review_General_crash_statistics_analysis	András Bálint (Chalmers)
EFrame_WP2_SoA_Risk_analysis	Johan Engström (Volvo)
EFrame_WP2_SoA_ ACCM (Analysis of Crash Contributing Mechanisms)	Jonas Bärgman (Chalmers)
EFrame_WP2_SoA_ Experimental analysis	Giulio Piccinini (Chalmers)

Based on the state-of-the-art review, a subset of analysis methods were identified and adapted to the present framework. In addition, some methods have been developed more or less from scratch. This section provides an overview of these methods with references to the relevant task reports containing more detailed information.

Identifying Level 1 target scenarios from statistical crash data

As explained above, the role of the Level 1 target scenario representation is to define general crash types and their statistical properties. Perhaps the simplest way to do this is to use pre-defined crash typologies in national crash databases such as STRADA (Sweden) or NASS-GES (USA). It is also possible to define new categories by selecting a subset of key defining variables in the database (usually those used to define crash kinematics), and chose the variable combinations that account for most cases (see Engström et al., 2015). These categories can then be further compared with respect to other variables such as weather or driver state. In many cases, such analyses already exist in the literature which can be used for present purposes. This approach was used to define Level 1 target scenarios in Task 4.3 in the present project. Here, an existing analysis of rear end crashes using NASS-GES data (plus some other US crash data sources) by Woodrooffe et al. (2012) was re-used and adapted to present purposes by re-categorizing the original crash categories into the present Level 1 target scenario categories (Engström, Bärgman and Lodin, 2016). This is illustrated in Figure 12.

Crash type	Definition
LV fixed	Stopped more than 100m prior to impact (sensor limitation)
LV stopped	Stopped at impact but later than 100 m prior to impact
LV slower	Moving slower at constant speed at impact
LV decelerating	Decelerating at impact
LV cut-in	Cuts in in pre-crash phase

Re-categorization

Data set	Crash severity						Total	
Severity level	Fatal (N)	%	Injury (N)	%	PDO (N)	%	N	%
SV following LV	47	18,4	6196	61,3	13991	64,1	20234	62.8
SV approaching a slower or stationary LV	198	77,6	3614	35,8	7017	32,1	10829	33.6
Cut-in	10	3,9	290	2,9	836	3,8	1136	3.5
Total	255	100	10100	100	21844	100	32199	100

Figure 12 Illustration of the definition of Level 1 target scenarios (for rear-end crashes) and associated statistics based on an existing analysis in the literature (see the T4.3 report, Engström, Bärgman and Lodin for details)

An alternative approach is to use a more data driven analysis to find relevant pattern in statistical crash data. This may be particularly useful for identifying key safety problems on a certain market (EUC1b; e.g., which combinations of factors are most predictive of severe injuries), which could serve as the basis for Level 1 target scenario specification in the next step. Recently, there has been an increased interest in applying statistical methods generally known as recursive trees in the context of road safety analysis, and this approach was also investigated in the present project. Specifically, a combination of random forest and random trees were applied on STRADA data (see the Task 4.2 report; Pirnia, 2016). The general methodology is outlined in Figure 13 (adopted from Pirnia, 2016).

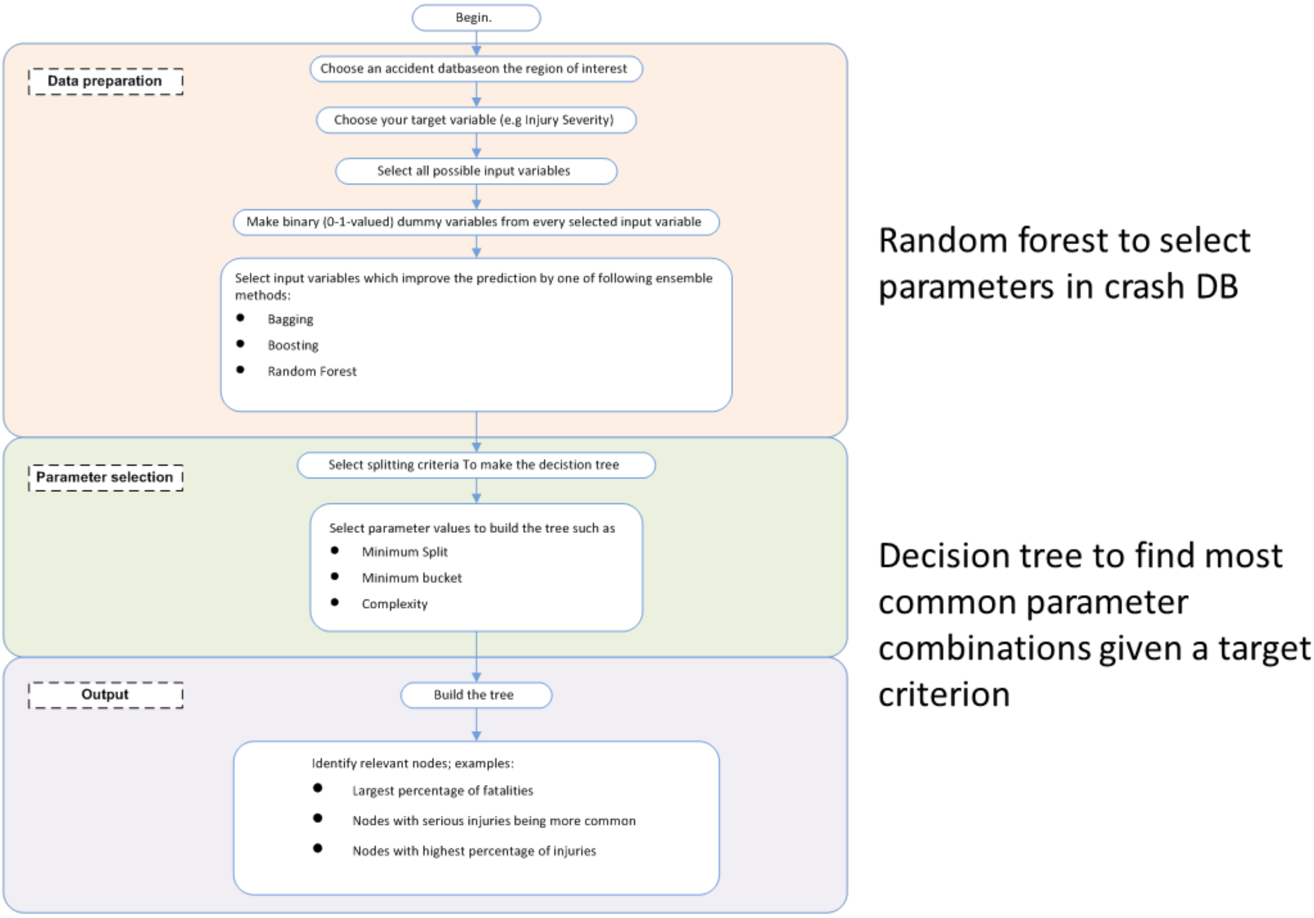

Figure 13 General statistical methodology, based on recursive trees, for identifying key safety problems in statistical crash data (from Pirnia, 2016).

An example of the output from this type of analysis on STRADA data, with crash severity as the target variable, is illustrated in Figure 14 (from Pirnia, 2016). It can be observed that the variable combination with the highest fatality probability is collisions between motor vehicles and pedestrians in non-urban areas. However, these crashes are very rare, accounting only for 1% of the data. By contrast, rear-end crashes on smaller roads (with speed limit < 110 kph) is the most common variable combination. However, in this case the zero fatality probability is close to zero.

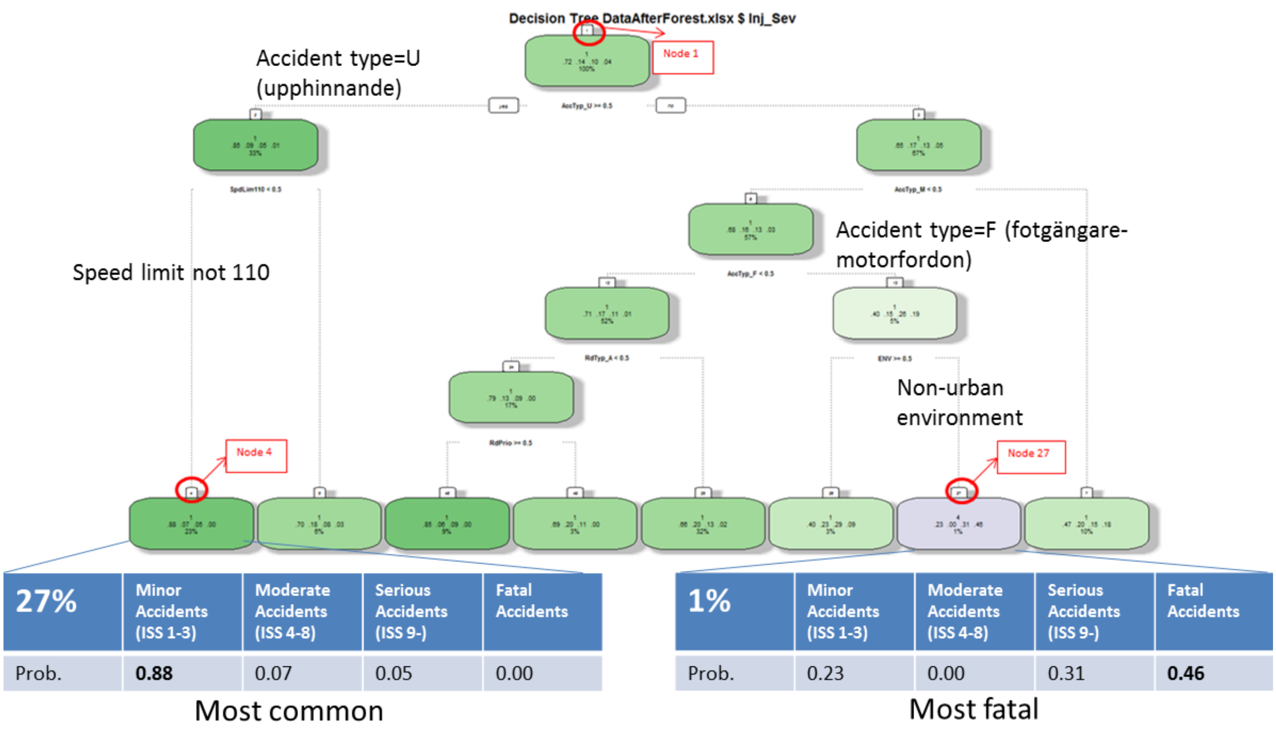

Figure 14 Example results from recursive tree analysis of STRADA data (from Pirnia, 2016)

Defining Level 2 target scenarios based on detailed crash/pre-crash

As described above, Level 2 target scenarios should represent the detailed causal mechanisms behind injuries and crashes. This generally requires analyses of more detailed crash data, in particular in-depth and naturalistic crash data. In-depth crash data typically include crash reconstructions, associated injury records and subjective pre-crash data based on driver interviews (e.g., the GIDAS, ETAC and INTACT databases). Naturalistic crash data typically include video of the forward roadway and the driver, as well as some (often limited) kinematic data (e.g., speed and acceleration). While both types of data is potentially relevant for understanding crash/injury causation mechanisms in both the crash and conflict phases, in-depth crash data is here viewed as the main source of input for the crash phase while naturalistic crash data is considered the main data source for the conflict phase.

There are several ways in which in-depth crash/injury data could be analyzed to derive injury causation mechanisms. One approach, employed in the present project (Thorn et al., 2016; Task 4.4), is to use decision trees similar to the random trees outlined above for Level 1 target scenarios. However, in this case, the decision tree was developed top-down by means of expert-based analysis rather than in the data-driven (bottom-up) way described above. The results from an analysis of injuries resulting from frontal collisions (based on the ETAC in-depth database) is illustrated in Figure 15 (see the Task 4.4 report, Thorn et al., 2016, for details).

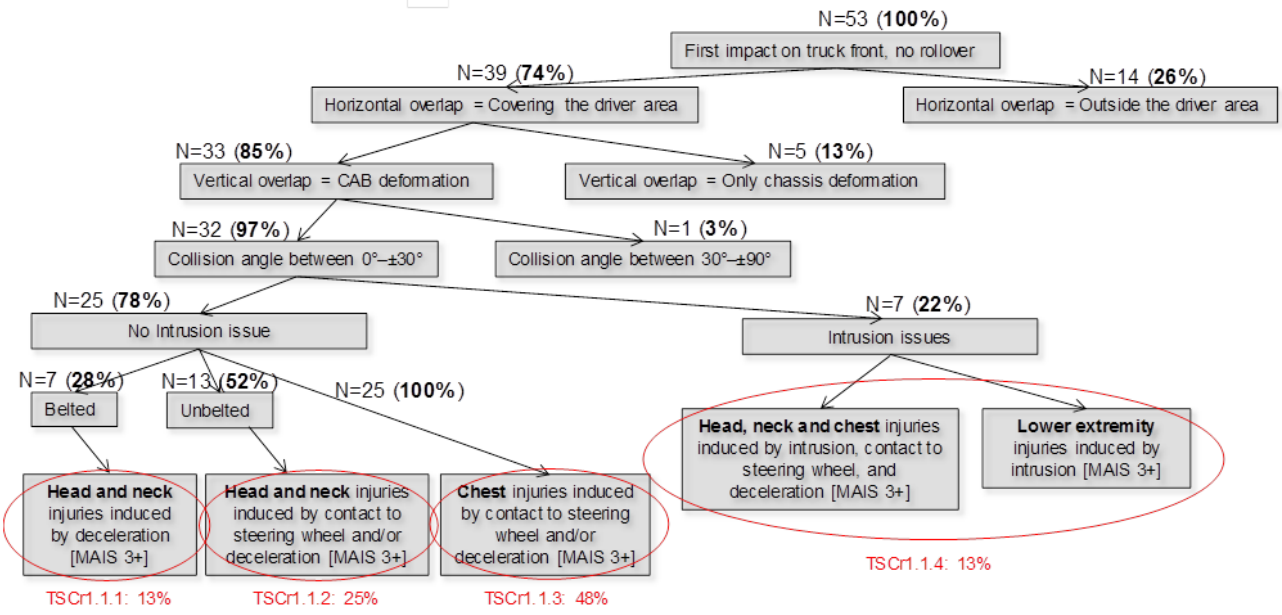

Figure 15 Analysis of injury causation mechanisms based on decision tree analysis. This analysis was the basis for the crash phase target scenarios and use cases shown in Figure ### above. See Thorn et al., (2016) for details.

For the analysis of crash causation mechanisms for (conflict phase) Level 2 target scenarios, a novel method was developed, partly within the present project. The method, named CANDE (Causation Analysis for Naturalistic Driving Events) is an expert-based method for identifying causal factors behind crashes (and near crashes) based on naturalistic crash data. It is based on previous developments within the ANNEXT project (Engström, Werneke, Bärgman, Nguyen and Cook, 2013) and is still in under development. The key idea is to first characterize the conflict itself and how it was induced. In the next step, the driver's corrective action to the conflict (or the lack thereof) is analyzed. The results from the analysis of individual crashes can then be superimposed in order to elucidate general causation patterns which can be used as the basis for defining Level 2 target scenarios. An example of such an analysis is shown in Figure 16. The causation pattern represented by these 10 aggregated crashes ("impaired reaction due to eyes-off-road while following") was identified as the most common mechanism behind truck/bus rear-end crashes in the Lytx naturalistic crash dataset used for this analysis.

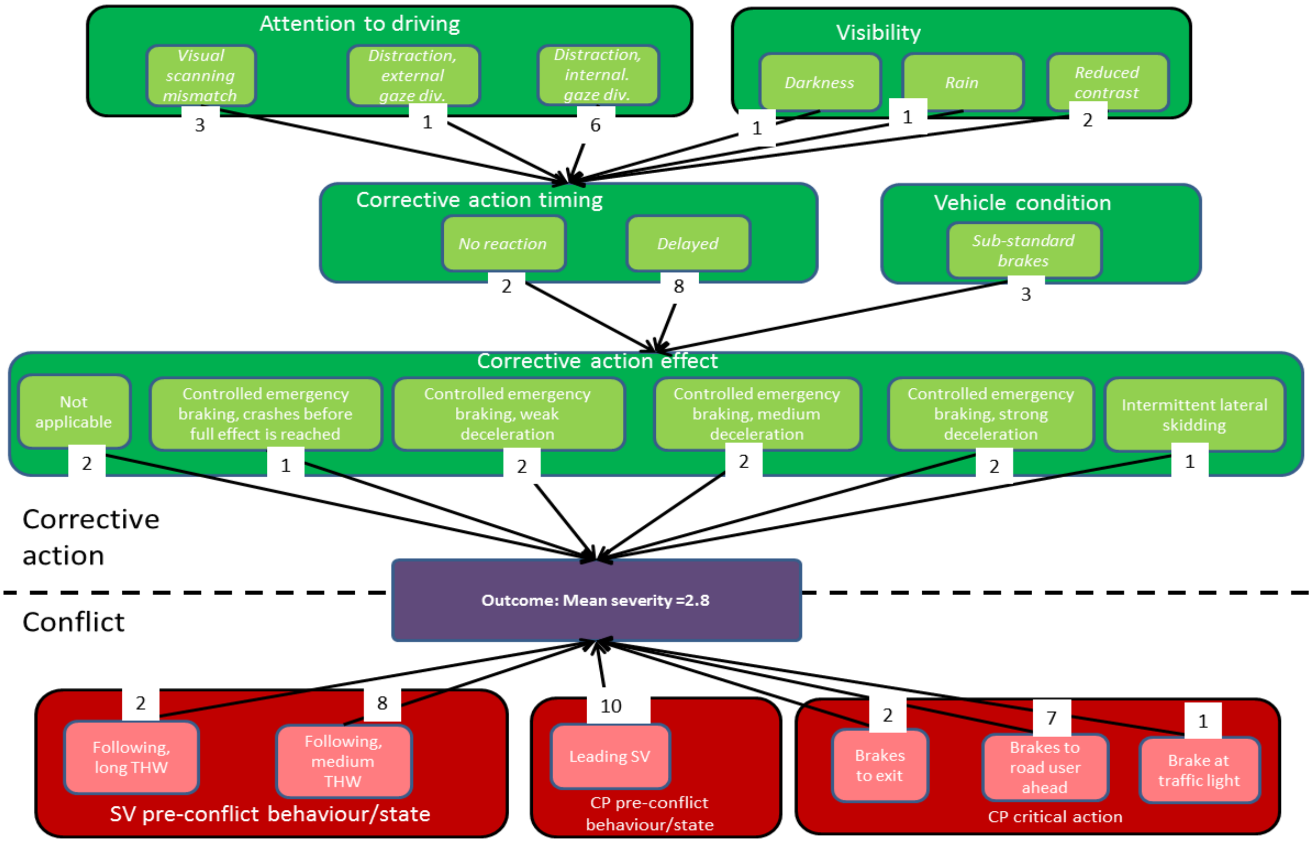

Figure 16 CANDE analysis for ten crashes representing the "Impaired reaction due to eyes-off-road while following" Level 2 target scenario. This analysis was the basis for the conflict-phase target scenario shown in Figure ### above (see Engström et al., 2016 for further details).

Customer safety analysis

The safety analysis methods described so far may, in principle, also be applied to the safety analysis at a specific customer. However, when conducting safety analysis at the customer level, several additional constraints apply. First, the crash data typically available from a single customer is generally limited, both in terms of the number of recorded crashes and the level of detail at which the crashes (and their causes) are described. Second, the majority of the crashes occurring in a fleet are relatively non-severe and often occurring outside road traffic (i.e. in work yards etc.). Hence, these crashes do not appear in traditional crash databases but may still result in significant costs and are thus of key relevance for the customer. On the other hand, when performing a safety analysis for a customer fleet, it may be possible to extract information not readily available in "traditional" crash data (for example, information a bad safety culture, reflected in unsafe driving habits or inappropriate vehicle maintenance, which may be addressed by Volvo safety services.

Thus, in order to support safety analysis at the customer level, a set of additional analysis methods were developed within the present project, as further described in the Task 3.3 report (Wege and Pirnia, 2016). First, a general methodology for customer safety investigation was developed with the purpose to identify safety issues and their associated costs. Second, a crash coding scheme was developed specifically for non-traffic crashes (documented in the Task 3.3.3 report; Pirnia, 2015).

Effectiveness estimation

Effectiveness estimation can be roughly divided into *prospective* and *retrospective* analysis. The goal of prospective analysis is to estimate the *potential* effectiveness of a safety feature (e.g., in terms of prevented crashes and/or injuries) before it is put on the market (e.g., in the early stages of development). This is of key importance for the prioritization of safety features in product development. By contrast, retrospective effectiveness estimation refers to the follow up of the *actual* effectiveness of safety features already on the market. By using the statistics defined for the Level 1 target scenarios, the effectiveness estimates for specific Level 2 target scenarios may be scaled up, yielding general safety benefits on the national/regional level.

Both prospective and retrospective effectiveness estimation were addressed in EFrame, as further outlined below. Moreover, a method for scaling up to the national level was developed and demonstrated for the conflict phase (Task 4.3).

Prospective effectiveness estimation

Crash phase

A general method for prospective effectiveness estimation of injury reduction for the crash phase is outlined in the Task 4.4 report (Thorn et al., 2016). The general methodology, first developed in Task 3.5 (Piccinini et al., 2015) is illustrated in Figure 17.

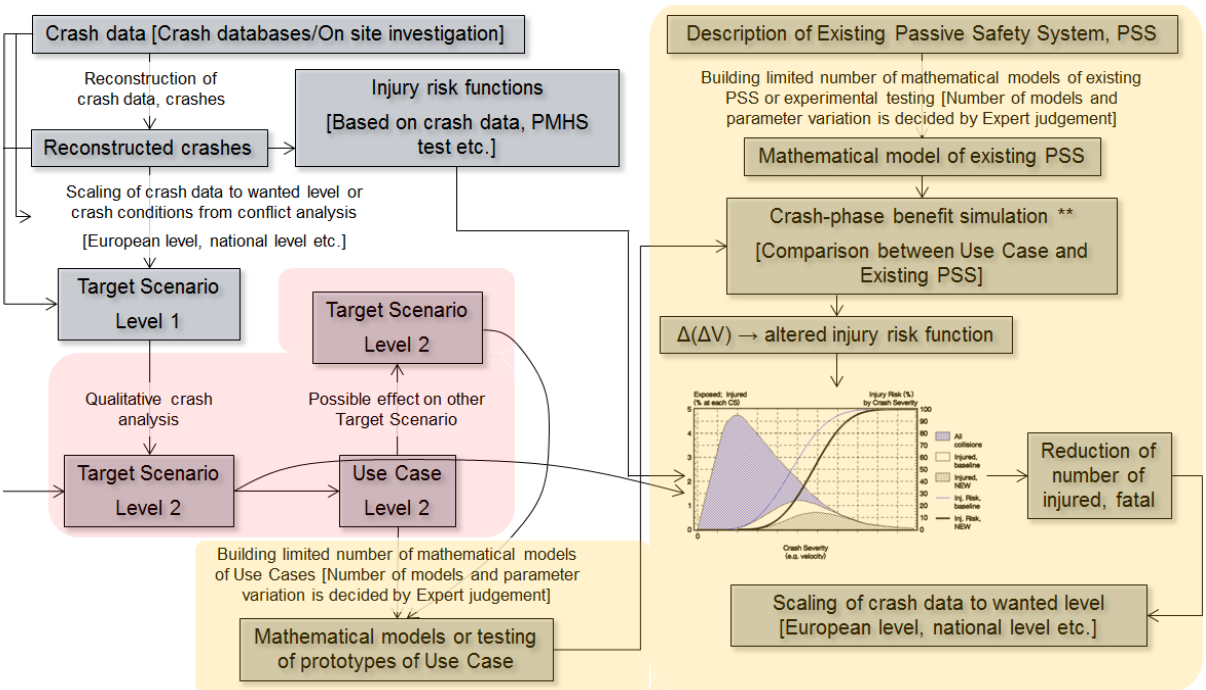

Figure 17 General flow chart for prospective effectiveness analysis for the crash phase (from Thorn et al., 2016)

As shown in Figure 17, the effectiveness estimation starts from the target scenario and use case definition. The first step is to derive a relationship between a crash impact measure (e.g., impact speed) and the risk for an injury above a certain level (say AIS2+) based on in-depth crash data (in this case the ETAC database). This results in an injury risk curve for the target scenario in question. Next, the exposure to different levels of crash impact (the dose) is derived from in-depth crash data. Multiplying the exposure with the injury risk curve yields the response curve representing the number of injured drivers (obtain by integrating the response curve). Finally, the general expected effect of passive safety systems is to shift the injury risk curve so that given impact results in a lower injury risk. The expected shift in injury risk for a specific countermeasure may be obtained through physical tests, crash simulations, expert judgments or combinations of those. Shifting the injury risk curve thus results in a new response curve (a lower number of injured people). This reduction thus represents the effectiveness of the feature for the use case in question. The method is further illustrated in Figure 18 and described in further detail in Thorn et al. (2016; see also the state-of-the-art review of risk analysis methods in Engström, 2014b).

If the statistical prevalence of the corresponding target scenario, the effectiveness estimate can be scaled up to safety benefits at the national level (e.g. , the number of AIS2+ injuries prevented per year in a country). However, this step was not performed in Task 4.4.

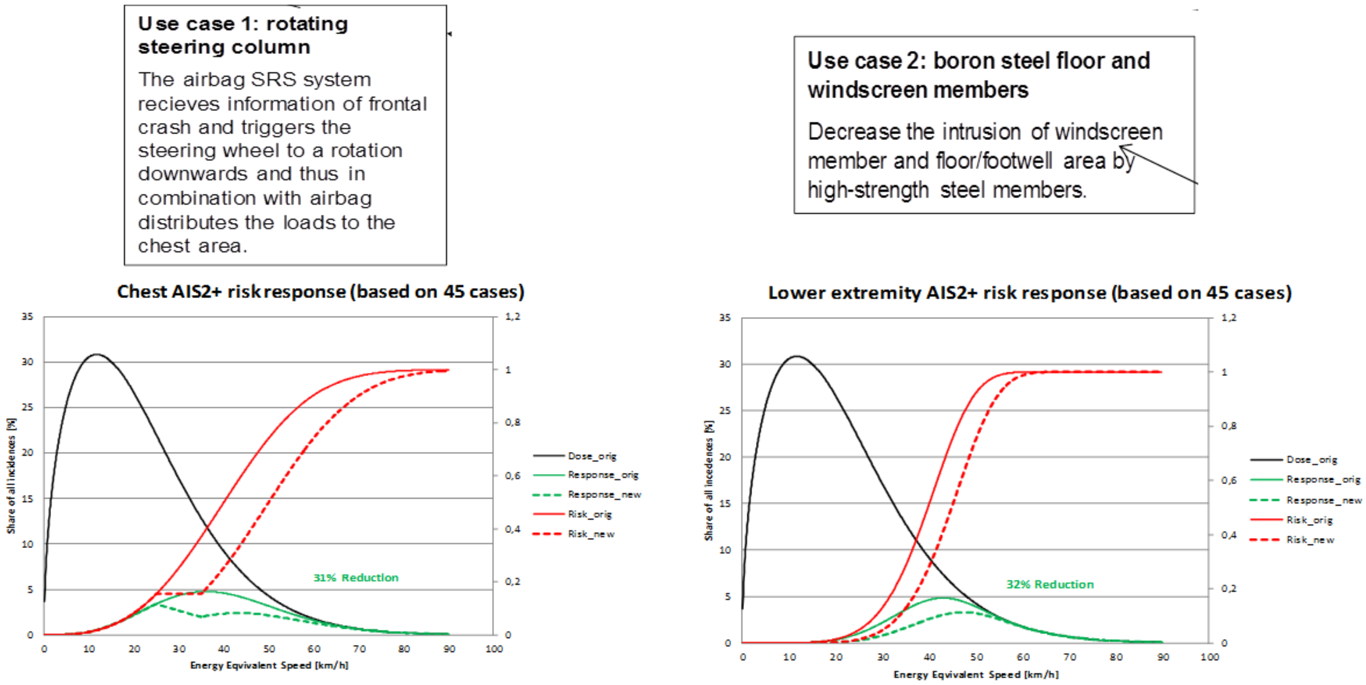

Figure 18 Example of AIS2+ injury prevention effectiveness estimation for two crash phase (passive safety) use cases (from Thorn et al., 2016).

Conflict phase

The general methodology for prospective effectiveness estimation for the conflict phase (active safety functions) is illustrated in Figure 19 (from Piccinini et al., 2015). The general logic is very similar to the corresponding process for the crash phase (Figure 17). However, while the crash phase analysis is mainly based on analytic dose-response functions, but effectiveness analysis for the conflict phase is based on counterfactual (what-if) simulation.

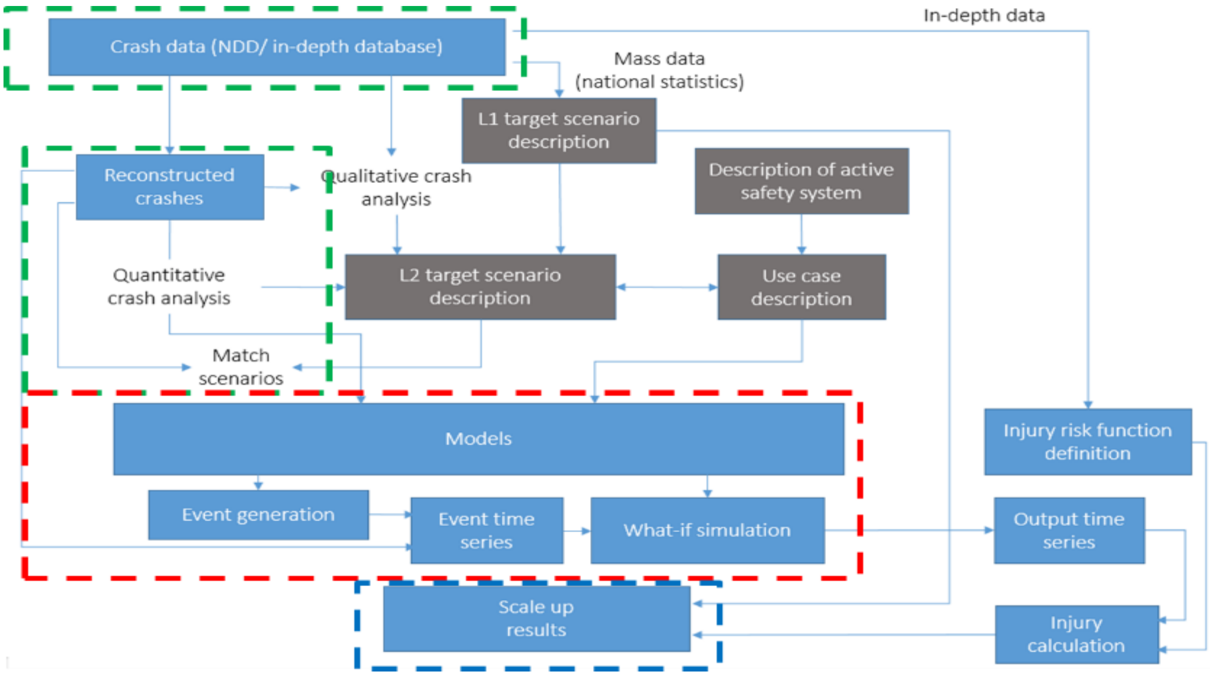

Figure 19 General flow chart for prospective effectiveness analysis for the conflict phase (from Piccinini et al., 2015)

The analysis starts from the target scenarios and use cases. Figure 20 shows an example of a target scenario hierarchy resulting from crash analysis. The general idea is then to recreate the Level 2 target scenarios in simulation along with models of the system functionality (as defined by the use case), the environment and the driver (Piccinini et al, 2015). The system effectiveness can then be calculated for each Level 2 scenario, for example, in terms of the proportion of prevented crashes. Methods for reconstructing scenario kinematics from naturalistic crash (Lytx) data have been developed in previous projects (e.g., Bärgman et al., 2013) but were further refined in the present project (see Engström, Bärgman and Lodin, 2016).

There are several different ways in which this process may be implemented in practice. In particular, this concerns how the individual crash scenarios (representing the Level 2 target scenarios) are generated for the simulation. One approach is to run the simulation on actual reconstructed naturalistic crashes in the dataset. Alternatively, one can use a Monte Carlo simulation approach where synthetic cases are generated based on kinematic distributions representing derived from the crash data (one could also envision several possibilities “in between”, e.g., generating different synthetic variants of each actual crash). Due to the limited amount of available crash data, the latter approach was adopted for the demonstration application in Task 4.4.

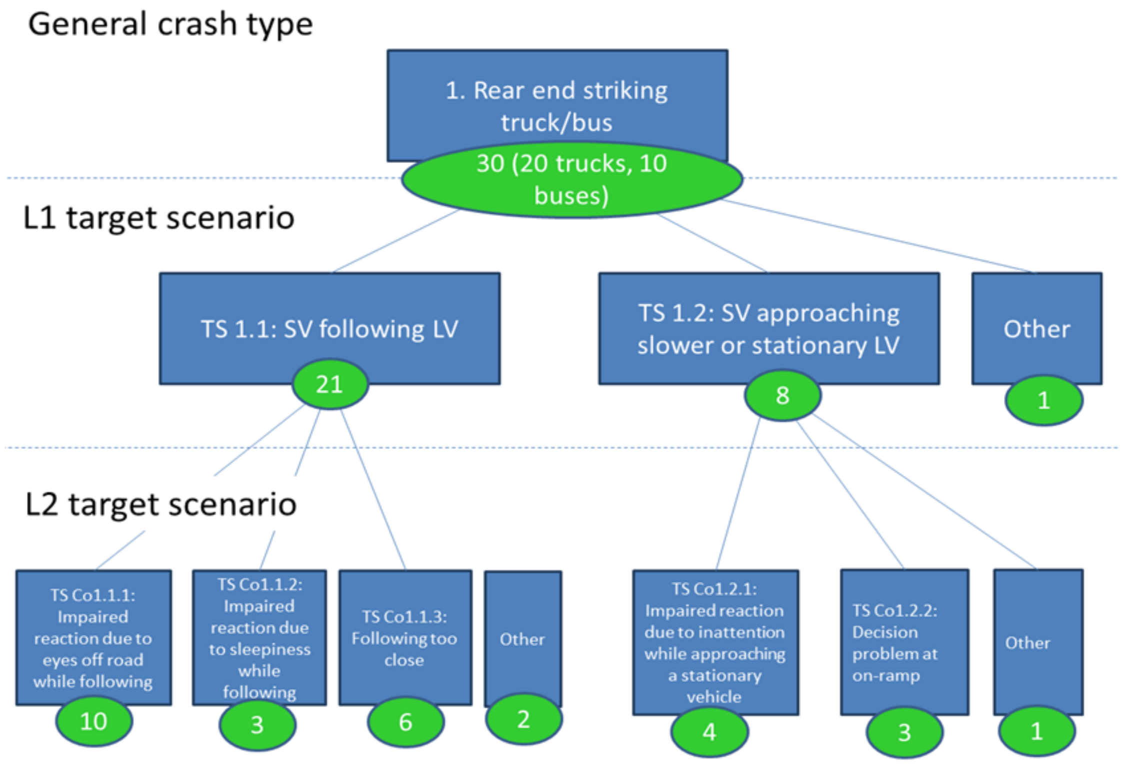

Figure 20 Example of a target scenario hierarchy for rear end conflicts (from the Task 4.3 report; Engström et al., 2016)

In Task 4.3, the method outlined above was applied to effectiveness estimation for an Advanced Emergency Braking (AEB) system, including Forward Collision Warning (FCW). Some results from the simulation are shown in Figure 21. The left panel shows the estimated percentage prevented crashes for four of the rear-end Level 2 target scenarios shown in Figure 20. Results are presented for AEB and FCW alone and in combination. In Figure 21, it can, for example, be observed that FCW reached about 50% crash prevention rate in the first target scenario (the ""impaired reaction due to eyes-off-road while following" target scenario exemplified in Figure 7and Figure 16 above). It can also be observed that AEB reached almost 100% crash prevention rate in all target scenarios. As discussed in the Task 4.3 report (Engström et al., 2016), this is probably due to assumptions of a perfectly working AEB system, thus not accounting for sensory limitations or adverse operating conditions. The right panel in Figure 21 shows the results of a sensitivity analysis, investigating how the crash prevention rate is affected if the AEB system obtains less actual deceleration than it requires (e.g., due to slippery road conditions or badly maintained brakes). As shown, if the actual deceleration is 20% less than requested by the AEB, the prevention rate drops below 50% in both scenarios (for AEB alone). This further illustrates how this type of counterfactual simulation can be used during development to investigate how effectiveness (e.g., crash prevention rate) is affected by different system parameter settings (i.e., EUC4, virtual prototyping). It should be emphasized that, due to the limited amount of data available, these results from the T4.3 effectiveness analysis should not be taken at face value. Rather, the goal here was only to demonstrate the method.

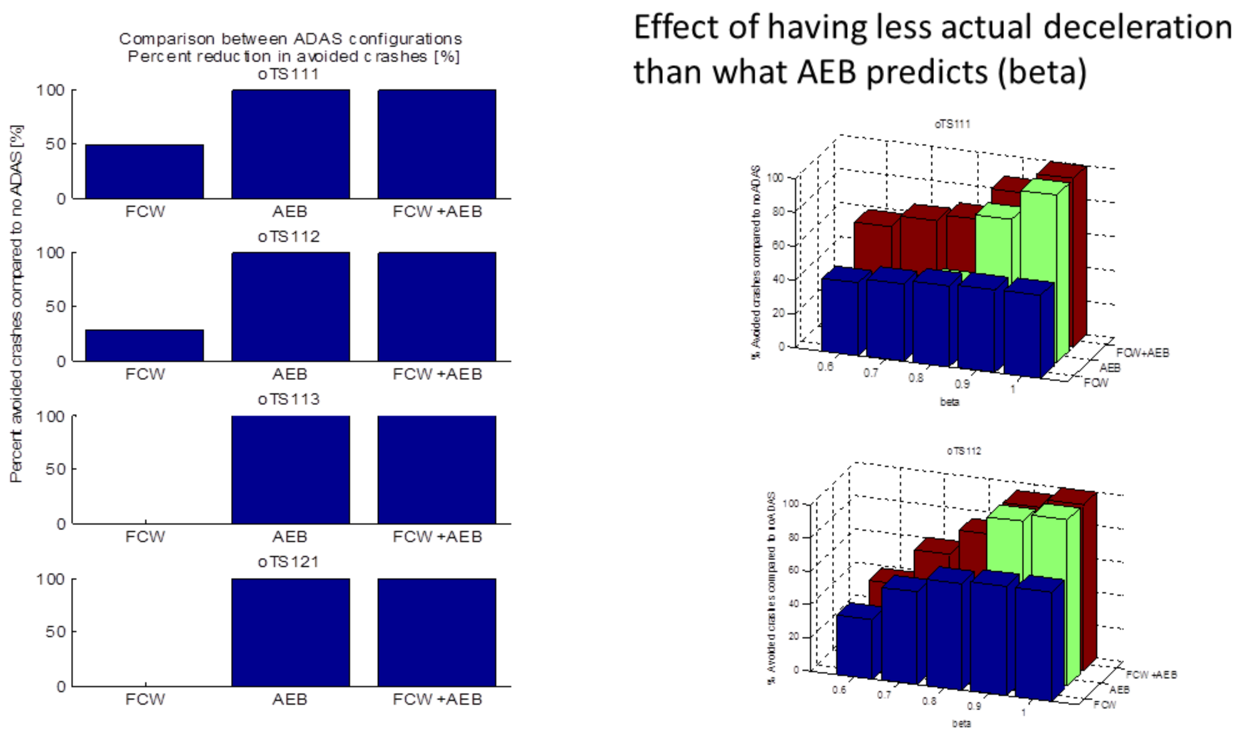

Figure 21 Results from the effectiveness analysis in Task 4.3 (from Engström et al., 2016)

The demonstration application in Task 4.3 also involved scaling up to US national statistics via the Level 1 target scenarios. This involved two major challenges. First, since the Level 2 target scenarios were defined based on naturalistic crashes, their relative prevalence had to be estimated based on the naturalistic data. Of course, the 30 Lytx crashes used in this demonstration cannot be considered statistically representative. However, the problem more fundamental since scaling up (in the present methodology) always has to rely on the naturalistic data (since Level 2 target scenarios never can be fully identified in police-reported crash data). At the same time, the counterfactual simulation methodology employed here simply cannot be performed based on statistical crash data only (since detailed information from the pre-crash phase is lacking). With larger naturalistic crash datasets, it seems likely that this representativity issue can be addressed by weighting factors in a similar way as for GIDAS today. Another approach, currently investigated in the QUADRAE FFI project, is to match target scenarios established in naturalistic data to in-depth (GIDAS) data, which may be used as an intermediate step before mapping to national statistics.

While the methodology for passive safety system (crash phase) effectiveness estimation (presented in the previous section and in Thorn et al., 2016) is relatively mature, the present simulation-based methodology for active safety systems (conflict phase) was more or less developed from scratch in the project. Thus, it clearly needs further development before being employed in actual development at Volvo. Further development of the method is currently undertaken in the QUADRAE project, in collaboration with Volvo Cars and Autoliv. A first goal there is to implement the same type of effectiveness estimation for AEBS demonstrated in the present project, but with more mature simulation tools (Prescan). In this way, the present approach for effectiveness estimation can be integrated with existing simulation tools for technical testing (e.g., models of imperfect sensors), thus yielding more accurate effectiveness estimates.

Retrospective effectiveness estimation

The project also addressed methods for following up the safety performance of Volvo products already on the market. This could involve comparisons between Volvo trucks and competitor brands with respect to the risk of crash involvement or occupant injury, or comparison between Volvo trucks with and without a certain safety feature.

The general goal with this type of analysis is thus to calculate estimates of risk, which calls on methods from the field of epidemiology (see the state-of-the-art review on risk analysis (Engström, 2014b) for an overview). Generally, risk estimation involves relating a road safety outcome measure (e.g., the number of injured occupants) to a measure of exposure (e.g., kilometers travelled); see Bálint, 2016; Bálint and Pirnia, 2015).

A general flow chart was developed for this type of analysis, shown in Figure 22. As can be seen, the methodology includes different options depending on the data available. If exposure data is available for each target category (in this case vehicle brand), the risk ratio can be directly estimated. If exposure data is not available, relative risk can still be estimated by means of *induced exposure* (see Bálint, 2016; Bálint and Pirnia, 2015; Engström, 2014b) if there are crashes that can be assumed to be unrelated to the target category (so-called comparison crashes or control crashes).

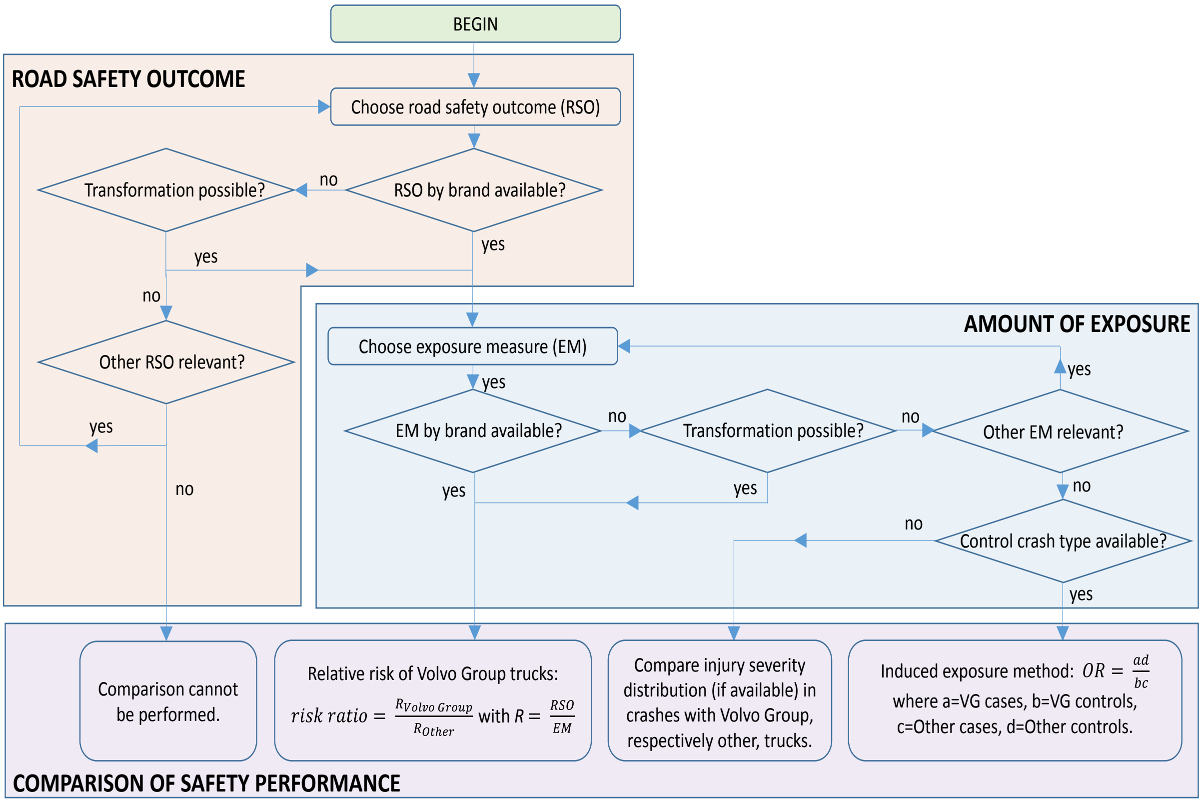

Figure 22 General flowchart for retrospective analysis of safety performance/effectiveness (from Bálint, 2016)

The demonstration application in T4.1 (Balint, 2016) was based on US national statistics (NASS-GES data. Due to the lack of information on whether the involved vehicles were equipped with safety systems the NASS-GES crash data, the demonstration focused on comparing US Volvo Group heavy trucks (>11.8 tons; Vehicle class 7-8; Volvo and Mack) to competitor trucks of the same class. In this demonstration, the risk ratio was estimated directly using US market share as the exposure measure. The exposure (market share) information was obtained from the online statistics portal Statista (see the Task 3.2 report, Bálint & Pirnia, 2015, for a further discussion on exposure data relevant for this application and Fagerlind, 2014, for a general review of existing exposure data).

Figure 23 shows an example of the results, where the relative risk of crash involvement (in crashes of all severities) is plotted for competitors in comparison to Volvo Group trucks.

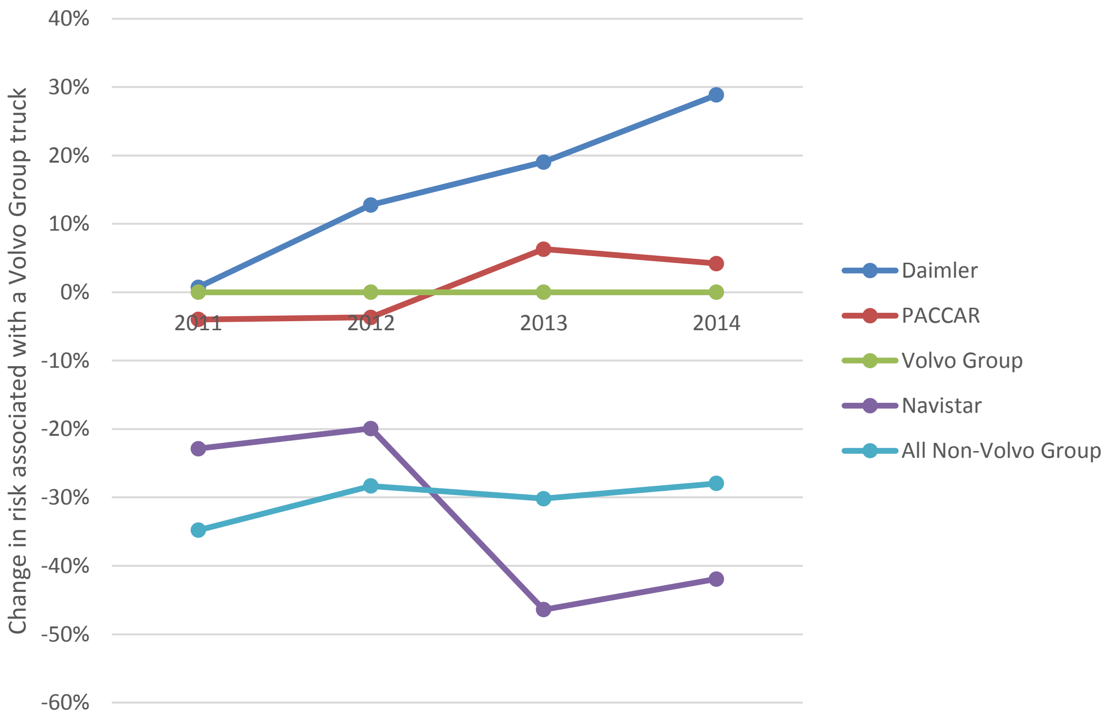

Figure 23 Risk of involvement in crashes of all severities by market share in the US for Volvo Group trucks, relative to competitors. Values above 0 indicate that Volvo Group trucks are more involved in crashes, while values below 0 indicate that Volvo Group trucks are less involved in crashes than trucks from the competitors, relative to market shares. (from Bálint, 2016)

Differences in safety performance between brands can be due to many reasons unrelated to the vehicles themselves, such as correlations between a fleet's preference for a certain truck brand and their company (safety) culture. Thus, while the brand comparisons reported in Bálint (2016) are interesting, the method is probably most useful for more specific comparisons relating to retrospective analysis of safety system effectiveness, similar to the work by Lie et al (2006) on safety benefits estimation of Electronic Stability Control (ESC). However, this requires information in the crash data on whether the involved vehicles were equipped with the safety system in question. While this is not part of the standard crash coding in most national statistical databases, it may be possible to obtain this information via the registration and chassis numbers (at least for Volvo trucks). Since exposure data is unlikely to be available for equipped vs. non-equipped trucks, the induced exposure method seems best suited in this case. A collaborative effort on retrospective effectiveness analysis of AEBS has recently been initiated between Volvo and the Swedish Transport Administration, and the methods developed in the present project could serve as one starting point for this type of analysis.

Data sources

As outlined in the previous sections, the analyses required to derive target scenarios relies primarily on three types of crash data: (1) National/regional crash statistics, (2) in-depth crash data and (3) naturalistic driving data. In addition, as outlined in the previous section, other types of data are needed as input to effectiveness analyses, for example exposure data for risk analysis.

In this section, the requirements and availability of such data is briefly discussed. For more extensive discussion on data needs see the Task 4.3 and Task 4.4 reports (Engström et al., 2016; Thorn et al., 2016). For more extensive reviews of available data, see the state-of-the-art reports addressing data sources (listed in Table 2).

Table 2 State-of-the-art reports addressing available data sources

Document name	Author
EFrame_WP2_SoA_Crash_Statistics-Mass_Data	Helen Fagerlind & András Bálint (Chalmers)
EFrame_WP2_SoA_In-depth_crash_data	Helen Fagerlind & András Bálint (Chalmers)
EFrame_WP2_SoA_Naturalistic_driving_data	Giulio Piccinini (Chalmers)
EFrame_WP2_SoA_ Experimental data	Giulio Piccinini (Chalmers)
EFrame_WP2_SoA_Exposure_data	Helen Fagerlind (Chalmers)
EFrame_WP2_SoA_Societal_data	Claudia Wege (Volvo)

National/region crash statistics (mass data)

As described above, this national/regional crash statistics is mainly needed for the definition of Level 1 target scenarios, in particular to derive general statistics (e.g., the prevalence of different crash types) and identify general traffic safety problems in a region.

While aggregated crash statistics is available at the international level from several sources (Fagerlind and Balint, 2014), more detailed, individual, crash records are needed to conduct the types of statistical analyses exemplified above. Such databases exist in most industrialized countries but only STRADA (Sweden) and NASS-CDS (USA) are currently available to AB Volvo. Access to other national databases typically requires direct contact with the authorities and it is still unclear if the data available in national databases other than those used here (e.g., Brazil and China) is sufficient for present purposes. For developing countries, this type of data generally does not exist at the required level.

However, some in-depth crash databases may be used as surrogates for national crash statistics, and should thus be sufficient to derive Level 1 target scenarios for present purposes. This holds in particular for the German GIDAS database which includes weighting factors for the German and European crash statistics. It seems possible that the Chinese version of GIDAS (CIDAS) may also be used in this way, at least in the future.

As demonstrated in Task 4.1 (Bálint, 2016), national crash statistics can also be used to follow up the safety performance (in terms of changes in crash/injury risk relative to competitors or non-safety-system-equipped vehicles) of products already on the market. However, this requires that the relevant information (vehicle brand, weight class, installed safety systems) is available. However, this is only the case for the most advanced databases (such as NASS-GES), and detailed information on available safety features is usually not available at all. Thus, additional efforts are probably needed to obtain the information needed for retrospective analysis of safety system performance (e.g., by using vehicle registration information to get the chassis number, based on which safety system information could be obtained internally at Volvo). However, this was not investigated in the present project.

In-depth crash data

In the present framework, in-depth crash data is mainly used as the basis for defining Level 2 target scenarios for the crash phase. However, in-depth crash data may potentially also be used to inform Level 2 target scenario definition for the conflict phase, although information on pre-crash causal mechanisms is usually rather limited. Moreover, as just mentioned, some in-depth data-bases (with case weighting factors to national/regional statistics) may be used to define Level 1 scenarios.

However, as discussed in the Task 4.4 report (Thorn et al., 2016) Volvo's availability to in-depth crash data meeting the EFrame requirements (sufficient number of truck cases, crash reconstruction and associated injury data) is currently relatively limited. Existing available databases for the European market include INTACT (Sweden) and ETAC (EU). The latter was used for the present analysis in WP4.4 (Thorn et al., 2016). However, the number of truck crashes in these databases is still relatively limited (26 and 624 respectively). The GIDAS database satisfies all the present requirements and contains about 2000 trucks crashes. As mentioned above, GIDAS can also be used to define the Level 1 target scenarios. However, Volvo does not currently have access to GIDAS and getting access is associated with a significant fee. The EFrame methodology clearly shows that investment in GIDAS would be a game changer with respect to the types of analyses that could be performed (Volvo Cars and Autoliv already has access).

In the US, detailed in-depth crash data for trucks is publicly available from the Large Truck Crash Causation Study (LTCCS), which contains about 1000 truck crashes. However, as noted by Thorn et al. (2016), the LTCCS data lacks information on crash severity (e.g. delta-V or Energy Equivalent Speed).

Naturalistic driving data

In the present framework, naturalistic crash data is considered the primary data source for defining Level 2 target scenarios for the conflict phase (as demonstrated in the Task 4.3 report; Engström et al., 2016). Reconstructed naturalistic crash time series are also used input to the counterfactual simulation used for effectiveness analysis. Moreover, naturalistic driving data (including "normal driving" as well as non-crash events such as near-crashes and incidents) can be regarded a key source for defining target scenarios for the non-conflict phase relating to unsafe behaviors (e.g. , tailgating as in the target scenario example in Figure 8). However, this was not further pursued the present project.

Naturalistic crash data has only recently become available. For passenger cars, a relatively large database of (+1000) naturalistic crashes is available through the major SHRP2 data collection effort in the US involving +3000 cars. For trucks, however, larger sets of naturalistic crashes are only available through commercial driver coaching service providers such as Lytx and SmartDrive. Through collaboration with Lytx, AB Volvo and Chalmers obtained unique access to an initial set of about 130 rear-end and intersection crashes (plus about 80 near crashes), of which a sub-set of the rear-end crashes (involving trucks and buses in the US) were used in the present project (Task 4.3; see Engström et al., 2016). AB Volvo, together with Volvo Cars, Chalmers, Virginia Tech Transportation Institute and University of Iowa, is currently working towards a more long-term partnership with Lytx which will ensure a regular inflow of naturalistic truck crashes, to which Volvo (and the other consortium partners) will have unique access. It is thus foreseen that the amount and quality of naturalistic crash data will increase substantially in the coming years. For example, the current generation of the Lytx data logger contains video-based sensing technology providing even more detailed pre-crash data, for example on lane position and the distance to surrounding objects.

Evaluating the safety performance of a customer fleet

Accidents are much more expensive than many fleets realize. The cost comprises more than the repair cost for the vehicle and often less might be covered by the insurance than assumed. It has been estimated that the full cost to the employer might actually be 15 to 75 US dollars for every US dollar recovered through an insurance claim (Fleet Forum Fleet Safety Guide, 2013).

The starting point for saving money is to understand costs. After a collision, vehicle repairs are just the tip of the iceberg. An Australian study (Davey, Jeremy and Banks, Tamara D, 2005) estimating the cost of motor vehicle incidents in Australia indicated that the total cost of a fleet vehicle insurance claim is four to 15 times higher than the average direct repair costs.

The challenge is that there are a lot of hidden costs of collisions and customers do not systematically evaluate the safety problem at their fleet. The general methodology for identifying the existing safety problems in a customer fleet (including methods on how to collect fleet management economics, fleet operations data and fleet data management (what kind of data, frequency of data collection, who follows up?)) was discussed and validated with in-depth interviews with the four main Swedish insurance companies (Folksam, IF, Trygg Hansa, and Lansforsäkringar). As a result of the work done in WP3 and the interviews conducted in WP4 the **Iceberg Model on Accident Related Customer Safety Costs** (Figure 24) was generated. In the Iceberg Model for accident related customer safety costs 18 different cost types were identified. Six of these 18 costs are direct customer costs called ”hard costs” – these costs are usually not recovered by any insurance company. The costumer directly faces these costs, they are visible in their economic books as a net costs. That is why we refer to them as “the top” of the iceberg. Underlying the direct costs are numerous hidden costs. 12 hidden cost types were identified and divided into either “unrecovered hard costs” (indirect costs) or “soft costs”. The first are either vehicle centered costs, driver centered costs, organization centered costs or environment centered costs (for more detail on each of these costs see the Figure below). The latter soft costs are even more hidden. They are often impossible to measure by a “hard number”, however can “hit” the costumer even more than a very high direct hard cost. Examples for soft costs are damage to reputation and image including reduced end-customer loyalty, the loss of existing fleet drivers or forthcoming difficulty in recruiting new employees (for more detail on each of these costs see the Figure below). A further detailed description of the model can be found in Wege and Pirnia (2016).

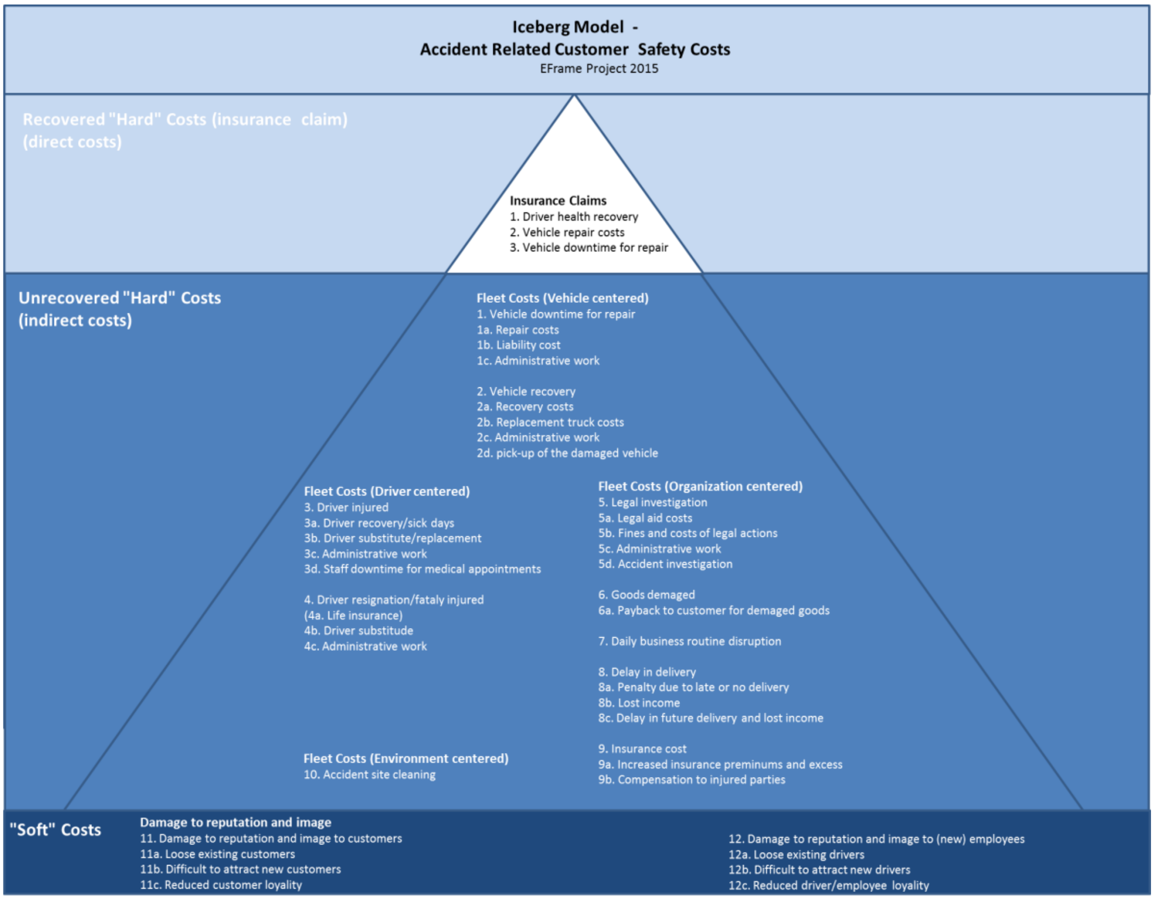

Figure 24 Iceberg Model on Accident Related Customer Safety Costs

Today there does not exist a solid methodology for identifying the safety problem at a customer fleet. Generally, it is easier to identify the mere number of accidents or even the type of accidents (e.g. rear-end damage when backing up at the customer site, see SRM II project for more detail). In comparison, it is a challenge to identify causes and consequences (outcomes such as costs) of accidents without having a solid accident analysis methodology in place. Within Task 3.3 we propose a step-by-step approach for such an analysis. The model that was established is partly based on the outcomes of the SRM II project (Löfstrand et al, 2015) and the outcomes of the Value-based-proposition project (Ali, Favreau, Löfstrand, Strömberg & Söderman, 2012).

The Iceberg Model was incorporated into a bigger model called **"Safety Diagnostic – A Model to evaluate the safety performance of a customer fleet"** (Figure 25). The model is divided into "long-term safety investigation of general fleet safety situation" and "short-term investigation on one incident/accident" at a fleet. The model covers steps I to VI :

I. Problem definition (incl. defining a target scenario),
II. Method
III. Tool
IV. Cause (either sharp end or blunt end) and prevalence
V. Consequence
VI. Solution (incl. defining a use case)

The model is divided into "long-term safety investigation of general fleet safety situation" and "short-term investigation on one incident/accident" at a fleet. The latter is much more enhanced than going out to an accident site shortly after the accident has happened (usually what the Accident Research Team ART at Volvo is doing in their daily work). For both types the cause and prevalence of the accident needs to be investigated using various methods that are described in the model (e.g. obtaining fleet records, observations, interviews). This problem analysis is using an holistic approach by identifying also psychological concepts (e.g. identification of staff moral) and organizational culture (e.g. safety culture, off-the-job safety or practices of staff screening such as their experience or health).

The consequences of the accident(s) are identified in-depth at the next stage. For the general and more long-term safety investigation type this leads directly into the solution stage where solutions are proposed (e.g. service offerings). For the short-term accident investigation on one case the next step would be a case description of the scenario of the accident. This case description is split into an accident reporting (e.g. using the INTACT interview guide or DREAM interview methodology) and a cost reporting (e.g. SRM II report; Löfstrand et all, 2015).

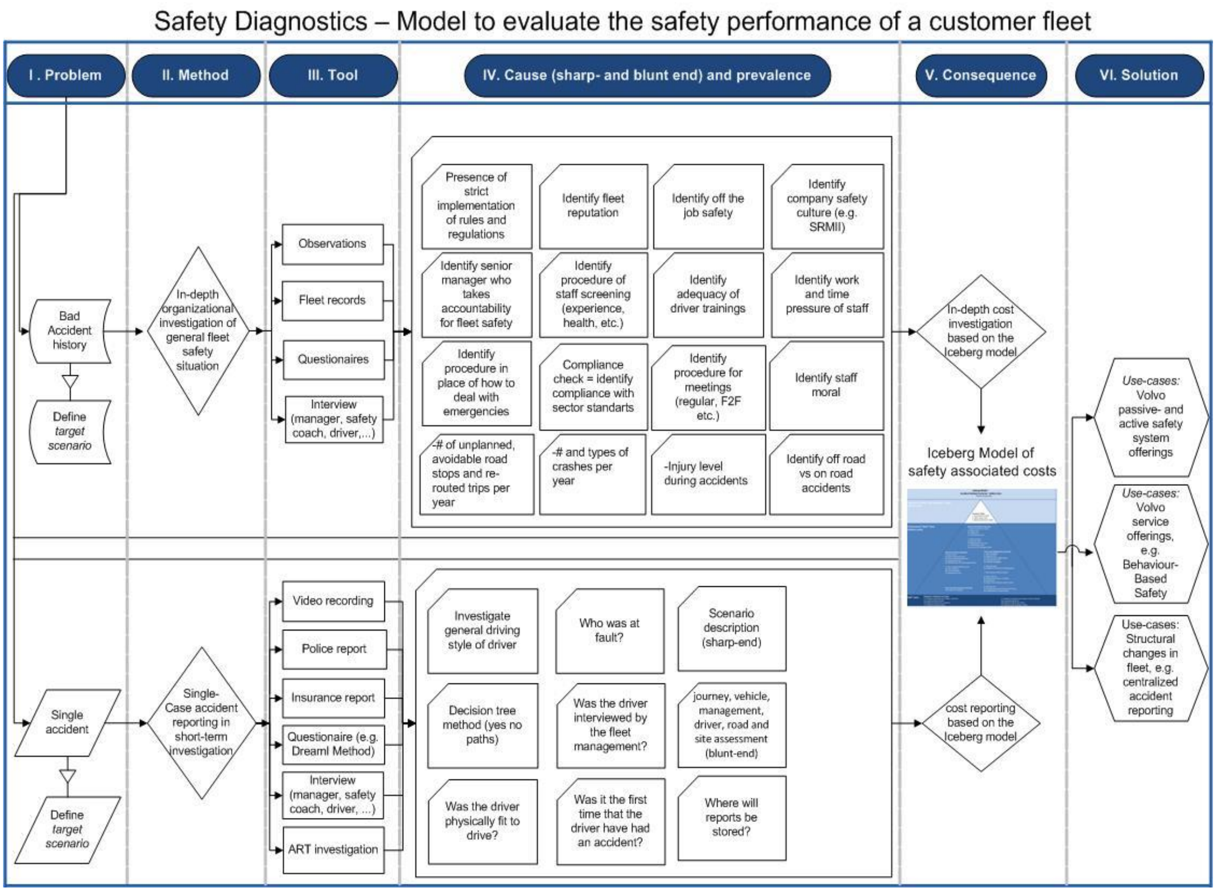

Figure 25 Customer Safety Analytics Methodology – A Model to evaluate the safety performance of a customer fleet

Insights from interviews with insurance companies

Within task 3.3 in-depth interviews were conducted with safety specialists from each of the four major Swedish transport insurance companies: Folksam, IF , Trygg Hansa, and Lansforsäkringa. The outcomes and insights from these interviews were used directly to shape the methodology for the customer safety analytics concepts: the long-term and short-term safety investigation methods and the Iceberg cost model.

The transcripts from the interviews are available on request. Data and visual representations of the data, such as graphs are available on request. Below is an executive summary of the interview results:

- Most insurance cost are caused by long term payments for disabled people not death
- Highest cost for brain injuries
- Third party insurance covers injuries
- Hospital cost covered by Swedish State
- 50-50 damage to vehicle and material cost
- A few percent of the claims go to courts with extra costs associated
- personal damages are more expensive but vehicle damages are more common
- Most common accident type for trucks in 2014 was hitting standstill object (like poles, rocks and etc. but not stand still vehicles) and it accounts for 23% of total number of accidents, around 3800/year (source Trygg Hansa)
- Second most common type of accident was damage to the window glasses which accounts for 19% of number of accidents (source Trygg Hansa)
- Third most common type is hitting parked vehicles, which accounts for 15% of accidents (source Trygg Hansa)
- The above numbers are regarding the number of accidents, but if cost is considered not numbers the most costly accidents are accidents will be again hitting standstill objects which account for 30% of the costs in 2014 (source Trygg Hansa)
- Then single accidents, like run off-road accidents are the second most costly with 20% of the costs in 2014 (source Trygg Hansa)
- Driver education and trainings are always welcome as an effect on claim value and royalty of customers. Part of driver education should be on usage of safety systems in the trucks in order to prevent occasional usage

In summary, there are a lot of hidden costs of collisions (on road and non-road). Volvo has developed a systematic approach on how to analyze the recurrent accident problems as well as for a single accident. This helps customers to understand their safety problem and helps Volvo to understand the organization. The models that were developed were the Iceberg Model of Safety associated costs and a model top evaluate the safety performance of a customer fleet - ”Safety Diagnostics Model” as well as a codebook to evaluate non-road accidents.

Due to difficulties of recruiting a customer fleet on which to test the methods developed in T3.3, within the timeframe of the project, the work demonstration of the customer safety analysis methods developed in T3.3 could not be conducted.

Conclusions

The present report provided a general overview of the safety evaluation framework developed in EFrame with some examples of how it can be used to address different safety evaluation needs within AB Volvo (defined here in terms of a set of Evaluation Use Cases).

For the framework to be used, it is critical that it is adopted by the AB Volvo Accident Research Team (ART) and further adapted to the in-house development processes at Volvo. One key issue identified in the project was the lack of sufficient in-depth or naturalistic driving data needed to define Level 2 target scenarios. A virtue of the present framework is that it clearly identifies the data needs for different types of analysis, which helps motivating future investments in data, both at Volvo and Chalmers.

In general, further research is needed to apply the framework on specific test cases other than those addressed in WP4, but also to further develop some of the specific methods. In particular, this concerns methods related to pre-crash causation analysis based on naturalistic crash data (e.g., CANDE) and pre-crash simulation methodologies for virtual prototyping (EUC4) and safety benefit analysis (EUC3). This is partly addressed in the recently started QUADRAE FFI project which thus can be regarded as a key receiver of EFrame results.

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Participating parties in the EFrame Project

Project key persons:

johan.a.engstrom@volvo.com

claudia.wege@volvo.com

robert.thomson@chalmers.se

giulio.piccinini@chalmers.se

jonas.bargman@chalmers.se

andras.balint@chalmers.se

elham.pirnia@volvo.com

fredrik.thornvall@volvo.com

stefan.thorn@volvo.com

helen.fagerlind@chalmers.se

karsten.heinig@volvo.com

Advisors:

Sofia Löfstrand, Volvo

Mikael Söderman, Volvo

Peter Kronberg, Volvo

Christian-Nils Boda, Chalmers

Folksam, IF , Trygg Hansa, and Lansforsäkringa

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