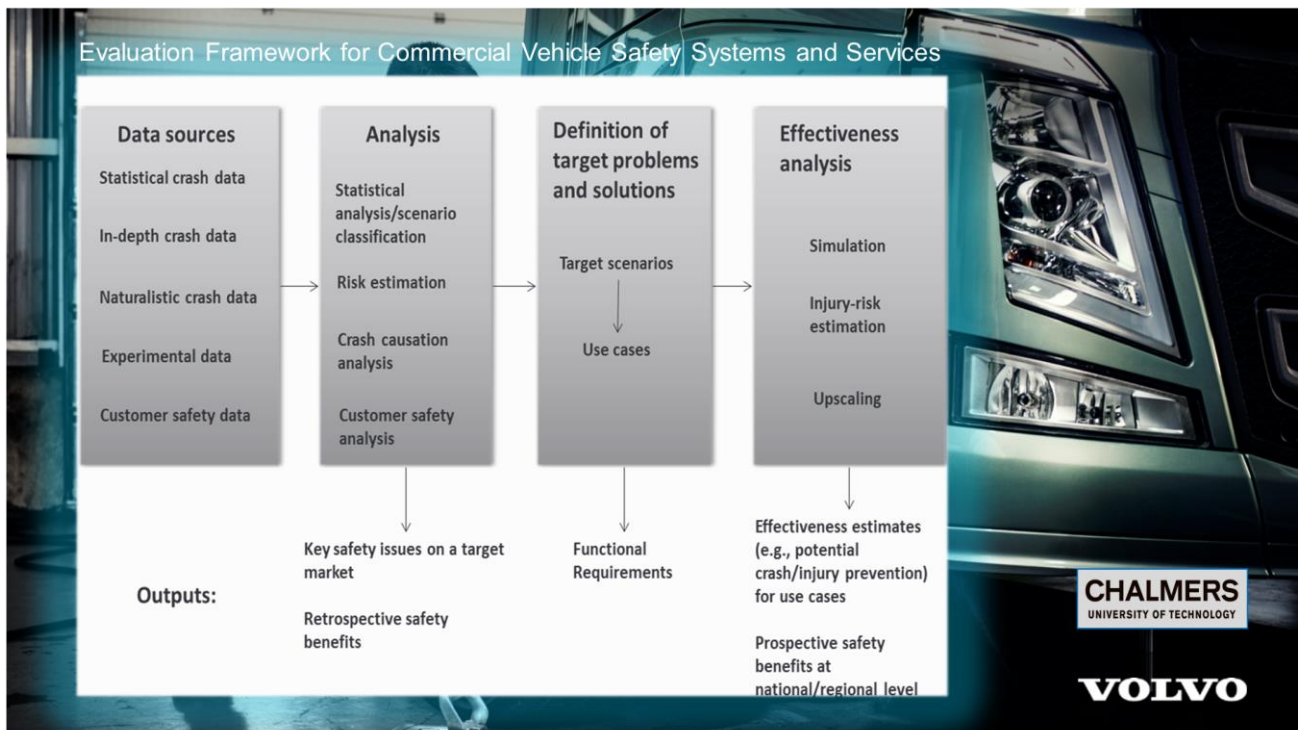


Evaluation Framework for Commercial Vehicle Safety Systems and Services (EFrame)



Project within 2013-01306 FFI Vinnova

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

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1. Executive summary

The main project aim 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 (1) identifying and focusing on the most important safety problems, (2) estimating the potential and actual safety benefits of safety systems and services and (3) identifying the data sources needed to perform these analyses.

The project started with identification of the general types of safety evaluation analyses 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 (WP1). Next, an initial sketch of the framework, in terms of the data sources and analysis needed to address the EUCs were developed (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 (WP4). Thus, the project objectives have generally been met, although further development and testing is needed on other concrete test cases beyond than those addressed in WP4.

The framework has the potential to reduce the number of killed and injured in traffic by focusing industrial development and academic research on the most effective safety systems and services and increases AB Volvo's international competitiveness by further strengthening its safety system/services offering. The project has also, thanks to its broad scope, fostered increased collaboration between different sub-fields of traffic safety analysis (e.g., passive safety, active safety and road user behavior analysis) and thus contributed to the development of a critical mass of competence at SAFER/Chalmers/Volvo in this area.

2. Background

Modern commercial vehicles are equipped with a range of passive and active safety systems with a strong potential to increase traffic safety and reduce safety-related costs, both from a societal and a transport operator perspective. In addition, the customer demand for different types of services aiming to increase safety and reduce associated

costs (for example behavior coaching services such as Lytx¹ or insurance-related driver profiling services, e.g. Wunelli²) is high.

To optimize the safety and cost benefits of these safety systems and services, a detailed understanding of (1) the problems that they are intended to solve, i.e., the targeted accidents and injuries and the associated costs, (2) the (actual and/or potential) effectiveness of the systems/services in preventing/mitigating these problems and (3) the data source required to conduct these analyses is needed. While a variety of data sources and methodologies exist that address different aspects of this problem (e.g., national accident statistics, in-depth accident analysis studies and databases, naturalistic driving studies and field operational tests and human body/structural mechanics/driver behavior modeling and simulation), there has been relatively little work on putting together these pieces in a comprehensive framework for safety evaluation of vehicle safety systems.

3. Objective

The general objective of the EFrame project was to develop a generic safety evaluation framework that integrates different relevant of data sources, methods and tools into a structured process for the safety evaluation of commercial vehicle safety systems and services. The framework should target not only severe accidents (injuries/fatalities) but also property damage only road crashes as well as non-traffic-related accidents (e.g., backing up collisions). It is important to stress that the goal is not to develop the framework and its components from scratch but to re-use and adapt as much as possible of the results from previous and ongoing projects in Sweden and elsewhere.

The more specific objectives were to:

1. ...define the general structure of the envisioned safety evaluation framework and the key requirements on its components
2. ...perform a survey the state-of-the-art for existing data sources, methods and tools that can be used as components in the safety evaluation framework and identify the key gaps where further research and development is needed
3. ...adapt and refine existing methods and tools to fit into the framework and develop new methods and tools to fill the gaps identified in (1)
4. ...demonstrate the application of the framework to the evaluation of a set of selected safety systems and services and update the framework based on potential problems encountered when applying the framework.

¹ www.lytx.com

² www.wunelli.com

4. Project realization

The project was structured around the four specific objectives outlined above, which were each addressed in a separate work package, as illustrated in Figure 1.

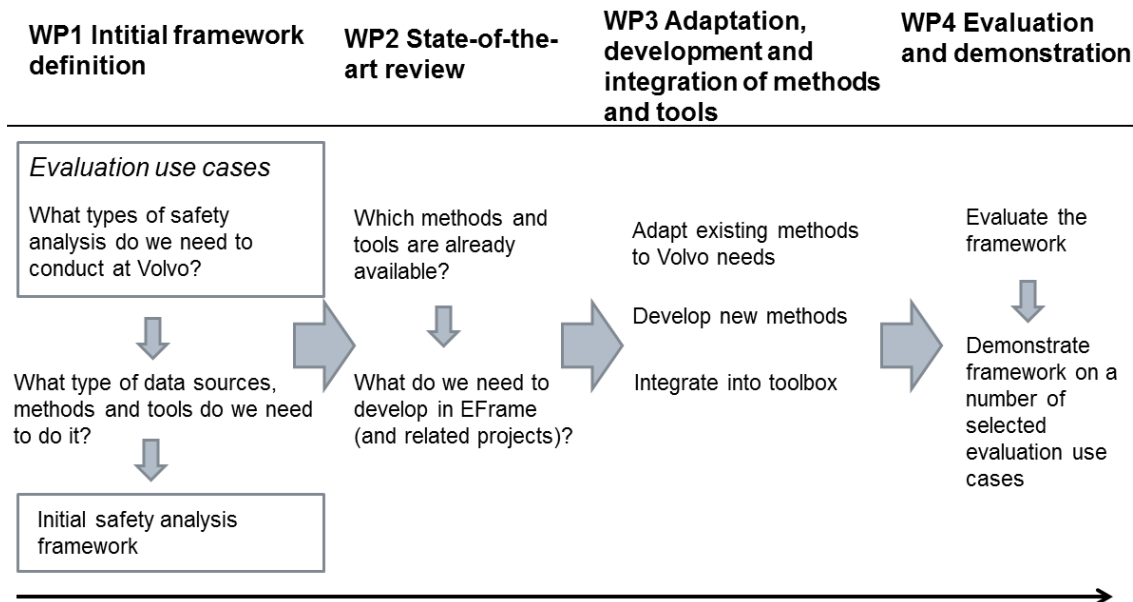


Figure 1 The general structure of the EFrame project

The key starting point for the project work was the definition of a set of so-called Evaluation Use Cases (EUCs) in WP1, which represented specific examples of how the envisioned safety evaluation framework was intended to be used at AB Volvo (the EUCs are further described in the following chapter). Thus, the EUCs defined the key requirements for the framework in terms of data sources and analysis methods. Based on this, an initial sketch of the framework was developed. WP2 then constituted a state-of-the-art analysis with the purpose to identify which framework components were already available and to what extent novel developments were needed in the project to realize the EUCs defined in WP1. Based on the results from WP2, WP3 then involved the development and/or adaptation of the required framework components needed to realize the EUCs defined in WP1. Finally, WP4 involved the demonstration and evaluation of the framework on a set of selected “test cases”. Based on this, the final framework was defined.

The concrete results from the four work packages are further described below.

5. Results and deliverables

5.1: WP1 Initial framework definition

As mentioned above, the starting point for the present work was to define the general requirements on the framework in terms of a set of Evaluation Use Cases. This resulted in the following EUCs:

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 initial safety performance of a customer fleet (e.g., in terms of crash rate or in terms of costs) and specific improvements (for the customer, e.g., in terms crash and associated cost reductions) offered by safety systems and services. The aim was to include both crashes on-road and off-road (e.g. at a customer site or in a closed logistical area like goods distribution at harbors).

Figure 2 illustrates the relation of the identified Evaluation Use Cases to the general Volvo safety development process (the “circle of life”). The EUCs were documented in the Powerpoint presentation “EFrame description of EUCs” which also contains further concrete examples.

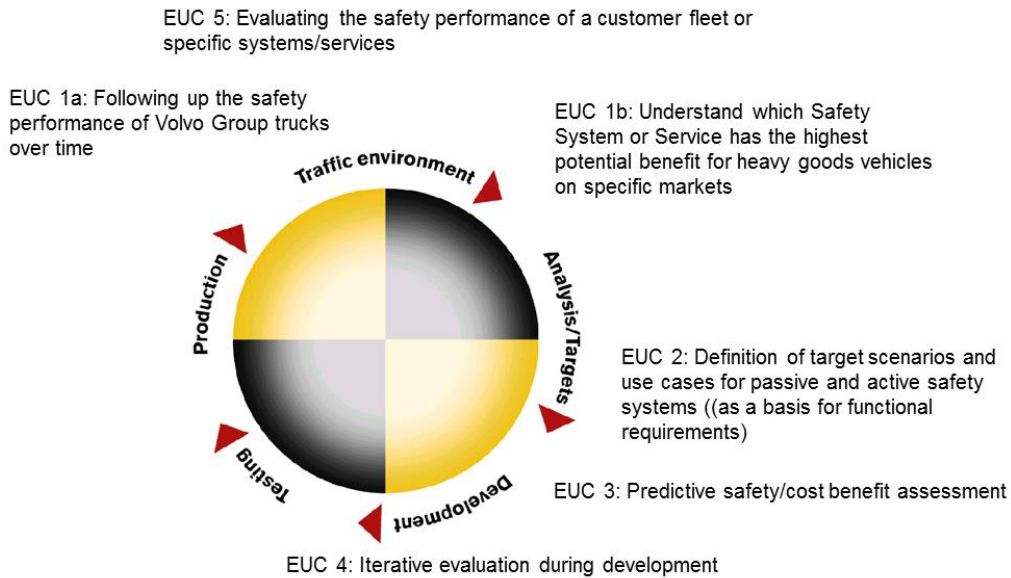


Figure 2 Illustration of the EFrame EUCs within the general Volvo safety development process (the “circle of life”)

Based on this set of EUCs, an initial sketch of the framework was developed, in terms of the required components (data sources and analysis methods) and their mutual relations. This initial sketch, shown in Figure 3, then served as the basis for the state-of-the-art analysis in WP2.

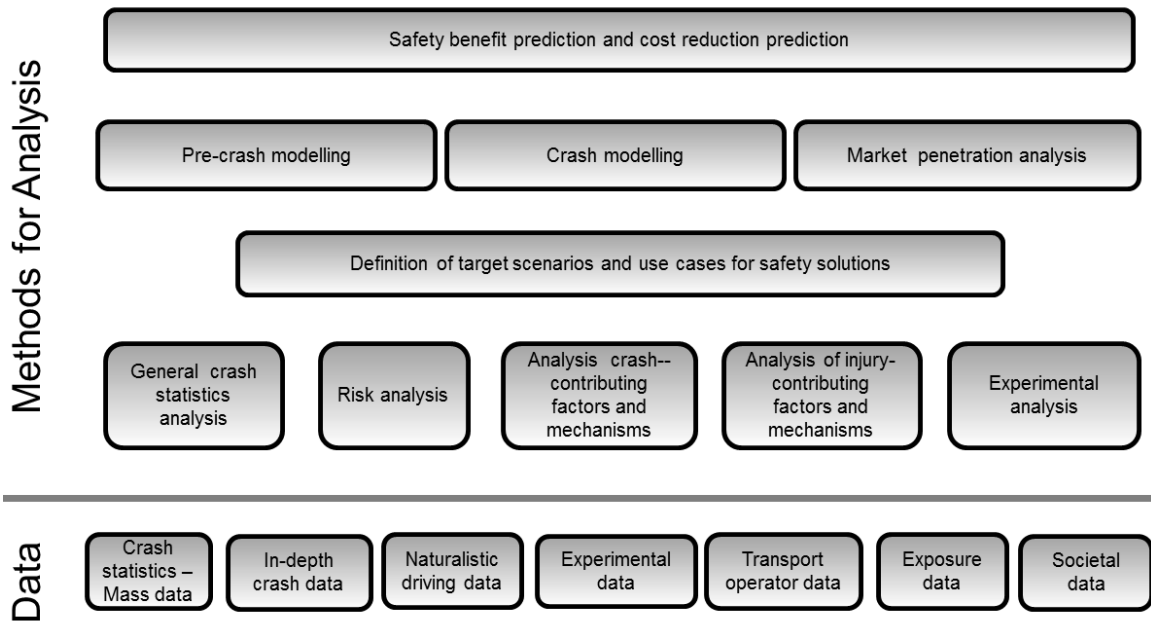


Figure 3 Initial sketch of the framework with the main required types of components

5.2 WP2: State-of-the-art analysis

The aim of the state-of-the-art analysis was to identify which components of the preliminary framework sketched in WP1 were already available and which required further development (in WP3). Thus, the review was organized around, and limited to, the components identified in WP1. Separate reviews were conducted for each component (with a few exceptions) and documented in review reports based on a common report template. The available state-of-the-art review reports are listed in Table 1. The conclusions from WP2 are summarized in the WP2 summary report³.

Table 1 List of state-of-the-art reports compiled in WP2

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)

³ Thompson, R. 2015. Summary of State of the Art – Work Package 2.

EFrame_WP2_SoA_Experimental data	Giulio Piccinini (Chalmers)
EFrame_WP2_SoA_Exposure_data	Helen Fagerlind (Chalmers)
EFrame_WP2_SoA_Societal_data	Claudia Wege (Volvo)
EFrame_WP2_SoA review_General_crash_statistics_analysis	András Bálint (Chalmers)
EFrame_WP2_SoA_Risk_analysis	Johan Engström (Volvo)
EFrame_WP2_SoA_ACCM	Jonas Bårgman (Chalmers)
EFrame_WP2_SoA_Experimental analysis	Giulio Piccinini (Chalmers)
EFrame_WP2_SoA_Target scenarios_and_use_cases	Johan Engström (Volvo)
EFrame_WP2_SoA review_Pre-crash_modelling	Johan Engström (Volvo)
EFrame_WP2_SoA_Crash_Modelling	Rob Thomson (Volvo)
EFrame_WP2_SoA_Safety-cost_benefit_prediction	Giulio Piccinini (Chalmers)

5.3 WP3: Adaptation, development and integration of methods and tools

Based on the review of available data sources and analysis methodologies in WP2, specific targets for adaption, development and/or integration of methods were defined in order to meet the needs of the Evaluation Use Cases (EUCs) defined in WP1. The work is summarized in the WP3 summary report.

The methods focused on are summarized below for each EUC:

EUC 1a: Following up the safety performance of Volvo Group trucks over time

The main focus here was on methods for comparing crash/injury risk between different vehicle populations (e.g., Volvo trucks vs. other brands or trucks equipped with a safety system vs. non-equipped trucks) based on national/regional statistical crash and exposure data. Various existing risk estimation approaches were investigated and adapted to the present purposes. In addition, availability of the needed crash and exposure data needed was investigated for different regions, concluding that this type of analysis requires more advanced databases (such as the Swedish STRADA and the US NASS General Estimation System). Moreover, a list of Key Performance Indicators (KPIs) defining road safety performance was compiled. Based on these components, a general methodology for addressing EUC1a was developed. This work is described in Task Report 3.2⁴.

⁴ Bálint, A. and Pirnia E. 2015. Task report of work achieved in WP 3 Task 3.2.

EUC 1b: Understand which Safety System or Service has the highest potential benefit for heavy goods vehicles on specific markets

In order to address EUC1b, it was decided to focus on data-driven methods for identifying key safety problems in a region based on available statistical crash data. The results from this analysis can then, on a high level, be used to understand what sorts of safety features have the greatest potential to address these problems. One approach for data-driven statistical analysis, increasingly used also in the traffic safety domain, is recursive trees (e.g., random forest and random trees) and it was decided to explore this further in WP3 and adapt it to present purposes. The initial exploration is documented in Task Report 3.2 and the final methodology was defined and tested in WP4 (see below).

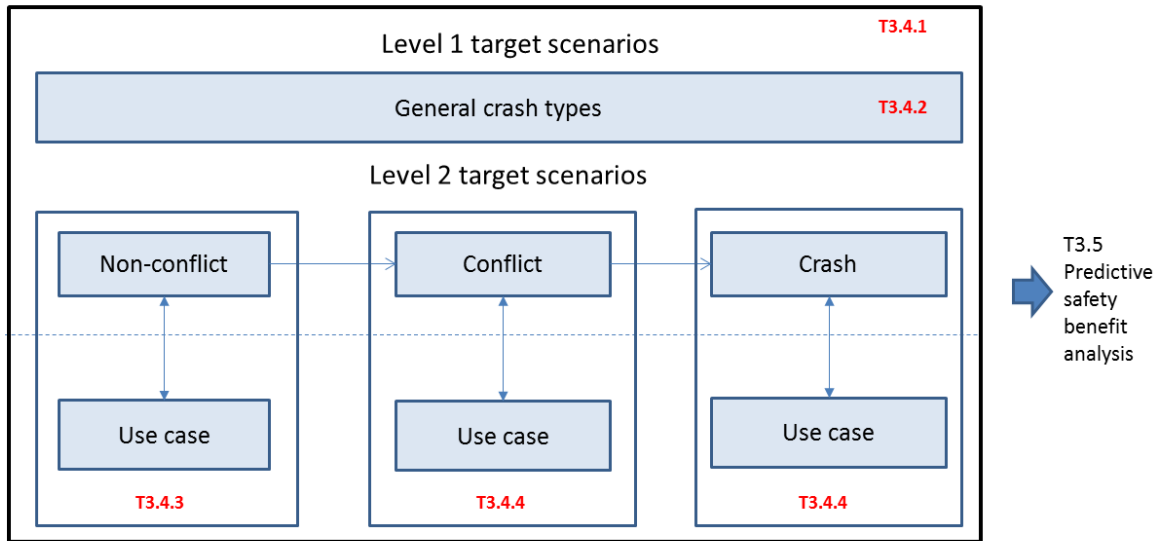
EUC 2: Definition of target scenarios and use cases for passive and active safety systems

This work involved the further development and adaptation of a methodology for target scenario and use case definition previously developed in the InteractIVe EU-funded project⁵. While InteractIVe mainly addressed active safety systems in the conflict phase, the present methodology needed to be expanded to cover the crash and non-conflict phases and related safety features (e.g., passive safety systems and behavior-based services respectively). It was concluded that, although the same overall logic should apply to all three phases, different specific methods and templates for defining target scenarios and use are needed. The overall proposed framework for target scenario and use case definition is illustrated in Figure 4. In addition, specific methods and templates for target scenario and use case definition for the three phases (non-conflict, conflict and crash) were developed as part of this task. Finally, a method for expert-based crash causation analysis based on naturalistic crash data (CANDE, Causation Analysis for Naturalistic Driving Events) was further developed based on previous work. The work is documented in the Task 3.4 report⁶.

⁵ Engström, J., Kanstrup, L., Brockmann, M., Hesse, T., Flemish, F., & Varalda, G. (2010a). Template for target accident scenario definition. interactIVe Internal Report; Engström, J., Kanstrup, L., Brockmann, M., Hesse, T., Staubach, M., Flemish, F., o.a. (2010b). Template for use case definition. interactIVe Internal Report.

⁶ Engström, J., Piccinini G.B., & Törnvall, F. 2015. Task report of work achieved in Task 3.4: Target scenario and use case definition.

Target scenarios: Defining the problem and the underlying mechanisms



Use cases: Defining how the problem is intended to be solved by a specific safety system/service

Figure 4 Target scenario and use case definition framework

EUC 3: Predictive (prospective) safety/cost benefit assessment

This work involved the development of processes for safety benefit analysis for the crash and conflict phases, linked to the target scenario and use case methodology defined in Task 3.4. As for the target scenario and use case methodology, the overall logic is similar for the different phases but the specific methodologies differ. More detailed methodologies for carrying out the benefit assessment was developed and demonstrated in WP4 (see below). The work is documented in Task Report 3.5⁷

EUC 4: Iterative evaluation during development

Due to resource constraints, this EUC was not directly addressed in WP3. However, the simulation-based tools developed for safety benefit analysis in WP4 can potentially also be used for iterative evaluation during development, as further outlined below.

EUC 5: Evaluating the safety performance of a customer fleet or specific systems/services

As Volvo is working towards establishing a future oriented relationship with their customers (Part of long-term commitment with the customer), it is important to have a holistic view on safety and cost benefit assessments. A proper diagnostic of the management figures/procedures at the customer is invalid for a holistic safety assessment. In EUC5 a solid methodology for such a diagnostic tool box (especially focusing on relevant data from customers and insurances) was established. The holistic view includes on-road and non-road vehicle crashes. Complementary to

⁷ Piccinini, G. 2015. Task report of work achieved in WP 3 Task 3.5. (EUC3)

the objectives above, an experimental methodology on how to evaluate a deployed safety service is proposed⁸.

5.4. WP4: Evaluation and demonstration

The objective of WP4 was to provide concrete demonstrations on how the methods and tools developed in WP3 could be used to address the EUCs, and based on this provide the final definition of the framework. To this end, a number of specific test cases were defined for each general EUC. The general results from WP4 are summarized in the WP4 summary report⁹.

5.1.1. Demonstrations

The results from the demonstrations are summarized below for each EUC.

EUC 1a: Following up the safety performance of Volvo Group trucks over time

The general safety performance evaluation methodology defined in T3.2 was used to compare Volvo trucks to competitor brands with respect to different safety KPIs (such as number of crashes or injuries). The analysis was based on US crash data (NASS-GES) and exposure calculated based on market share. The results showed that the method is generally feasible but requires relatively detailed crash and exposure data which is only available for certain markets (with advanced crash reporting and database systems). The work is documented in Task 4.1 Report, EUC1a¹⁰.

EUC 1b: Understand which Safety System or Service has the highest potential benefit for heavy goods vehicles on specific markets

This work demonstrated the application of recursive tree methods (random forest plus decision tree methods) for identifying general safety problems on STRADA (Swedish national crash statistics) data. The approach is very promising and may also be used more directly for the definition of target scenarios (EUC2). The results are reported in the Task 4.1 Report, EUC1b¹¹.

EUC 2-4: Definition of target scenarios and use cases, predictive (prospective) safety/cost benefit assessment

⁸ Wege, C. and Pirnia, E., Task report of work achieved in WP 3 Task 3.

⁹ Thompson, R. 2016. Summary of WP4 – Proof of Concept of EFRAME Methodologies.

¹⁰ Balint, A. 2016. Task report of work achieved in WP 4 Task 4.1. EUC1a: Following up the safety performance of Volvo Group trucks over time

¹¹ Pirinia, E. 2016. Task report of work achieved in WP 4 Task 4.1. EUC1b: To understand which Safety System or Service has the highest potential benefit for heavy goods vehicles on specific markets.

The general methodology for safety benefits assessment, including initial target scenario and use case specification was demonstrated both for passive safety features in the crash phase and active safety features in the conflict phase.

The demonstration for the conflict phase constituted simulation-based safety benefit assessment of an Automatic Emergency Braking System (AEBS). This involved the definition of target scenarios and use cases based on US national crash data (NASS-GES) as well as naturalistic crash data (obtained from Lytx¹²) to understand detailed crash causation mechanisms. Moreover, novel methods for system effectiveness calculation through counterfactual (what-if) simulation and upscaling to national-level crash statistics were developed, based on the general framework in T3.2. The approach proved promising although the results from this particular demonstration application could not be generalized due to limited number of naturalistic crashes available. It was also demonstrated how this type of simulation-based effectiveness analysis could be used in the context of EUC4 (iterative development through virtual prototyping). The work is documented in the T.4.3 report¹³.

A similar demonstration of safety effectiveness evaluation for the crash phase is reported in the Task 4.4 report¹⁴. The demonstration focused on target scenarios (injuries) related to frontal collisions with use cases relating to protective features in the cabin (a rotating steering wheel column and boron steel floor and windscreen members). The effectiveness of these features in preventing injuries in the target scenarios was analyzed analytically by deriving injury-risk functions based on in-depth crash and injury data obtained from the ETAC database). Like for the conflict phase demonstration, the approach was feasible and promising but the present analysis was somewhat limited by the small size of the ETAC database.

EUC 5: Evaluating the safety performance of a customer fleet or specific systems/services

The general methodology for identifying the existing safety problems in a customer (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?, etc.) 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 5) was generated. A detailed description of the model can be found in T.3.3 report¹⁵.

¹² <https://www.lytx.com>

¹³ Engström, J., Bärghman, J. and Lodin, J. 2016. Task report of work achieved in WP 4 Task 4.3 (EUC2-4): Safety benefit estimation for an Advanced Emergency Braking System.

¹⁴ Thorn, S. and Törnvall, F. 2016. Task report of work achieved in WP 4 Task 4.4.

¹⁵ ¹⁵ Wege, C. and Pirnia, E., Task report of work achieved in WP 3 Task 3.

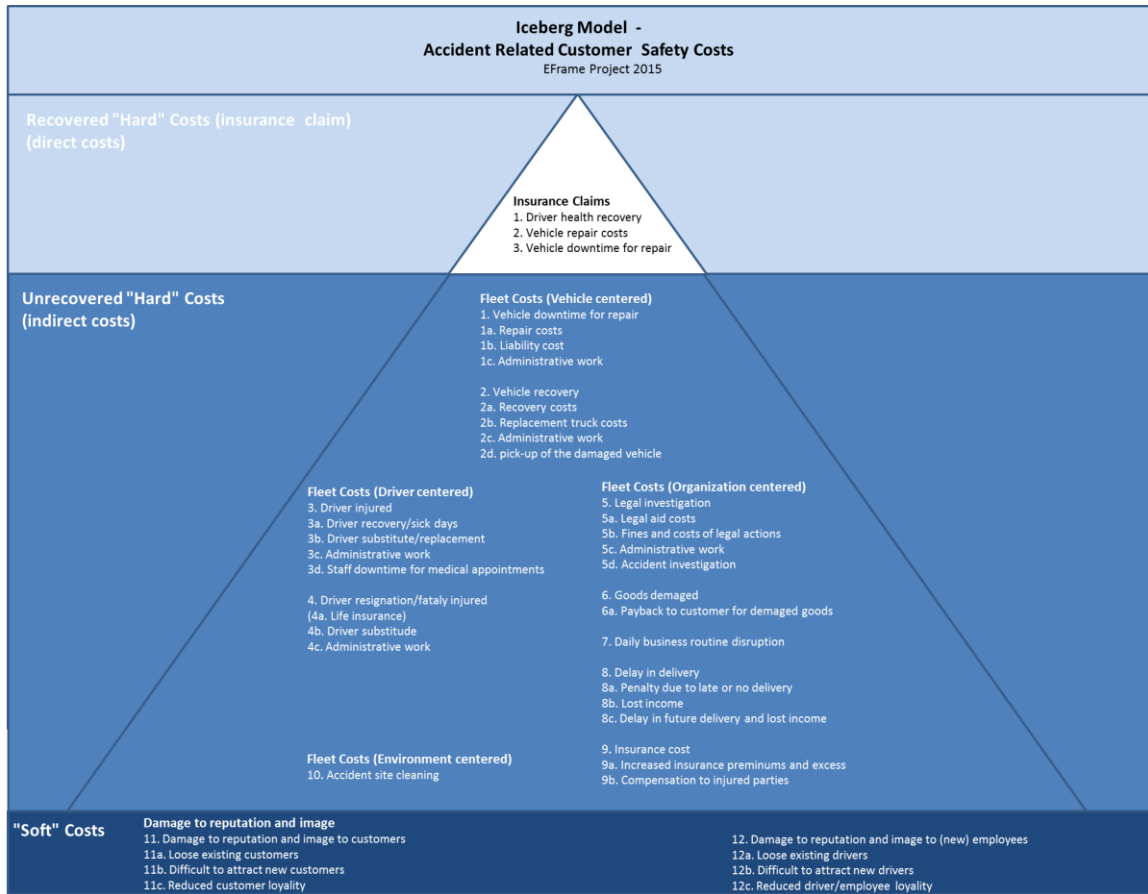


Figure 5 Iceberg Model on Accident Related Customer Safety Costs

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.

5.1.2. Evaluation and final framework specification

In general, the framework and the individual methods worked well in the test cases addressed in WP4. However, one issue identified was that it is not feasible to maintain a strict one-to-one mapping between (Level 2) target scenarios and use cases, since a single safety feature may apply to several target scenarios. Moreover, a safety feature may have unintended effects in crash scenarios that it was not aimed to target. Moreover, it was suggested to make some changes the overall structure of the target scenario hierarchy.

Another issue that became clear in WP4 was the lack of sufficient amounts of in-depth or naturalistic crash data, especially for safety benefit evaluation purposes (both for passive and active safety purposes). Such data does exist (e.g., in the German GIDAS database) and a key benefit of the present framework is that it yields clear requirements on the type of data needed to realize the Evaluation Use Cases by means of the proposed methods. This could help to motivate future investments in data both on the industrial and academic side.

Based on the outcome of these demonstration applications, a high-level final specification of the framework was developed, reported in the Final Evaluation Framework Specification¹⁶. The final framework is schematically illustrated in Figure 6 below.

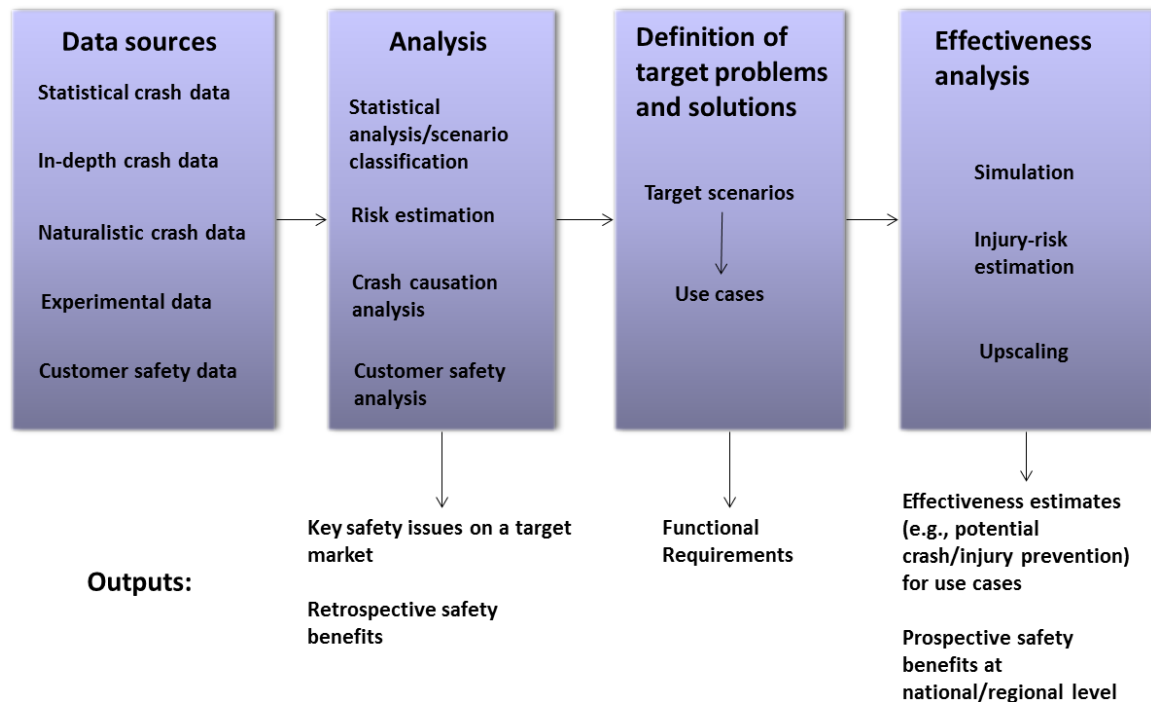


Figure 6 High-level view of the final evaluation framework

5.5. Delivery to FFI-goals

The Swedish parliament decided in 2009 on a national road safety target where the number of road fatalities in Sweden should be halved until 2020 and the number of serious injuries reduced by 25%. It is expected that new safety systems and services addressed by the FFI program for Vehicle and Traffic Safety are able to contribute

¹⁶ Engström, J. 2016. EFrame: Final Evaluation Framework Specification.



significantly toward reaching this target. The present project has contributed to this target by

- ...facilitating a better understanding of the basic problems addressed by the FFI program for Vehicle and Traffic Safety, that is, accidents and injuries, and offering a structured safety evaluation methodology that helps to focus development on the most effective crash/injury countermeasures
- ...facilitating following up the safety benefits of systems and services on the market. This will, among other things, greatly aid the effect analysis needed in 2020 to follow up to what extent the target has been reached and to what extent this can be attributed to safety technologies developed within FFI
- ...enhancing knowledge in the traffic safety analysis field and creating a critical mass at Volvo and Chalmers that will form the basis for future R&D in this area

More generally, the framework will enhance Volvo's international competitiveness and help the company to maintain its status as a leading commercial vehicle manufacturer in safety.

6. Dissemination and publications

6.1 Knowledge and results dissemination

The key for the EFrame results to have a real impact is that it is adopted as part of actual system/service development at Volvo. Thus, a major Volvo-internal dissemination event has been planned for August 2016. External dissemination at Chalmers/SAFER will also take place after the summer holidays.

Another key dissemination channel is through knowledge transfer to new projects. One key example here is the target scenario use case specification and safety benefits estimation methodologies developed in EFrame (documented mainly in the Task 3.4, 3.5 and 4.3 reports) which is currently used as starting points for the QUADRAE FFI project (aiming at the development of quantitative driver models for simulation and virtual prototyping of active safety systems). In this way, the concepts developed in EFrame are disseminated to, and further developed with, other industrial stakeholders (Volvo Cars and Autoliv).

6.2 Publications

Due to resource constraints within Chalmers and Volvo, no scientific publications have been produced from EFrame. However, we still believe that many of these results are

publishable and we still have an intention to publish a set of papers. In particular, this concerns the counterfactual simulation work reported in Task Report 4.3 which constitutes a major novel scientific contribution from the project. A publication is planned on the CANDE (Causation Analysis for Naturalistic Driving Events) methodology developed as part of WP3.

The final report will be published at the projects website:

<http://www.chalmers.se/en/projects/Pages/Evaluation-Framework-for-Commercial-Vehicle-Safety-Systems-and-Services.aspx>

7. Conclusions and future research

As described above, the key objective of the EFrame project was to develop a generic framework for safety evaluation to be used in an industrial, commercial vehicle manufacturer, setting and to demonstrate this framework on a set of representative safety evaluation problems. As such, the project objectives have clearly been met. However, the eventual impact of the framework will depend on the extent to which it is actually being deployed in actual development at Volvo and in further academic research at Chalmers/SAFER.

One key issue identified in the project was the lack of sufficient in-depth or naturalistic driving data, especially to realize EUC3 (safety benefit analysis). Another short coming was the difficulties of recruiting a customer fleet on which to test the methods developed concerning safety costs (Iceberg Model on Accident Related Customer Safety). A key benefit of the present framework is that it clearly identifies the data needs for the required types of analysis, which helps motivating future investments in such 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 the individual 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 can be regarded as a key receiver of EFrame results.



8. Participating parties and contact person

Project Manager:

Claudia Wege; claudia.wege@volvo.com

Authors of the final project report:

Johan Engström; johan.a.engstrom@volvo.com

Claudia Wege; claudia.wege@volvo.com

Project key persons:

johan.a.engstrom@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

FFI

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FORSKNING OCH INNOVATION

Adress: FFI/VINNOVA, 101 58 STOCKHOLM
Besöksadress: VINNOVA, Mäster Samuelsgatan 56, 101 58 STOCKHOLM
Telefon: 08 - 473 30 00
ivss@v.v.se
www.ivss.se