HIGH SPEED RAIL ASSESSMENT,
PHASE 3

**Norwegian National Rail Administration**

## Report - Risk and Safety Analysis

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| 3 |  |  |  | - |  |
| 4 |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

# Table of contents

# List of tables

## List of figures

# List of abbreviations

| | |
|---|---|
| AAR | Association of American Railroads, US |
| ATC | Automatic Train Control |
| ATOC | Association of Train Operating Companies in the United Kingdom |
| AVE | Alta Velocidad Espagñol, Spanish HS train concept |
| CER | Community of the European Railways |
| CSM | Common Safety Methods |
| CST | Common Safety Targets |
| CSI | Common Safety Indicator |
| DMU | Diesel Multiple Unit |
| EIM | European Rail Infrastructure Managers |
| EMU | Electric Multiple Unit |
| EN | Euronorm |
| ERA | European Railways Agency |
| EqFa | Equivalent Fatalities (means a measurement of the consequences of significant accidents combining fatalities and injuries, where one fatality is considered statistically 10 major or 100 minor injuries). |
| ERADIS | European Railway Agency Database of Interoperability and Safety |
| ETCS | European Train Control System |
| EU | European Community |
| FLIRT | Fast Light Innovative Regional Train, EMU produced by Stadler Rail AG |
| FRA | Federal Railroad Administration, US |
| HS | High Speed |
| HSL | High Speed Line |
| HSR | High Speed Rail |
| HVAC | Heating Ventilation and Air Conditioning |
| IC | InterCity |
| ICE | InterCity Express, German HS train concept |
| ICAO | International Civil Aviation Organization |
| Interfleet | Interfleet Technology, International Rail technology Consultants |
| JBV | Jernbaneverket, Norwegian National Rail Administration |
| KIT | Karlsruhe Institute of Technology |
| km | Kilometres |
| min | Minute |
| Mio. | Million |
| NRV | National Reference Value |
| NNR | Notified National Rules |
| NSA | National Safety Authority |
| OHL | Overhead Line |
| Pkm | Passenger kilometres |

| Q | Probability |
|---|---|
| RA | Railway Authority |
| RAC-TS | Risk Acceptance Criterion for technical systems |
| RSSB | Railway Safety Standards and Boards, UK |
| SCB | Swedish Statistisk Centralbyrå |
| SI | Safety Integrity |
| SIL | Safety Integrity Level |
| SJT | Statens Jernbanetilsyn (Norwegian Railway Inspectorate) |
| SRA | Safety Regulatory Authority |
| SSB | Statistisk sentralbyrå |
| TGV | Train à grande vitesse, French HS train concept |
| THR | Tolerable Hazard Rate |
| TSI | Technical Specifications for Interoperability |
| UIC | International Union of Railways |
| UK | United Kingdom |
| UNIFE | Union des Industries Ferroviaires Européennes, Association of the European Rail Industry |

# 1   Summary – risk assessment and safety

## Summary - Risk assessment on the high speed lines

The risk assessment focuses on specifying a parametric model for each of the 4 corridors to estimate the underlying residual risks of the corridors. Based on the two generic risk models for two system variants (track upgrade with mixed traffic and new track with high speed operation only) from phase 2, corridor information such as average speed, single track vs. double track, tunnel and viaduct contingents, mixed traffic vs. passenger traffic allows a refinement of the risk model parameters and consequently a reduction in the underlying uncertainty of the model.

Nevertheless a substantial degree of uncertainty remains and is inherent in estimating risks for complex transport systems. The range of possible outcomes for estimated average equivalent fatalities depends on an infinite set of influencing variables. The number of reported equivalent fatalities in Norway and the rest of Europe varies substantially year over year and a few major accidents drive the average for certain time spans. This is especially true for high speed train operation where one major accident may change the picture for the years to come. Comparing conventional rail and high speed rail, the probability distribution of conventional rail related fatalities per year (and also per accident) seems to follow a lognormal distribution whereas the high speed rail related fatalities seem not to follow a probability distribution at all. This assumption makes it even more difficult to estimate the expected number of fatalities per year as statistical data regarding number of severe accidents for high speed trains is very limited.

Comparing the accident scenarios for conventional railways and high speed railways the overall accident rates for high speed railways is estimated to be lower than for conventional train operation. This is due to:

- No level crossing accidents
- Probability for collision train - train substantially lower because of more modern signalling systems and less mixed operation with freight trains
- Propability for collision train – object lower because of separation of track and environment (fences etc)
- Probability for derailment lower because of new or upgraded tracks
- Probability for person injured at platform lower because of less stations and safer boarding process

This result is somewhat compensated by the fact, that for the 3 accident scenarios:

- Collision train-object
- Collision train-train
- Derailment

The consequences in estimated equivalent fatalities are more severe due to higher kinetic energy / speed and a higher number of exposed persons. As the two influencing variables level out the estimated risk level for high speed train operation is comparable to the operation with conventional trains. It would be more favorable for high speed operation when considering platform related accidents when the train is at standstill, as the risk for injuries during boarding processes is substantially lower for high speed trains.

From a risk perspective the implementation of high speed corridors in Norway is admissible. A breach of the current Norwegian risk acceptance criteria is not to be expected and it is recommended that a decision to build high speed lines or not shall be based on economic and environmental assessments, and not safety.

## Perspective

With the risk analysis included in this report potential factors which are supposed to influence the risk and in the following the safety level regarding the operation of a new high speed railway system in Norway have been identified. Collective and individual risks have been estimated for two assumed system variants and further refined for specific corridors. Therefore the evaluation of events which may cause accidents and the prediction of potential consequences has been done. In this context, beside the described results, the risk assessment at hand provides an excellent basis for the following safety process.

The risk levels can be reduced by further safety management in a HSR project, focusing on planning and implementation of risk mitigation measures. When implementing a stringent safety management process going forward and avoiding safety related drawbacks of railway infrastructure and rolling stock by doing so, the risk level of high speed train operation will come at the very low end of the described risk spectrum and will in the end provide the safest long distance travel mode as currently experienced in different European countries.

## Summary – Societal safety

The safety of a HSR system can be looked at in isolation where fatality rates per passenger kilometer or train kilometer can be estimated. This has been done in the risk assessment of this work. The safety analysis evaluates the impact of a HSR system on the entire societal transport safety level.

The total transport safety level in this study reflects the total number of fatalities due to travelling by using available modes of transportation. Modes of transportation can be cars, coaches, trains, airplanes, ferries etc. This means that the total safety level is the sum of the safety levels of all modes of transportation.  Any change in distribution between the modes of transportation used affects the total safety level as will a transfer of passengers from existing modes of transportation to a new mean of transportation like a HSR system.

In this perspective a generalized assessment model has been developed that estimates future levels of transport safety and expected changes in safety as a function of transport mode distributions and the introduction of HSR. Economic valuation of the changes in safety level is also performed by the model based on the value of a statistical life.

The model has been used to calculate the safety level of the Norwegian transport system for journeys longer than 100 kilometers and excluding lorry traffic with and without HSR for four different corridors.

The following major conclusions were drawn from the safety analysis:

- The safety difference between a Norwegian transport system with and without HSR is small and with additional mitigation measures, that are discussed in the risk assessment report, the differences could be even smaller or even lead to a decrease in the total number of fatalities in the transport system.

- Implementation of HSR on any of the corridors will result in a slightly higher number of fatalities in the Norwegian transport system (only journeys above 100 kilometers are included). The reason for this is mainly that, according to the future transport predictions by Atkins, there will be a substantial increase of the total amount of transported passenger kilometers when HSR is introduced. The predicted addition of HSR transport volum is very high compared to the reduction in transport volumes for other transport modes.

- The car transport decrease is predicted to be limited after implementation of HSR, whereas the air transport is predicted to be subject to a larger decrease. The car has a lower specific safety level (more fatalities/passenger kilometer) than air transport and train, and air has a higher safety than train transport. Thus, the substantial transfer of passengers from air to train in combination with a substantial addition of HSR traffic results in a decrease in total safety (i.e. an increase of yearly fatalities) that cannot be compensated by the slight reduction in transport volumes for other transport modes.

- The transfer of freight traffic from lorry to rail is predicted by the HSR-study to be very limited, resulting in only a minor impact on the total safety.

- The slight increase of the total number of fatalities must be put in relation to this increase in transport volumes. The implementation of HSR is expected to contribute 1.1 to 1.8 fatalities per additional total billion passenger kilometer, depending on which of the four studied corridors that is implemented. The increased number of fatalities must be put in relation to other possibilities to increase the transport volumes in Norway.

- In the fatality rate calculations in the risk assessment platform accidents have been left out. Since more platform accidents occur on older trains than on newer trains the outcome would probably be favourable to HSR compared to conventional rail if platform accidents were included.

- The safety calculations are associated with substantial uncertainties. A sensitivity analysis shows that the input data for the car transport volumes and safety have the largest impact on the total uncertainty of the calculations. The reason for this is that car traffic is the major mode of transport in the Norwegian transport system and thus contributes most to the expected number of fatalities in the transport system. For the economic calculations, also the selection of the discount rate provides a substantial contribution to the total uncertainty.

- Finally, it once again should be stressed that the change in societal safety levels due to HSR implementation is relatively limited for journeys longer than 100 km in the Norwegian transport system, especially if the increase in total transported passenger kilometers is considered.

# 2   Subject – Risk Assessment

## 2.0   Introduction

This part describes the result from risk assessment in Phase 2, and the result of risk
assessment on the 4 defined corridors in Phase 3.

## 2.1   Definitions

Table 1: Definitions

| Term | Description |
|---|---|
| accident | an unintended event or series of events that results in death, injury, loss of system or service, or environmental damage [1] |
| collective risk | the risk from a product, process or system to which a population or group of people (or the society as a whole) is exposed [1] Comment: Collective risk is often termed as societal risk |
| commercial risk | the rate of occurrence and the severity of financial loss, which may be associated with an accident or undesirable event [1] |
| environmental risk | the rate of occurrence and the severity of extent of contamination and/or destruction of an natural habitat which may arise from an accident [1] |
| equivalent fatality | a convention for combining injuries and fatalities into one figure for ease of processing and comparison [1] |
| failure | A failure is the termination of the ability of an item to perform the required function [1] |
| hazard | a condition that could lead to an accident [1] |
| hazardous event | "Hazard event" is used but not be defined in EN 50126-1. It should be noted that the term, as used in the standard, is not consistently related to a hazard only. In most cases, the term has been used in the standard to mean an "accident" and should be interpreted as such [1] |
| individual risk | the risk from a product, process or system to which an individual person is exposed [1] |
| Railway Authority | In EN 50126-1 this term is defined as: The body with the overall accountability to a Regulator for operating a railway system. [1] |
| risk | the rate of occurrence of accidents and incidents resulting in harm (caused by a hazard) and the degree of severity of that harm (interpretation according to [1]) |
| safety barrier | a system or action, intended to reduce the rate of an hazard or a likely accident arising from an hazard and/or mitigate the severity of the likely accident The effectiveness will depend on the extent of the independence [1] |

| Term | Description |
|------|-------------|
| tolerable risk | EN 50126-1 [2] defines this term as the maximum level of risk of a product that is acceptable to the Railway Authority (RA) |
| | The RA is responsible for agreeing the risk acceptance criteria and the risk acceptance levels with the Safety Regulatory Authority (SRA) and providing these to the Railway Support Industry (RSI). Usually, it is the SRA or the RA by agreement with the SRA that defines risk acceptance levels. Risk acceptance levels currently depend on the prevailing national legislation or national/other regulations. In many countries risk acceptance levels have not yet been established and are still in progress and/or under consideration [1] |

## 2.2 Purpose of the HSR-risk assessment

The risk assessment at hand shall provide a calculation model which is suitable to determine an expected residual risk of a new High-Speed-Rail-System in Norway. The result shall consider as well the risk for a single person (individual risk) as also the risk for the society (collective risk). As another aspect the estimated risk shall be comparable with risk acceptance criteria. As it is an attribute of any risk analysis- or prediction-model the quality of the result of the suggested models strongly depends on the quality / reliableness of the available input parameters. In this phase of the risk assessment all values shall be interpreted as examples only.

## 2.3 Scope of the HSR-risk assessment

As a requirement on the part of JBV [3] the risk assessment should contain concepts based on the existing network and InterCity strategy and on the other side mainly separated high-speed lines. In order to have a principal differentiation for the risk assessment two system-variants have been appointed. Both system-variants represent "extreme" developments and serve as the basis of the risk model described in chapter 2.5.3 et seq.

Based on this model the risk assessment is performed for specific corridors in chapter 2.8.

Chapter 2.4 identifies the typical attributes of both basic system-variants. Some attributes may differ when adapted to the specific corridors.

Chapter 2.5 presents the general approach of the risk assessment: the statistical data which serves as basis for the risk assessment and a model for comparison of safety in conventional and high-speed services.

In chapter 2.8 the results from chapter 2.5 are taken and adapted to specific corridors.

Chapter 2.9 provides information about safety improvement in railway services in the past and future, in chapter 2.6 a sensitivity analysis is performed.

In chapter 2.10 notes on mitigation measures are given.

## 2.4 System-variants

The first principal variant is represented by an upgrade of an existing track to be a High Speed Rail track. Attributes of the rolling stock in system-variant 1 are:

- maximum speed is 200 km/h for high-speed-trains

- mixed traffic (high-speed-trains, conventional passenger trains, freight trains)

- mainly tilting vehicles used for high-speed-trains

- F-ATC on the system-level
- ETCS not used

Attributes of the track are:

- mixture of single and double track line
- ballasted track
- signalling allows trains operating in both directions
- several (old) level crossings on the not upgraded part of the line
- higher number of stations (for passenger and for crossing of trains) compared to system-variant 2
- higher time and effort related to track maintenance
- long period for upgrade of the existing system while operation at the same time
- increased passing of urban agglomerations compared to system-variant 2
- lower maximum incline compared to system-variant 2
- less percentage of tunnel trackway compared to the system-variant 2
- maximal length of tunnels less compared to the system-variant 2
- percentage of bridges trackway less compared to the system-variant 2
- maximal length / maximal height of bridges less compared to the system-variant 2

Attributes of the traffic mode are:

- bimodal passenger traffic (long-distance and local transport)
- bimodal traffic (freight trains / mass passenger transport / HSR-trains)
- transit of regional stations with stopping or speed reduction

The second variant is represented by a complete new track, which is used exclusively by high speed trains. Attributes of the high speed rolling stock in system-variant 2 are:

- maximum speed is 300 km/h
- none-tilting vehicles
- ETCS at all trains

Attributes of the track are:

- single track line
- exclusively slab track
- very stable track leads to decreased maintenance compared to system-variant 1
- passing points allow trains operating in both directions
- no level crossings
- reduced passing of urban agglomerations compared to system-variant 1 (fractional track routing parallel to speedway or highway)

- increased contingent of profile fixing (lanes / embankments) compared to the system-variant 1

- increased contingent compared to scenario of parts of track with increased sensitivity to side wind

- higher maximum incline compared to system-variant 1

- increased percentage of tunnel trackway compared to the system-variant 1

- maximal length of tunnels higher compared to the system-variant 1

- increased percentage of bridges trackway compared to the system-variant 1

- maximal length / maximal height of bridges higher compared to the system-variant 1

Attributes of the traffic mode are:

- no regional transport

- exclusively High Speed traffic

- no transit through regional stations (trains circumscribe without stopping or any speed reduction)

- complete new stations (platform not in curves)

## 2.5  Risk assessment, general approach

General approaches for risk assessments for railway-systems are described in various standards and vary in different industrial sectors [4]. The risk assessment for HSR Norway, which is described in this document, is based on the European railway standard [2] and consists of four work packages:

- Definition of risk acceptance criteria;

- Hazard identification and assessment of consequences;

- Probability and frequency;

- Determination of risks.

Due to the fact that European Standards, particularly [2], do not provide a normative risk tolerability criterion Interfleet has developed a suggestion concerning risk tolerability for the planned Norwegian high speed rail project. This suggestion considers as well Common Safety Methods (CSM) of the European Railway Authority (ERA) as safety guidelines of the Norwegian National Rail Administration Jernbaneverket (JBV).

### 2.5.1  Risk acceptance criteria, general introduction

The construction of a safe, modern integrated railway network is one of the EU's major priorities. Railways must become more competitive and offer high-quality, end-to-end services without being restricted by national borders. The European Railway Agency (ERA) was set up to help create this integrated railway area by reinforcing safety and interoperability. With the final constitution of the ERA in 2006 major safety tasks, such as to establish Common Safety Targets (CST) and monitor the safety performance on Europe's railways, have been assigned to this organisation. Internationally a number of different risk assessment methodologies and risk acceptance criteria have been used to date. Examples for risk acceptance criteria are given in [1] are *Minimum Endogenous Mortality (MEM), Globalement Au Moins Equivalent (GAME) and As Low As Reasonable Practicable (ALARP)*. For all risk assessments it is essential to establish the methodology followed by the definition of targets of risk acceptability. Due to

different national laws and provisions even in the recent past no Europe-wide risk acceptance criteria has been accepted and practised. As a result of this situation safety targets vary and they usually base on the same principle as the chosen methodology for the risk assessment. To this day safety targets are derived for example as tolerable limits for a whole system, e.g. for the rail system in a specific country, or they are allocated to specific risk causes, e.g. hazards related to the system or sub-systems.

With date of 24.04.2009 and the regulation No. 352/2009 [5] of the commission of the European community a binding base for the performance of risk analysis is available.

*http://www.eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:108:0004:0019:DE:PDF*

The European Railway Agency has also published a common method for the evaluation and assessment of risk in a guideline [5] at the date of 06.01.2009.

*http://www.era.europa.eu/Document-Register/Documents/ERA-2009-0048-00-00-EN.pdf*

Considering the common safety methods for the evaluation and assessment of risks in accordance to the EG-regulation [5] one of the following three risk acceptance criteria can be used:

- Code of practice (TSI, notified national regulations, European standards);

- Similar reference system;

- Explicit risk estimation and harmonized risk acceptance criteria.

These three principles are exchangeable and there is no demand for a ranking between them. For the HSR Norway risk assessment Interfleet proposes explicit risk estimation and the comparison of the estimated risks with harmonized risk acceptance criteria regarding collective and individual risk. In addition the Risk Acceptance Criteria for Technical Systems (RAC-TS) [5][20] shall apply for functional safety aspects. Both approaches are described in the following chapters.

### 2.5.1.1  Risk Acceptance Criteria for Technical Systems (RAC-TS)

For the HSR Norway risk assessment Interfleet proposes the appliance of explicit risk estimation and the harmonized Risk Acceptance Criteria for Technical Systems (RAC-TS) [5][20].

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Risk Acceptance Criteria for Technical Systems (RAC-TS):

Any failure mode of a function resulting in a hazard that has a credible immediate potential for catastrophic consequences shall not occur with a rate of occurrence higher than $10^{-9}$ per operating hour.

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The decision for the usage of RAC-TS is mainly justified on the following aspects:

- Codes of practice (for example TSI, NNR, European Standards) describe various technical and operational requirements for rail-systems but they do not consider any quantitative safety targets or safety integrity requirements.

- A similar reference system for the planned Norwegian high speed rail project is not available and sufficient convincing data of such a system are missing not least due to the short time of operation.

- RAC-TS has been agreed by UNIFE in the meantime;

- TSI CCS [6] for High-Speed-Systems give a reference for a tolerable risk which could be generally applied to new functions or systems: "For the safety-related part of one onboard

unit as well as for one trackside unit, the safety requirement for ETCS Level 2 is a tolerable hazard rate of $10^{-9}$ / hour …".

- Various projects in different countries have proposed the same target for safety-critical functions (e.g. electronic interlocking) in the railway-sector.

- The approach is used for more than 20 years successfully in the civil-aviation-sector and is standardized in [7].

For the understanding of RAC-TS the significant notions and the reference conditions have to be defined:

- A technical system is a product developed by a supplier including its design, implementation and support documentation.

   o The development of a technical system starts with its System Requirements Specification and ends with its safety approval.

   o Human operators and their actions are not part of a technical system.

   o Maintenance is not included in the definition, although maintenance manuals are.

- [8] defines a function as a specific purpose or objective to be accomplished that can be specified or described without reference to the physical means of achieving it.

- [2] describes catastrophic consequences as "Fatalities and/or multiple severe injuries and/or major damage to the environment".

- Credible potential means that it must be likely that the particular failure mode will result in an accident with catastrophic consequences.

- Immediate potential in this context means that no credible barrier exists that could prevent an accident.

It has to be mentioned that the appliance of RAC-TS is limited to functional safety, which can be seen as the inherent safety aspect of a technical system. All other safety aspects issues, e.g. operational safety, have to be considered using an alternative risk approach because in those cases (e.g. avoidance of collisions with 3rd persons on track) RAC-TS is not applicable.

### 2.5.1.2  Explicit risk estimation and harmonized risk acceptance criteria

Widely used risk acceptance criteria are boundary values for either risk concerning single persons (individual risk) which are using a (technical) system and for the risk related to a society (collective risk). Descriptions concerning the usage of boundary values for individual / collective risks are given amongst others in [2], [4] and [9].

As a further risk acceptance criterion (beside RAC-TS) the following tolerable boundary values, accepted and used in Norway [10], provide the basis for the risk assessment at hand:

Individual risk:

- 1st person less than 12.5 fatalities / 100.000.000 working hours;

- 2nd person (passengers) and 3rd person less than 0.0001 fatalities for the most exposed individual.

Collective risk:

- less than 11 fatalities per year for the total railway net

Considering the collective risk it has to be mentioned that for any additional technical system, such as a potential new high-speed rail system, existing risk acceptance values have to be proofed and where necessary adjusted.

## 2.5.2  Risk assessment, bottom-up-approach for RAC-TS

As described before, the risk acceptance criteria RAC-TS is proposed for functional safety aspects of a potential new high-speed railway system in Norway. By the usage of RAC-TS so called tolerable hazard rates (THR) shall be identified. The bottom-up-approach in this regard covers the following steps and is described afterwards.

RAC-TS-approach:

1. Hazard-identification;

2. Qualitative consequence (severity) estimation;

3. Evaluation if RAC-TS is applicable for specific hazard;

4. Estimation / quantification of safety barriers and THR-allocation.

### 2.5.2.1  Hazard identification

Precondition for a risk assessment related to RAC-TS is the correct and complete identification of all relevant hazards. The hazard identification process used for the HSR-Norway risk analysis is in line with the approach described in [11]. An empirical phase using structured analysis (Interface Analysis) and exploiting past experience and a creative phase (brainstorming of safety experts combined with analysis of different hazard-checklists) increase confidence that all significant hazards have been identified.

As long as a technical system is not finally defined, the hazard identification has to be performed on a functional system level. Therefore the system, in this case the planned Norwegian High-Speed-Rail-System, can be seen as a "Black box". Hazards depend in particular on the system boundary and the respective interfaces.
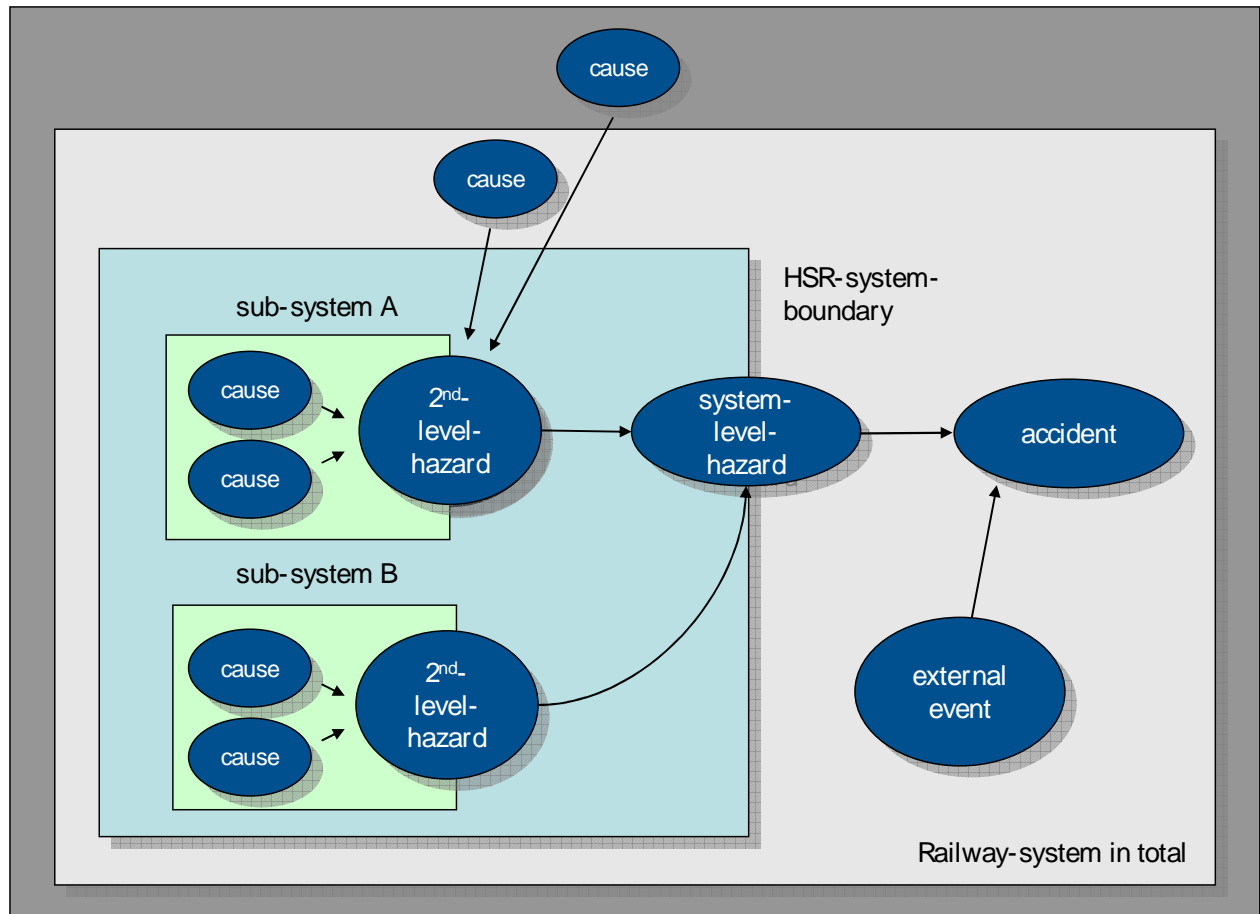
Figure 1: Hazard identification

System-level-hazards occur at the HSR-systems-boundary while 2nd-level-hazards occur at sub-systems-boundary. Generally hazards are directed to the outside. Causes for hazards on the 2nd level can be divided in internal and external causes.

For a pragmatically approach a high speed rail system, and so the HSR-system, can be divided in two major sub-systems:

- Rolling stock;
- Infrastructure.

While rolling stock consists of locomotives / traction vehicle and wagons, the appropriation of constituent parts of the infrastructure is more complex. Principally all technical parts which are not related to rolling stock but are needed / used for the operation of the HSR-system, e.g. tracks, bridges, tunnels, rails, railway control centre, stations, power supply etc., shall be appropriated to the infrastructure. Considering these aspects the following interfaces at system-boundary can be described:

Table 2: HSR-System, interfaces

| No. O | External Interface |
|---|---|
| 1 | vehicle $\Rightarrow$ passenger |
| 2 | vehicle $\Rightarrow$ personnel |
| 3 | vehicle $\Rightarrow$ third party |
| 4 | vehicle $\Rightarrow$ environment |
| 5 | infrastructure $\Rightarrow$ passenger |
| 6 | infrastructure $\Rightarrow$ personnel |
| 7 | infrastructure $\Rightarrow$ third party |
| 8 | infrastructure $\Rightarrow$ environment |

### 2.5.2.2  Qualitative consequence (severity) estimation

The classification of severity level is an essential requirement for the application of RAC-TS, respectively a risk matrix. Normative classifications are currently not available in the railway-sector. Corresponding delineations, e.g. in [2] have to be seen only as examples. Concerning classification / gradation of the different consequences to persons a factor 10 is given exemplarily in [1] and widely-used especially in the rail-sector:

1 Equivalent fatality = 1 fatality = 10 major injuries = 100 minor injuries

This consequence classification has been used in the further analysis in this document. If any other gradations shall apply, the calculation model (see chapter 2.5.3.3) allows an easy appliance.

Table 3 describes the classification of severity level, which is given exemplarily in [2].

Table 3: Hazard severity level, according to Table 3 in EN 50126-1 [2]

| Severity Level | Consequence to persons or environment |
|---|---|
| Catastrophic | Fatalities and/or multiple severe injuries and/or major damage to the environment |
| Critical | Single fatality and/or severe injury and/or significant damage to the environment |
| Marginal | Minor injury and/or significant threat to the environment |
| Insignificant | Possible minor injury |

So called risk matrices are common tools to express risks in several industry sectors. The semi-qualitative matrix which is given as an example in [2] can be adjusted with the target value for the frequency of occurrence of a hazardous event in order to appoint the reference-rate of occurrence $10^{-9}$ per operating hour for catastrophic consequences.

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| Frequency of occurance of a hazardous event | Risk Level | | | |
|---|---|---|---|---|
| Frequent (tbd) | | | | |
| Probable (tbd) | | | | |
| Occasional (tbd) | | | | |
| Remote (tbd) | | | | |
| Improbable (tbd) | | | | |
| Incredible ($10^{-9}$ per hour) | | | | RAC-TS |
| | tbd | tbd | tbd | > 1 fatality or multiple severe injuries |
| | Insignificant | Marginal | Critical | Catastrophic |

Figure 2: Risk matrix with RAC-TS reference value

RAC-TS can be used to calibrate the risk assessment method. For the calibration the tolerable field "RAC-TS" can be extrapolated linear within the matrix. This means that all fields on that line or there under represent tolerable risks. Precondition for the extrapolation is that the categories for severity level at one hand and for the frequency of hazardous events on the other hand are separated by the same factor. An example is shown in Figure 3.

| Frequency of occurance of a hazardous event | Risk Level | | | |
|---|---|---|---|---|
| Frequent ($10^{-4}$ per hour) | intolerable | intolerable | intolerable | intolerable |
| Probable ($10^{-5}$ per hour) | intolerable | intolerable | intolerable | intolerable |
| Occasional ($10^{-6}$ per hour) | tolerable | intolerable | intolerable | intolerable |
| Remote ($10^{-7}$ per hour) | tolerable | tolerable | intolerable | intolerable |
| Improbable ($10^{-8}$ per hour) | tolerable | tolerable | tolerable | intolerable |
| Incredible ($10^{-9}$ per hour) | tolerable | tolerable | tolerable | RAC-TS |
| | Insignificant | Marginal | Critical | Catastrophic |

Factor 10 (between each frequency level)

Factor 10   Factor 10   Factor 10 (between severity levels)

Figure 3: Example for calibration of risk matrix

### 2.5.2.3  Evaluation if RAC-TS is applicable for specific hazard

RAC-TS can be applied for the risk assessment directly if

- the failure mode relates to a function of the High Speed Rail system and

- the potential is catastrophic and

- there are no credible barriers to prevent an accident.

If these aspects apply, a tolerable hazard rate (THR) of THR $< 10^{-9}$ per hour can be allocated to the technical function which is related to the specific hazard.

Examples for such functions -> hazards are:

- Ensure correct setting of points -> undetected wrong setting of points in main line operation;

- Ensure adequate breakage -> Loss or inadequate breakage;

RAC-TS (THR $< 10^{-9}$ per hour) can not be applied directly, if either the hazard consequence is not catastrophic or there are credible barriers to prevent an accident. In those cases the THR has to be adapted as described in chapter 2.5.2.4.

### 2.5.2.4  Estimation / quantification of safety barriers and THR-allocation

As described before only in case of immediate potential for a hazardous event the frequency of occurrence for that specific hazardous event can be deducted directly by reading off the corresponding value from the risk matrix (see Figure 4). In all other cases of functional safety the risk matrix has to be applied in respect to the parameters severity level and influence of barriers. Examples for functions that have no credible immediate potential are

- Loss of fire-extinguishing function;

- Loss of emergency exit function;

- Loss of service brake.

The following example describes the THR-allocation in respect to the parameters severity level and influence of barriers: An actual potential 10 times less than catastrophic consequence would reduce the requirement also by the factor 10 to $10^{-8}$ per hour (see example in Figure 4). An additional safety barrier which is effective in 50% of all cases would reduce the requirement finally to $5*10^{-7}$ per hour.

| Frequency of occurance of a hazardous event | Risk Level | | | |
|---|---|---|---|---|
| Frequent ($10^{-4}$ per hour) | intolerable | intolerable | intolerable | intolerable |
| Probable ($10^{-5}$ per hour) | intolerable | intolerable | intolerable | intolerable |
| Occasional ($10^{-6}$ per hour) | tolerable | intolerable | intolerable | intolerable |
| Remote ($10^{-7}$ per hour) | tolerable | tolerable | intolerable | intolerable |
| Improbable ($10^{-8}$ per hour) | tolerable | tolerable | tolerable | intolerable |
| Incredible ($10^{-9}$ per hour) | tolerable | tolerable | tolerable | RAC-TS |
| | Insignificant | Marginal | Critical | Catastrophic |
| | Severity levels of hazard consequence | | | |

Figure 4: Risk matrix applied for hazard with lower severity but credible immediate potential

For the risk assessment at hand and particularly for the identification and dimensioning of potential consequences the evaluation of data / statistics (see chapter 2.5.3.3) has been used. The existence and potential of credible barriers to prevent accidents depends significantly on the architecture / design of a technical system. The influence of safety barriers regarding the safety of a potential new high-speed rail system in Norway has to be evaluated in a later project phase considering more detailed information concerning the technical solution.

### 2.5.2.5  Hazard list

As the result of the above described bottom-up-approach a semi-qualitative risk assessment has been worked out. The assessment includes a hazard identification which has been supplemented by qualitative risk estimation. Out of the hazard summary all hazards which are related to functional safety aspects have been identified. All other hazards that are not related to functional safety aspects are indicated in the hazard list as not applicable for RAC-TS.

The hazard list which represents Annex 1 of the document at hand is directly linked to the performed top-down risk assessment described in the following chapters. The list includes information regarding causes as well as regarding potential consequences of hazards.This information has also been used to quantifiy the risks in the different system-variants. Furthermore the hazard list should be seen as a basis for following tasks, such as the definition of tolerable hazard rates for safety functions. For this task detailed information regarding the technical design of a potential new high-speed rail system is required in order to determine / quantify the residual risk reduction factors.

### 2.5.3  Risk assessment, top-down-approach

In addition to the identification of system-level-hazards by the described bottom-up-approach the expected residual risk of a new HSR-system has been evaluated using a top-down-approach for the explicit risk estimation. The purpose of this risk estimation is the calculation of either the expected risk for single persons (individual risk) as well as the risk for the society (collective risk). The top-down-approach for the risk assessment is characterized by the steps described in chapter 2.5.3.1 to chapter 2.5.3.8. The model described in the following is suitable to be fitted accordingly to the awareness / knowledge related to the foreseen technical solution / planning of a potential new Norwegian high speed rail system in later project phases. A more detailed and / or higher quality of data for key figures (values of calculation-parameters) should also be used for an adoption of the suggested calculation model.

#### 2.5.3.1  Definition of Top-Events

In a first step all relevant so-called Top-Events have been defined. Top-Events can be seen as accidents with potential severe consequences. Due to the fact that consequences of specific accidents (e.g. collision) may vary extensively, a differentiation for "collision" as well as for "injury of person / passenger" seems to be reasonable. For the risk assessment at hand the following Top-Events have been identified by evaluation of the hazard identification (see chapter 2.5.2.1 and hazard table in the annex). The list of Top-Events is also in accordance with input on side of JBV. At this point it should be mentioned that in particular the [10] has been very helpful for this risk assessment.

- Derailment;
- Collision train-train;
- Collision train-object;
- Fire;
- Passenger injured at platform;
- Level crossing accidents;
- Person injured at track side;
- Other accidents.
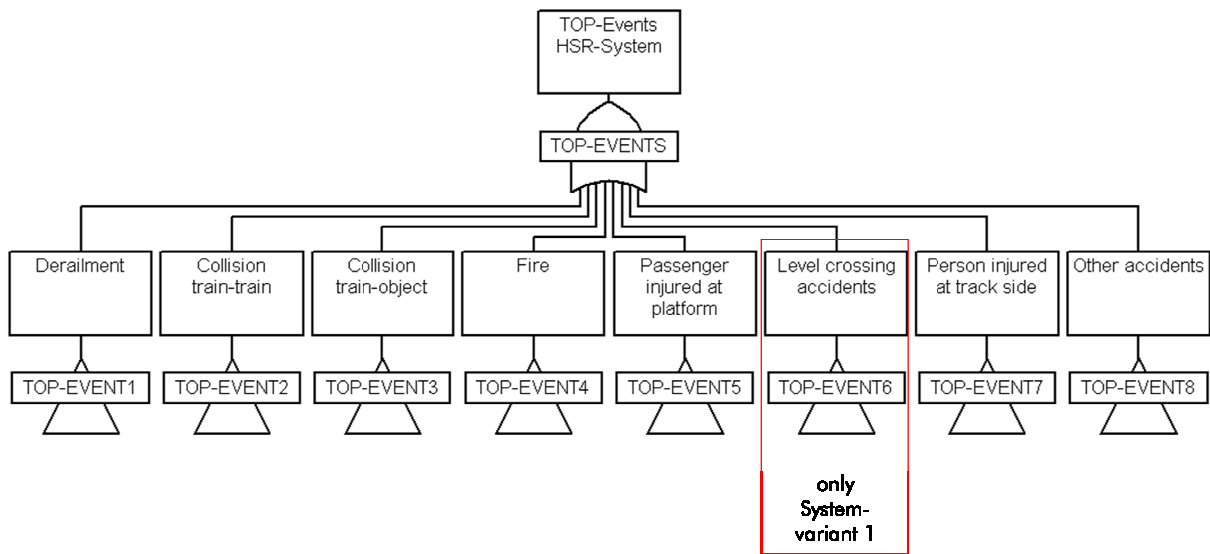
Figure 5: Top-Events, overview

The Top-Event 8 "Other accidents" has been defined in order to consider accidents scenarios which are not related to the first seven Top-Events. For this phase of the risk assessment electric shock accidents and affection by dangerous goods are included in the assessment. Accidents in warehouses, workshops and depots are excluded due to the fact that they are not captured in the available data [12][13]. The performed top-down-approach considers the different system-variants respectively their specific attributes as described in chapter 2.3. For example the Top-Event "Level crossing accidents" is only relevant for the system variant 1 (upgrade of existing system) because corresponding directives exclude the planning of level crossings for new high-speed rail systems (system-variant 2). Also the scenarios (effects) in case of the occurrence of a Top-Event have to be differentiated in respect of the system-variants (see chapter 2.4).

### 2.5.3.2  Quantification of Top-Events

The top-down-approach is based on the expected occurrence of defined Top-Events itself as well as on the supposed severity of potential consequences.

For every Top-Event the number of expected events per year had to be determined. In an ideal case this parameter could have been evaluated by analysis of railway statistics of a comparable rail system. At this point it has to be mentioned that European statistics [12] mainly allude to mixed traffic rail systems. Due to this fact those statistics do not enable to directly draw conclusions regarding a potential exclusively high-speed rail system. On the other hand existing Norwegian statistics / data [13] do not consider any high-speed aspects. For the risk assessment at hand the relevant input parameter (number of events per year) has been evaluated by different activities that complement one another:

- Analysis of rail statistics and accident reports;

- Estimations based on Expert Judgement.

The first point has been done by evaluation / analysis of available Norwegian rail statistics [13] (see chapter 2.5.3.3.1) as well as other European statistics [12] (see chapter 2.5.3.3.1 and 2.5.3.3.2) and accident reports. On base of those data the expected frequency of occurrence of every Top-Event has been estimated for both system-variants 1 and 2. The main question in this context is, if a potential new High Speed Rail operation would presumably cause changes of the specific accident rates and / or a change of consequences of accidents, which are

quantified as equivalent fatatlities, compared to the actual Norwegian rail situation. In those cases, where presumable no change is expected, the evaluated data [12][13] for either accident rates or number of equivalent fatatlities have been applied. For all other cases the degree of the presumable change of both aspects has been determined by estimation. Reasons and underlying thoughts / considerations are stated as well as suggestions regarding possible adaptions of the risk model in further project phases. Evaluations of further and more detailed statistics are advised to minimize the level of uncertainty of the risk assessment for a potential new Norwegian high-speed rail system.

### 2.5.3.3 Top-Event, evaluation of rail statistics

#### 2.5.3.3.1 Top-Event, Norwegian rail statistics

For this analysis local data with focus on the Norway Rail System is crucial. The national rail safety authority "Jernbaetilsynets" releases annual reports concerning safety and accident statistics [13]. Events per year can be evaluated by analysis of this railway statistics. According to the scope of work appropriate figures are needed in relation to the determined Top-Events. The data source [13] provide figures and detailed description incidents but in a difficult way to evaluate statistically. Reasons for that are:

• No existence of figures with direct, clear relation to mentioned Top-Events;

• Different type of data is reported in different ways during the years;

• Change of definitions (e.g. "railway accident", and "severe injury") in the meantime;

• Change of classifications of events (damage) and definition of requirements for the classification;

• Only accidents or events over a certain size (severity) are reported.

This statistic data is published with direct relation to any damage. The total railway traffic is considered in this report. So events which appear without mentioning and notification are disregarded. For an exact consideration that part has to be measured. In addition there exists lack of data. So a continuous and transparent evaluation isn't possible. Because of that the following evaluations were made and some conclusions were drawn:

Average number of derailments has decreased over the last 50 years (40 per year to 5 to 10 per year in 2009). The most derailments today appear on freight trains. Furthermore it becomes considerable that today's derailments don't cause any fatalities or severe injuries under normal circumstances. Damages on material and/or environment are the consequences which have to be considered.

Also the number of level crossing accidents has decreased during the last 50 years from an average of 40 per year to 5 to 10 per year. During the years 1995 and 2004 a sum of 116 level crossing accidents occurred. Because of that, a number of 28 persons were killed and 8 persons were severely injured.

The outcome of the Top-Event "collision train-train" varies in the period 1978 to 2005 between 0 and 5 accidents per year. The trend is constant with an average of slightly more than one collision per year. This is the type of accident that has caused the most fatalities (passengers and employees). Due to the fact of the difficult evaluation it has not been possible to extract the exact numbers of fatalities. Catastrophic collisions with multiple fatalities occur, but not frequently, the latest occurred in year 2000.

The occurrence of "collision train-object" varies extremely over the last years. Between 1978 and 2005 an amount of 0 to 17 accidents appears per year. The trend is slightly increasing with

an average level around 6 accidents per year. It has been estimated that about the half of these accidents are due to slide of snow, ice or stone.

One scenario for person injured at platform is when using the entrance system to get in or off the train. Since the changed definition of railway accidents in this statistic this Top-Event presumes only vehicle in motion. That means, accidents related to the entrance system are not reported in the reports after 2003. Before 2003 several severe injuries were mentioned in the description (employees and 3rd party), unfortunately no figures were presented.

Also no figures were published concerning the Top-Event "fire". For fire in vehicle some severe injuries are mentioned because of the consequence of smoke inhalation.

It has not been possible to separate the Top-Event "person injured at track side" from "person injured at level crossing" before year 2006. In addition several (84) incidents without consequences mentioned in year 2000 normally closed to Top-Event "person injured at track side". But in the same year there have been some fatalities and severe injuries.

### 2.5.3.3.2  Other Data Sources

The following data sources have been assessed additionally to the statistical data above:

- ERADIS - Common Safety Indicators Database (ERADIS-CSID)

- UIC Safety Database (UIC-SDB)

Up to the year 2005 information on safety performance of the European railways has been difficult to find. The Safety Directive 2004/49 introduces common safety indicators (CSIs), which have to be collected by the national safety authorities and delivered to the ERA. Due to this fact a standardized method for collecting and reporting accident data has been accomplished for the years 2006-2009. The ERADIS-CSID reports accumulated accident data for each supplying country (29 countries + Eurotunnel). For the report at hand, the accident statistics of Germany, France, Norway and Sweden have been evaluated.

The UIC Safety Database (UIC-SDB) is an internet application organised within the Infrastructure Forum activities. It is continuously maintained and developed in agreement with the Safety Platform, according to the necessities introduced by safety managers and EU bodies.

The Safety Platform brings together safety directors (or employees with a comparable remit in line with the job titles used and corporate structure) from member companies of the UIC. Amongst these is a mixture of Infrastructure Managers and Railway Undertakings as well as a number of organisations such as ATOC in the UK, representing groups of railway companies. This plenary structure is then supported by a core group made up of UIC member companies based in Austria, Belgium, France, Germany, Great Britain, India, Italy, Japan, Poland, Spain, Sweden, Switzerland and United States of America. Considerable additional independence is provided by having representatives from organisations such as the Community of the European Railways (CER), European Rail Infrastructure Managers (EIM) and Railway Safety Standards and Boards (RSSB) in Europe and FRA/AAR in the USA.

Overall 20 European countries supply accident data to the UIC-SDB and for the statistical analysis all data has been evaluated.

### 2.5.3.3.3  Definitions

The UIC database collects all significant accidents (any accident causing at least one fatality or serious injury or damage over 150k€ or tracks blocked for more than 6 hours). Accidents in warehouses, workshops and depots are excluded. Accident classifications used are:

- Collisions
    - train collision with an obstacle
    - train collision with another train
- Derailment
- Accidents to person caused by rolling stock in motion
    - individual hit by train
    - individual falling from a train
- Fire in rolling stock
- Accidents involving dangerous goods
    - without dangerous goods release
    - in which dangerous goods are released
- Electrocution by traction power
- Other

The ERADIS database uses another definition of typical accidents according to the Safety Directive 2004/49:

- Collisions of trains, including collisions with obstacles within the clearance gauge

- Derailments of trains

- Level-crossing accidents, including accidents involving pedestrians at level-crossings

- Accidents to persons caused by rolling stock in motion, with the exception of suicides

- Fires in rolling stock

- Others

### 2.5.3.3.4  Evaluation procedure

UIC (20 supporting countries) and ERADIS (as already stated Germany, France, Norway and Sweden) accumulated accident data (number of accidents, fatalities and serious injuries divided in passengers, staff and third persons) from the years 2006-2009 were imported into an MS-Excel database together with the accumulated train kilometres for each year. Then accident rates in number of accidents per train km for each type of accident were calculated by calculating accident rates for each year and taking the mean over four years. Equivalent fatality rates based on the commonly known approach to count 10 seriously injured persons as equivalent to 1 fatality were calculated for each group of affected persons based on the UIC database. To be able to compare the results of the different accident definitions a mapping table was introduced, as well as a mapping table with the top event definition introduced with the report at hand.

The results based on the UIC database are shown in the following table:

Table 4: Accident statistics UIC

| Top-Event | Accident rate per train km | Fatality rate per train km | Fatality rate  per accident |
|---|---|---|---|
| Collision train-object | 2,0E-08 | 4,3E-09 | 0,21 |
| Collision train-train | 7,4E-09 | 8,8E-10 | 0,12 |
| Derailment | 2,3E-08 | 3,1E-09 | 0,14 |
| Other | 1,2E-08 | 6,9E-09 | 0,60 |
| Passenger injured at platform | 1,7E-07 | 8,1E-08 | 0,48 |
| Person injured at level crossing | 1,4E-07 | 8,7E-08 | 0,63 |
| Person injured at track side | 2,0E-07 | 1,5E-07 | 0,72 |
| Fire in rolling stock | 6,3E-09 | 1,5E-10 | 0,02 |

Accident rates for the Norwegian rail network based on the ERADIS database:

Table 5: Accident statistics Norway ERADIS

| Top-Event | Accident rate per train km |
|---|---|
| Collision train-object | 1,1E-07 |
| Collision train-train | 7,4E-09 |
| Derailment | 4,9E-08 |
| Other | 1,2E-08 |
| Passenger injured at platform | 1,7E-07 |
| Person injured at level crossing | 3,3E-08 |
| Person injured at track side | 5,5E-08 |
| Fire in rolling stock | 4,3E-08 |

If we now assume that the fatalities per type of accident should be the same for Norway as compared to 20 European countries and the distribution of the fatality rates for the different exposed person groups follows the same patterns as well, we get the following risks of fatality per year (assuming accumulated 48Mio. train km) and person group:

Table 6: Distribution of fatalities to person groups, UIC

| Top-Event | other | passengers | staff |
|---|---|---|---|
| Collision train-object | 73,9% | 11,6% | 14,5% |
| Collision train-train | 14,3% | 21,4% | 64,3% |
| Derailment | 62,0% | 22,0% | 16,0% |
| Other | 91,9% | 3,6% | 4,5% |
| Passenger injured at platform | 86,6% | 9,3% | 4,1% |
| Person injured at level crossing | 99,1% | 0,2% | 0,6% |

| | | | |
|---|---|---|---|
| Person injured at track side | 95,7% | 2,3% | 2,0% |
| Fire in rolling stock | 8,9% | 89,4% | 1,6% |

Table 7: Collective Risk parameters Norway

| Top-Event | Accident rate per train km | Fatalities per year - collective | Fatalities per year - other | Fatalities per year - passengers | Fatalities per year - staff |
|---|---|---|---|---|---|
| Collision train-object | 1,1E-07 | 1,16 | 0,85 | 0,13 | 0,17 |
| Collision train-train | 7,4E-09 | 0,04 | 0,01 | 0,01 | 0,03 |
| Derailment | 4,9E-08 | 0,32 | 0,20 | 0,07 | 0,05 |
| Other | 1,2E-08 | 0,33 | 0,31 | 0,01 | 0,02 |
| Passenger injured at platform | 1,7E-07 | 3,89 | 3,37 | 0,36 | 0,16 |
| Person injured at level crossing | 3,3E-08 | 0,98 | 0,97 | 0,00 | 0,01 |
| Person injured at track side | 5,5E-08 | 1,90 | 1,82 | 0,04 | 0,04 |
| Fire in rolling stock | 4,3E-08 | 0,01 | 0,00 | 0,01 | 0,00 |
| | | | 7,53 | 0,64 | 0,46 |

Comparing the results with the mean number of fatalities and severe injuries reported in [13]during the same period 2006-2009 we note a good correlation keeping in mind that accidents at platforms with train not moving (stations) are no longer reported in [13]:

Table 8: Comparison of risk parameters

| | Fatalities per year - other | Fatalities per year - passengers | Fatalities per year - staff |
|---|---|---|---|
| Risk model | 7,53 | 0,64 | 0,46 |
| Norwegian data source [23] | 1,60 | 0,60 | 0,33 |

### 2.5.3.4  Evaluation of accident rate

This chapter includes a description of evaluation of accident rates using the example of the Top-Event "Fire". Based on the accident rates evaluated by available statistical data [12][13], a prediction of the expected change of the specific accident rate related to the system-variant 1 or 2 has been the next step within the risk assessment. In this context the hazards as well as the causes related to each Top-Event have been examined. The numbers of causes and the character of those causes themselves have been considered for the estimation of the expected accident rates. As an example for the principal approach the following Figure 6 shows the fault trees for the Top-Event "Fire". The green colour is used to label elements in the diagrams (fault trees as well as event trees) which can be quantified by the evaluation of the statistical data [12][13].

PÖYRY          Interfleet Technology          SWECO
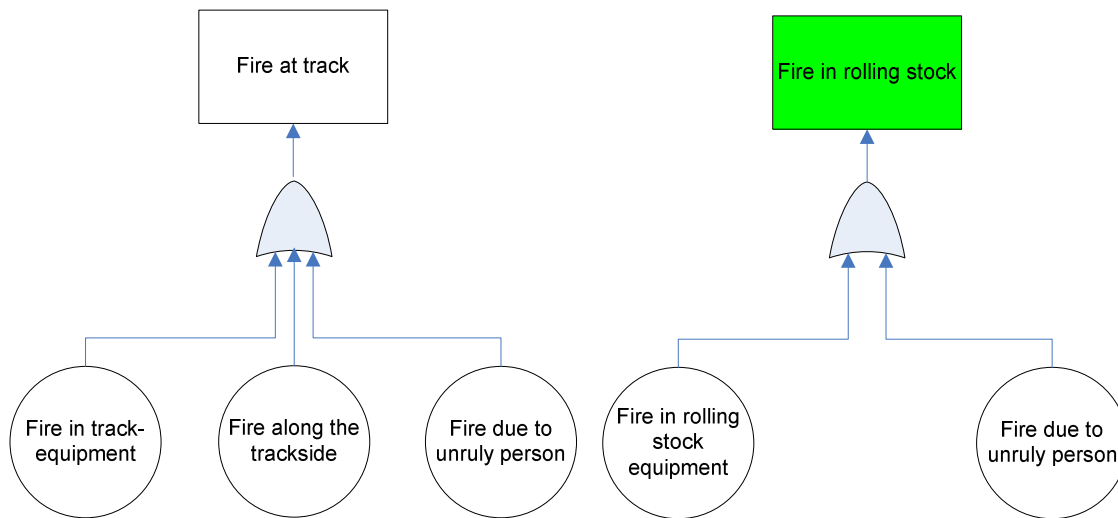
Figure 6: Fire, causes

"Fire at track" is not specificely comprehended in the available data and therefore this aspect could not be quantified. It is supposed that "fire at track" does not influence the resulting risk related to fire significantly. As it can be seen in the figure above, two different major events may cause fire. None of both events is specificly related to high-speed rail systems and therefore for the Top-Event "Fire" no presumable change of the accident rate compared to the existing railway net has to be expected and the parameter can be estimated as:

$$\Delta\lambda_A = 1$$

### 2.5.3.5  Consequence analysis for every Top-Event

Another core area within the risk assessment has been the prediction of potential consequences. Consequences can be expressed as described before as equivalent fatalities (see chapter 2.5.2.2) per accident. For every Top-Event presumable changes of the so-called fatality rate have been evaluated for the defined system-variants. Therefore it has been necessary to proof if the new potential high speed traffic would influence directly the number of (equivalent) fatalities in case of an accident. As an example for the principal approach the following figure shows the event tree for the hazard "fire in rolling stock".
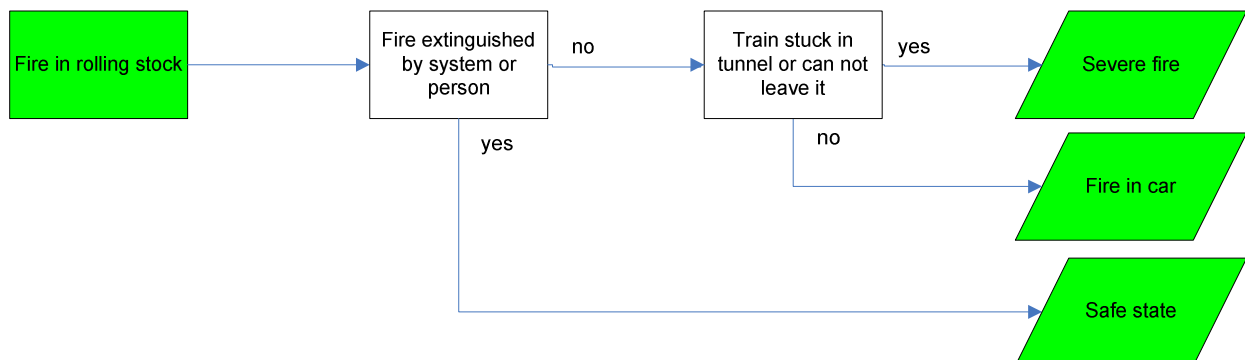
Figure 7: Fire, consequence analysis

As it can be seen different accident scenarios may occur. "Severe fire" represents fire in a train, which is stuck inside a tunnel or can not leave it. The second scenario represents fire inside a car in open track or at station / depot. For the system-variant 1 no presumable change of the fatality rate compared to the existing rail net has to be expected.

$\Delta \lambda_F = 1$

For the system-variant 2 a potential increase of the fatality rate ($\Delta \lambda_f > 1$) is expected due to an increased percentage of track inside tunnels for the new system compared to the existing rail net and due to the expected higher number of passengers which may be exposed to the hazard.

### 2.5.3.6  Estimation / calculation of the collective risk

According to CLC/TR 50126-2 [1] risk mathematically is represented as

$$Risk = Rate\,(of\ accidents) \times Degree\ of\ severity\,(of\ harm)$$

The collective risk has been determined for every Top-Event and if relevant data were available also for specific scenarios. The multiplication of the accident rate (evaluated / estimated number of events per year of every Top-Event) with the fatality rate (number of equivalent fatalities per accident) results in a value for the collective risk (equivalent fatalities (EqFa) per year).

$$R_{coll.Top-Event\,i} = \Delta \lambda_{A\,Top\,i} \cdot \lambda_{A\,Top\,i} \cdot \Delta \lambda_{F\,Top\,i} \cdot \lambda_{F\,Top\,i}$$

with

$\lambda_{A\ Top\ i}$ = Accident rate (for a specific Top-Event i)

$\lambda_{F\ Top\ i}$ = Fatality rate (for a specific Top-Event i)

Due to the fact that accidents may affect passengers and / or personal and / or 3rd persons, a differentiation of the collective risk value between these groups has been done for every Top-Event. The differentiation is based on the percentaged distibution regarding affected persons which has been evaluated by European data (see Table 6).
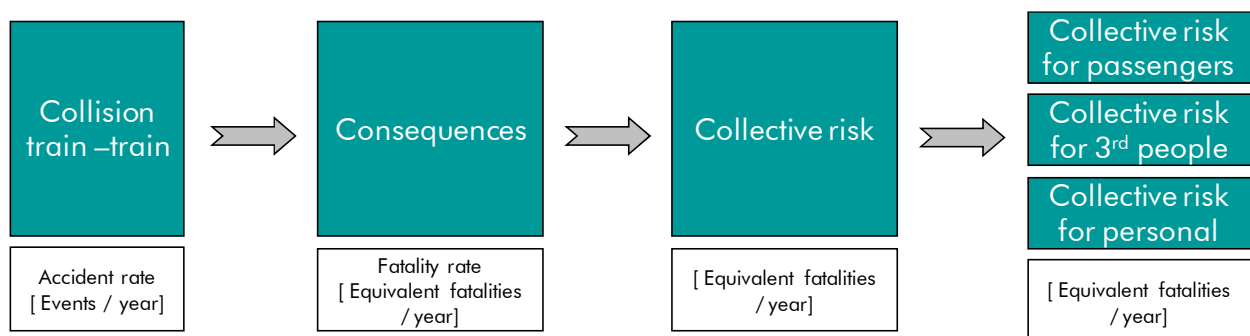


Figure 8: Derivation of the collective risk

### 2.5.3.7  Residual collective risk for every system-variant

By calculation of the resulting collective risk for every system-variant the proof of the first risk acceptance criteria (see chapter 2.5.1.2) can be achieved.

$$R_{coll.res.} = \sum_{i=1}^{n} \lambda_{A\,Top\,i} \cdot \lambda_{F\,Top\,i}$$

The addition of all determined collective risks of the different Top-Events results in an indication for the resulting collective risk (equivalent fatalities per year). This calculation has been done for both system-variants. An overview of the residual collective risk is shown in Table 45.
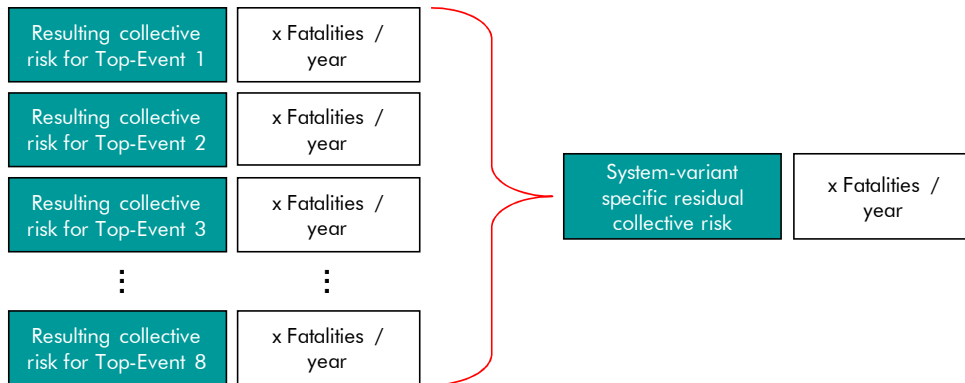
Figure 9: Example of derivation of the residual collective risk

### 2.5.3.8  Individual risk for every Top-Event

As described in chapter 2.5.3.6 the collective risk related to passengers and / or personal and / or 3rd persons has been determined. By calculation of the resulting individual risk for the specific groups of persons and of every system-variant the proof of the second risk acceptance criteria (see chapter 2.5.1.2) can be achieved. Therefore the division of the calculated collective risk (equivalent fatalities per year) values with the number of affected persons (passengers, personal, residents etc.) [1] results in the individual risk.
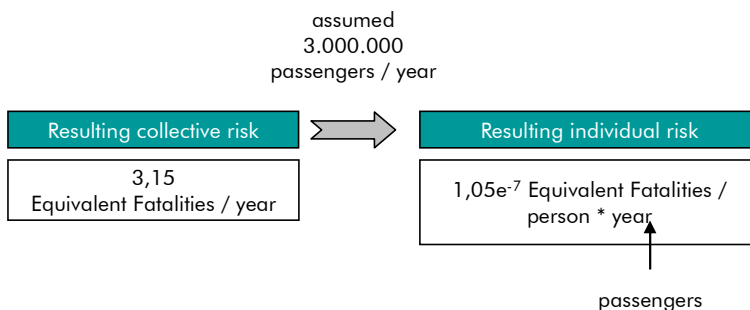
Figure 10: Example of derivation of the individual risk

Mathematically the coherency between collective and individual risk can be simplified described as following:

$$R_{ind;system-variant\ j.} = \frac{R_{coll;system-variant\ j.}}{n}$$

with:

$R_{ind;\ system-variant\ j}$  individual risk for a single user of the system(-variant) j or an individual which is affected / exposed by the system(-variant) j

---

[1] The assumed number of passengers per year shall be seen exemplarily. The authors advise further evaluation of statistics in order to justify the assumptions.

$R_{coll;\ system\text{-}variant\ j}$      collective risk of the system(-variant) j

n      number of users of the system(-variant) j or number of individuals which are affected / exposed by the system(-variant) j

The calculations regarding the individual risk for the different groups of persons is based on the operating figures:

Table 9: Operating figures

| Persons | Number | Comment |
|---|---|---|
| Passengers | 3.000.000 (individual) passengers | According to "Presentasjon av Jernbaneverket mai 2010", presented on JBV home page, more than 56.000.000 passengers travelled by train in 2009. The supposed number of 3 Mio. (individual) passengers is deduced by a average of approximately 20 train rides per individum and year. |
| Personal | 13.500.000 working hours | Source: ERADIS [12]. The number of working hours is considered to include all personal of JBV and outside companies. |
| 3rd people | 3.000.000 people | Conservative estimation considering that not every person in Norway (~ 5.000.000 residents) is exposed and / or affected by the railway system. |

An overview of the resulting individual risks for the different Top-Events is shown in Table 45.

### 2.5.3.9  Residual individual risk

Analogous to the calculation of the resulting collective risk for every system-variant compliance to the second risk acceptance criteria (see chapter 2.5.1.2) can be checked.

$$R_{PG\ ind.} = \sum_{i=1}^{n} R_{PG\ ind.Top\ i}$$

The sum of all determined individual risks of the different Top-Events considering the different groups of individuals results in an indication for the resulting individual risk (fatalities per person * year). This calculation has been done for both system-variants.
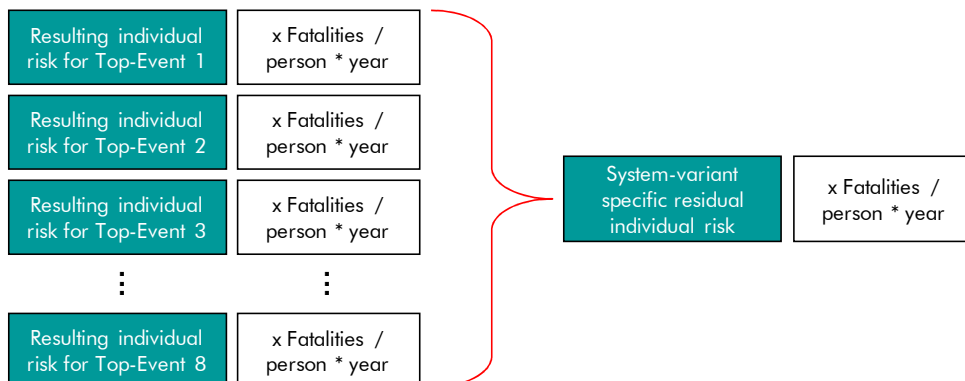


Figure 11: Example of derivation of the residual individual risk

An overview of the residual individual risk is shown in Table 45.

### 2.5.3.10 Top-Event-specific risk assessment

The following chapters 2.5.3.10.1 to 2.5.3.10.8 include detailed descriptions regarding risk-evaluation and –predictions for the two system-variants considered in this document. It should be noted that at this stage of the risk assessment the shown combined fault and event trees are not exhaustive and are shown only to facilitate information of possible risk influencing factors. The calculated (equivalent) fatalities per year and following the values concerning residual individual risks are based on the Norwegian average of 48 Mio. train kilometres per year and a supposed 5% additive train kilometres for a new high-speed rail system in Norway.

#### 2.5.3.10.1 Top-Event 1, Derailment

"Derailment" is defined as a Top-Event by JBV [10] and it is identified (see chapter 2.5.3.1) as the Top-Event 1 in this risk assessment. Based on Norwegian statistics [13] and the data related to "Derailment" the parameters for the risk assessment of Top-Event 1 as shown in Table 10 have been evaluated.

Table 10: Top-Event 1, statistical data [13]

| Top-Event | $\lambda_a$ per train km | Fatality rate per train km | Fatalities per accident | Fatalities per year |
|---|---|---|---|---|
| Derailment | 4,9E-9 | 3,1E-9 | 0,14 | 0,322 |

As described in chapter 2.5.3.2 the risk assessment at hand focuses on presumable changes of either the specific accident rate ($\Delta\lambda_a$) and / or the expected consequences given in fatalities per year. Due to the fact that those values could not be determined by the evaluation of statistical data [59][60], estimations by expert judgement have been required. The reasons and underlying thoughts / considerations regarding the taken estimations are described in the following for both system variants. For all blocks displayed in green colour in the following diagrams, the available statistics [12] [13] include informations regarding frequency of occurrence and / or consequences. On the other hand the diagrams consist of some elements (displayed in white colour) which do influence either the hazard rate or the consequences which can not be quantified by the available statistics [12] [13].

System-variant 1:

Figure 12 combines a fault tree to show causes which might lead to derailment as well as an event tree to display potential consequences related to system-variant 1.
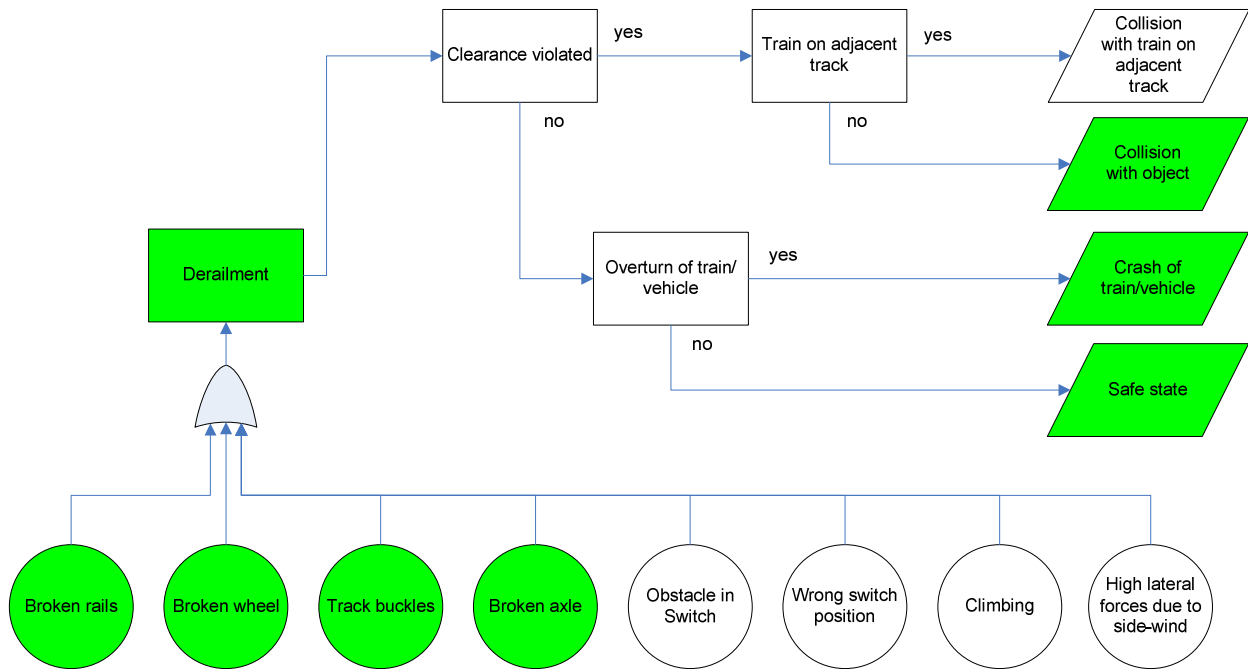
Figure 12: Top-Event 1 „Derailment", system-variant 1

The evaluation of Norwegian statistics [12] shows that derailments are mainly caused by failures of infrastructural equipment (e.g. rail, switches, interlocking blocks etc.). A minor contingent is related to technical failures onside rolling stock (e.g. breakage of wheels / axles / rail). The speed itself has not been identified as a major factor / cause for derailment even if considering that a derailment might be caused by overspeeding through a speed restriction. The higher forces on e.g. wheels or axles have to be compensated by adequate dimensioning / design. Due to an increased average speed the risk of derailment caused by side wind is supposed to be slightly higher as in the existing rail net, but appropriate windbreaks could be used to avoid a higher risk. Considering these aspects a differentiation regarding the accident rate for derailment on existing mixed rail traffic on one hand and for system-variant 1 on the other hand seems not to be required and in this phase of the risk assessment factor 1 regarding the potential change of the accident rate has been estimated:

$$\Delta\lambda_A = 1$$

The evaluation of Norwegian statistics further shows that the major contingent of derailments is supposed not to be followed by collisions. Anyway, the fatality rate per derailment is supposed to be higher in a High Speed Rail system as in the existing Norwegian Rail system due to the possibility of derailments followed by crashes and / or collisions, which would include higher kinetic energy due to an increased speed (estimated average speed of 120 km/h for system-variant 1 compared to an estimated average speed of 50 km/h in the existing net). The proportion of the masses of new high speed trains to conventional passenger trains (estimated to 1,5) is another factor which has to be considered. The accident rate also depends on the number of exposed persons, which presumably would be higher in system-varaint 1 compared to the existing net (estimated 400 passengers in high speed trains compared to estimated 100 passengers in conventional passenger trains).

$$\Delta\lambda_{FTop2} = 1,5 \cdot \frac{120^2}{50^2} \cdot \frac{400}{100}$$

An estimated increase as shown in the formula above results in an order of magnitude of about:

$\Delta\lambda_F = 35$

System-variant 2:

Regarding to "Derailment" Figure 13 shows causes as well as potential consequences related to system-variant 2. The main difference to system-variant 1 is the exclusion of derailments followed by collisions with other trains on adjacent track.
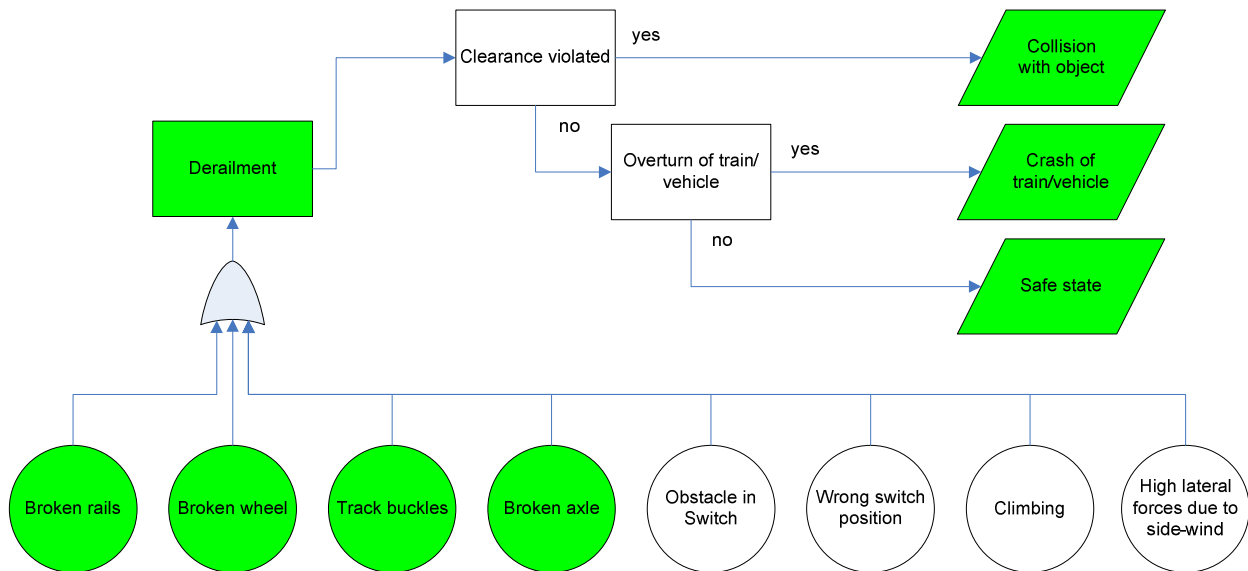


Figure 13: Top-Event 1 „Derailment", system-variant 2

For system-variant 2, the consequence analysis should consider higher average speed and the higher number of tunnels and bridges. As an influencing parameter a potential higher risk due to sidewind have to be considered. In this phase of the risk assessment these factors can not be quantified due to lack of data. On the other hand for a new (exclusively) high-speed rail system, the probability of derailment and so the accident rate is supposed to be lower than in system-variant 1 as well as in the existing railway net, due to a more stable track and a reduced number of equipment (e.g. switches, interlocking blocks etc.) and less maintenance. As these factors influence the accident rate but can not be quantifed at this phase of the risk assessment a factor 0,5 regarding the potential change of the accident rate for system-variant 2 has been estimated:

$\Delta\lambda_A = 0,5$

The authors advise further analysis of causes, particularly side wind effects, related to derailment as well as the evaluation off reliable data / statistics concerning probability / frequency of derailment in exclusively high-speed rail systems in order to justify the assumptions.

The fatality rate per derailment for system-variant 2 is influenced by different factors such as:

• Accident scenario after derailment (crash and / or following collisions);

• Higher kinetic energy in case of crash or collision may increase the fatality rate;

• Higher number of exposed passengers may increase the fatality rate;

• A higher percentage of railroad embankments, cambers, tunnels and bridges may increase the fatality rate because of potential more serious crashes / collisions after derailment;

- Reduced passing of urban agglomerations and industrial areas may decrease the fatality rate.

Analogous to the evaluation of system-variant 1 the major factors influencing the consequences which can be quantified are the resulting kinetic energy and the exposed passengers.

$$\Delta \lambda_{FTop2} = 1{,}5 \cdot \frac{250^2}{50^2} \cdot \frac{400}{100}$$

An estimated increase as shown in the formula above results in an order of magnitude of about:

$\Delta \lambda_F = 150$

It should be noted that the risk of a violation of the train envelope may increase at higher train speed as well due to the fact that there exists a linear relationship of the quantity of derailed cars in relation to train speed which ultimately enhances the fatality rate per derailment.

Table 11 gives an overview of the choosen parameters as well as the estimated values and the calculated risk given in fatalities per year for both system-variants, based on the assumption of supposed 5% additive train kilometres for a new high-speed rail system in Norway.

Table 11: Risk estimation, Top-Event 1

| Top-Event 1: Derailment | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rail-System | $\lambda_a$ per train km | $\Delta\lambda_{a\text{-}hs1}$ | $\lambda_a$ per train km (HSR) | Fatalities per accident | $\Delta\lambda_{f\text{-}hs1}$ | Fatalities per accident (new) | Fatalities per year |
| Existing system | 4,9E-8 | - | - | 0,14 | - | 0,14 | **0,322** |
| System-Variant 1 | 4,9E-8 | 1 | 4,9E-8 | 0,14 | 35 | 4,71 | **+ 0,579** |
| System-Variant 2 | 4,9E-8 | 0,5 | 2,5E-8 | 0,14 | 150 | 20,44 | **+ 1,256** |

Considering the percentaged distibution evaluated by European data (see Table 6) the resulting collective risk as shown in Table 11 can be allocated to the different groups of affected persons as described in Table 12.

Table 12: Distribution of collective risk, Top-Event 1

| Top-Event 1: Derailment, collective risk | | | | | |
|---|---|---|---|---|---|
| Persons | Fatalities per year | Distribution | Fatalities per year, existing rail net | Fatalities per year, System-variant 1 | Fatalities per year, System-variant 2 |
| others | | 62,0% | 0,199 | 0,559 | 0,979 |
| Passengers | 0,322 | 22,0% | 0,071 | 0,197 | 0,346 |
| Personal | | 16,0% | 0,051 | 0,143 | 0,251 |
| | | | **0,322** | **0,899** | **1,576** |

The individual risk depends on the number of exposed / affected persons.

Table 13: Distribution of individual risk, Top-Event 1

| Top-Event 1: Derailment, individual risk | | | | |
|---|---|---|---|---|
| Persons | Number of exposed / affected persons | Individual risk [Fatalities / person * year] | | |
| | | existing rail net | System-variant 1 | System-variant 2 |
| others | 3.000.000 | 6,65E-08 | 1,86E-07 | 3,26E-07 |
| Passengers | 3.000.000 | 2,36E-08 | 6,60E-08 | 1,16E-07 |
| Personal | 7.500 | 6,86E-06 | 1,92E-05 | 3,37E-05 |
| | | **6,95E-06** | **1,95E-05** | **3,41E-05** |

In order to minimize existing uncertainties of the risk assessment at hand it is essential to continue the analysis regarding expected changes of the specific accident rates ($\Delta\lambda_a$) and the expected consequences given in fatalities per year by evaluation of more detailed data as they are given in [12] [13].

As accident statistics [12] [13] show, consequences in case of a derailment may come up in very different spectrums. Derailment with only minor or severe outcome is possible, but also catastrophic outcome like rollover are realistic. At the end of the consequences spectrum worst case accidents, e.g. derailment followed by collision with edifices (buildings, bridges etc.) or with other train on adjacent track are extreme unusual but can not be excluded completely. It has also to be mentioned that any catastrophic accident like for example the ICE-accident in Germany, Eschede [15] would lead to a massive exceedance of defined risk acceptance criteria (either individual or collective risk).

### 2.5.3.10.2 Top-Event 2, Collision train-train

"Collision train-train" is defined as a Top-Event by JBV [10] and it is identified (see chapter 2.5.3.1) as the Top-Event 2 in this risk assessment. Due to no data related to "Collision train-train" in Norwegian statistics [13] the accident rate evaluated in [12] , which is shown in Table 14, has been used as the basis for the risk assessment for Top-Event 2.

Table 14: Top-Event 2, statistical data [12]

| Top-Event | $\lambda_a$ per train km | Fatality rate per train km | Fatalities per accident | Fatalities per year |
|---|---|---|---|---|
| Collision train-train | 7,4E-9 | 8,8E-10 | 0,12 | 0,042 |

As described in chapter 2.5.3.2 the risk assessment at hand focuses on presumable changes of either the specific accident rate ($\Delta\lambda_a$) and / or the expected consequences given in fatalities per year. Due to the fact that those values could not be determined by the evaluation of statistical data, estimations by expert judgement have been required. The reasons and underlying thoughts / considerations regarding the taken estimations are described in the following for both system variants. For all blocks displayed in green colour in the following diagrams, the available statistics [12] [13] include informations regarding frequency of occurrence and / or

consequences. On the other hand elements of the diagrams (displayed in white colour), may influence either the hazard rate or the consequences but the influence of these elements could not be quantified by the available statistics [12] [13].

System-variant 1:

Figure 14 and Figure 15 combine fault trees to show causes which might lead to collisions train-train as well as an event tree to display potential consequences related to system-variant 1.
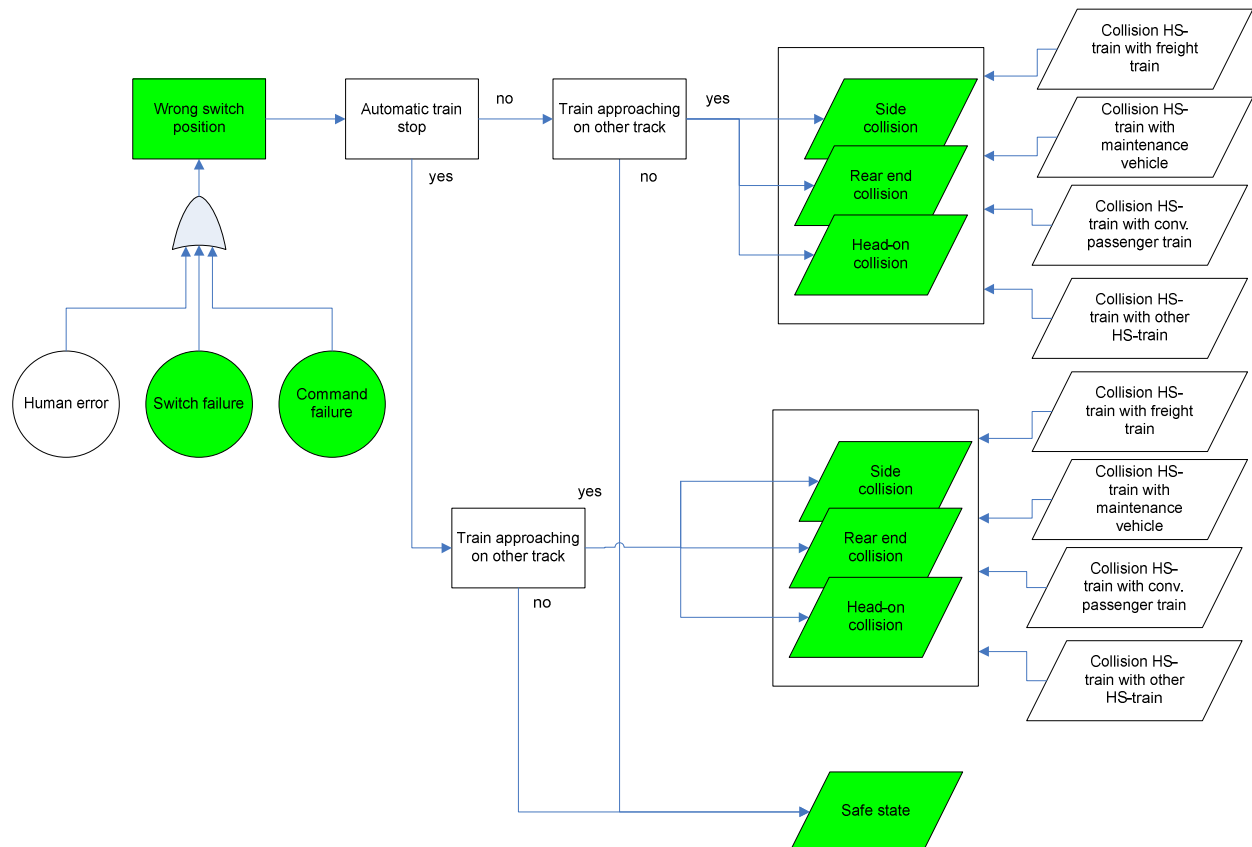


Figure 14: FTA / ETA system-variant 1, wrong switch position
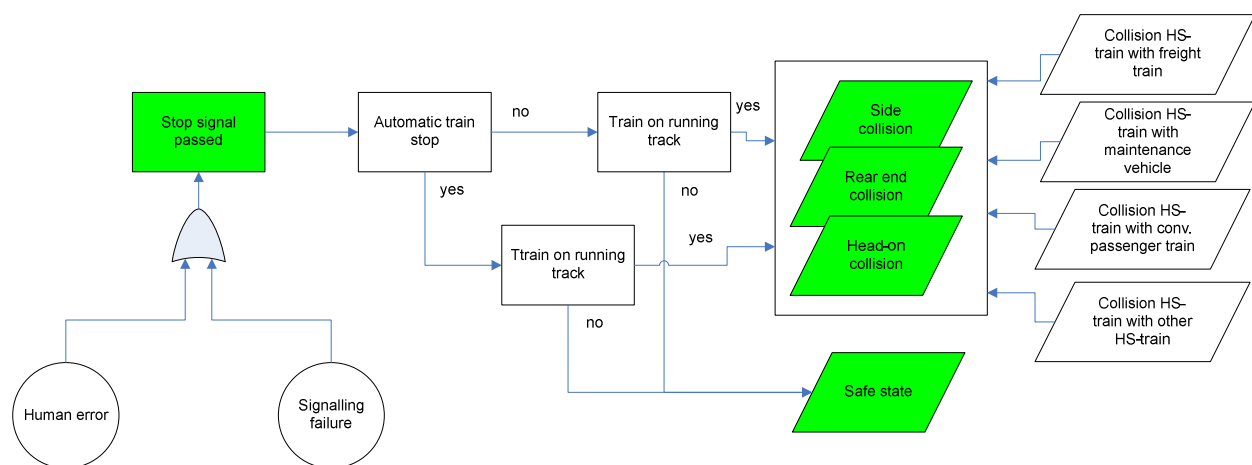
Figure 15: FTA / ETA system-variant 1, stop signal passed

The evaluation of Norwegian statistics shows that collisions train-train are mainly caused by failures of infrastructural equipment (e.g. rail, switches, interlocking blocks etc.). The speed itself has not been identified as a major factor / cause for collision train-train. A small influence might be the higher braking distance at higher speeds. Considering this aspect a differentiation regarding the accident rate for collision train-train on existing mixed rail traffic on one hand and for system-variant 1 on the other hand seems not to be required and in this phase of the risk assessment factor 1 has been estimated:

$$\Delta\lambda_A = 1$$

The fatality rate per collision train to train is supposed to be higher in a High Speed Rail system as in the existing Norwegian Rail system. Reasons may be on one hand higher kinetic energy in case of collision due to due the higher average speed (estimated 120 km/h for system-variant 1 compared to estimated 50 km/h in the existing net) and on the other hand the presumed higher number of potentially affected persons (estimated 400 passengers in high speed trains compared to estimated 100 passengers in conventional passenger trains). The proportion of the masses of new high speed trains to conventional passenger trains (estimated to 1,5) is another factor which has to be considered.

$$\Delta\lambda_{FTop2} = 1,5 \cdot \frac{120^2}{50^2} \cdot \frac{400}{100}$$

It is supposed that a major contingent of collisions between train in the existing Norwegian net as well as in other countries is related to collisions of shunting locomotives at low speed. An estimated increase as shown in the formula above results in an order of magnitude of about:

$$\Delta\lambda_F = 35$$

System-variant 2:

Figure 16 and Figure 17 combine fault trees to show causes which might lead to collisions train-train as well as an event tree to display potential consequences related to system-variant 2.
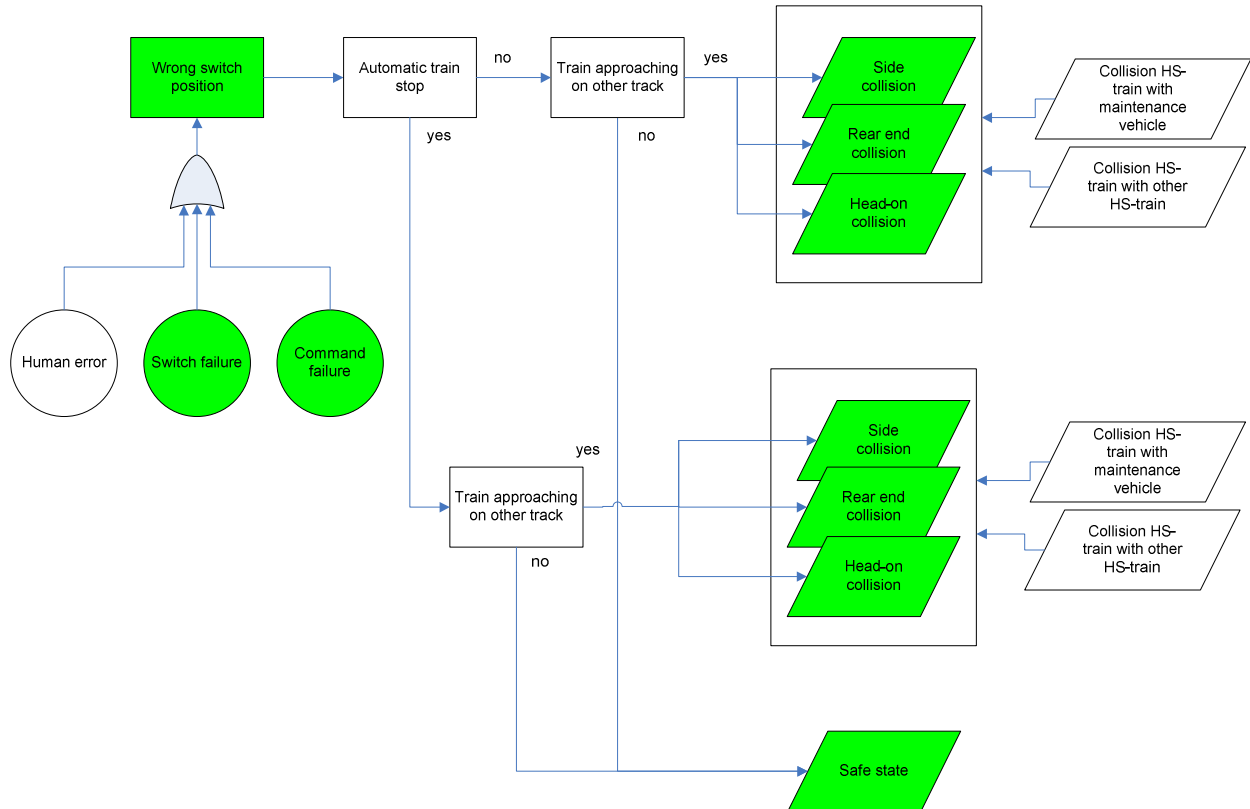
Figure 16: FTA / ETA system-variant 2, wrong switch position
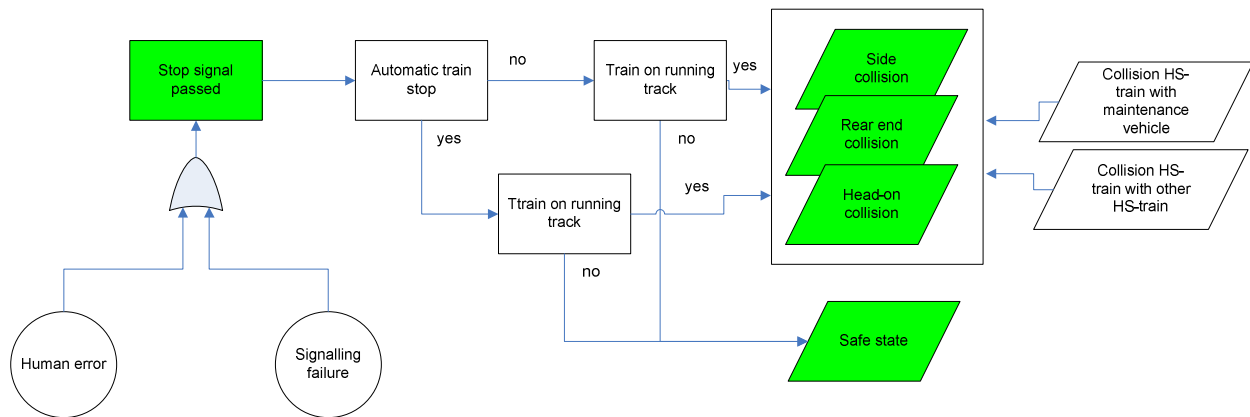


Figure 17: FTA / ETA system-variant 2, stop signal passed

As described before collisions train-train are mainly caused by failures of infrastructural equipment (e.g. rail, switches, interlocking blocks etc.). Considering this aspect the accident rate for collision train-train in system-variant 2 is supposed to be lower due to a reduced number of potential collision points (train passing points) and less trains in operation. As a first consideration in this phase of a risk assessment, a reduction by the factor 100 for the accident rate of collision train-train seems to be justifiable and sufficient.

$$\Delta\lambda_A = 0,01$$

The fatality rate per collision train to train is supposed to be even higher as it has been estimated for the system-variant 1. Collisions in system-variant 2 may only occur between high

speed trains or maintenance vehicles and high speed trains. Analogous to the evaluation of system-variant 1 the major factors influencing the consequences are the resulting kinetic energy and the exposed passengers.

$$\Delta\lambda_{F\,Top2} = 1{,}5 \cdot \frac{250^2}{50^2} \cdot \frac{400}{100}$$

An estimated increase as shown in the formula above results in an order of magnitude of about:

$\Delta\lambda_F$ = 150

Table 15 gives an overview of the parameters as well as the estimated values and the calculated risk given in fatalities per year for both system-variants, based on the assumption of supposed 5% additive train kilometres for a new high-speed rail system in Norway.

Table 15: Risk estimation, Top-Event 2

| Top-Event 2: Collision train-train | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rail-System | $\lambda_a$ per train km | $\Delta\lambda_{a\text{-}hs1}$ | $\lambda_a$ per train km (HSR) | Fatalities per accident | $\Delta\lambda_{f\text{-}hs1}$ | Fatalities per accident (new) | Fatalities per year |
| Existing system | 7,4E-9 | - | - | 0,12 | - | 0,12 | **0,042** |
| System-Variant 1 | 7,4E-9 | 1 | 7,4E-9 | 0,12 | 35 | 4,10 | **+ 0,076** |
| System-Variant 2 | 7,4E-9 | 0,01 | 7,4E-11 | 0,12 | 150 | 17,79 | **+ 0,003** |

Considering the percentaged distibution evaluated by European data (see Table 6) the resulting collective risk as shown in Table 15 can be allocated to the different groups of affected persons as described in Table 12.

Table 16: Distribution of collective risk, Top-Event 2

| Top-Event 2: Collision train-train | | | | | |
|---|---|---|---|---|---|
| Persons | Fatalities per year | Distribution | Fatalities per year, existing rail net | Fatalities per year, System-variant 1 | Fatalities per year, System-variant 2 |
| others | | 14,3% | 0,006 | 0,017 | 0,006 |
| Passengers | 0,042 | 21,4% | 0,009 | 0,025 | 0,010 |
| Personal | | 64,3% | 0,027 | 0,078 | 0,029 |
| | | | **0,042** | **0,120** | **0,045** |

The individual risk depends on the number of exposed / affected persons.

Table 17: Distribution of individual risk, Top-Event 2

| Top-Event 2: Collision train-train | | | | |
|---|---|---|---|---|
| **Persons** | **Number of exposed / affected persons** | **Individual risk [Fatalities / person * year]** | | |
| | | **existing rail net** | **System-variant 1** | **System-variant 2** |
| others | 3.000.000 | 2,00E-09 | 5,61E-09 | 2,16E-09 |
| Passengers | 3.000.000 | 3,00E-09 | 8,39E-09 | 3,23E-09 |
| Personal | 7.500 | 3,60E-06 | 1,01E-05 | 3,88E-06 |
| | | **3,61E-06** | **1,01E-05** | **3,89E-06** |

In order to minimize existing uncertainties of the risk assessment at hand it is essential to continue the analysis regarding expected changes of the specific accident rates ($\Delta\lambda_a$) and the expected consequences given in fatalities per year by evaluation of more detailed data as they are given in [12] [13].

### 2.5.3.10.3 Top-Event 3, Collision train-object

"Collision train-object" is defined as a Top-Event by JBV [10] and it is identified (see chapter 2.5.3.1) as the Top-Event 3 in this risk assessment. On base of Norwegian statistics [13] and the data related to "Collision train-object" the parameters for the risk assessment of Top-Event 3 as shown in Table 18 have been evaluated.

Table 18: Top-Event 3, statistical data [13]

| **Top-Event** | **$\lambda_a$ per train km** | **Fatality rate per train km** | **Fatalities per accident** | **Fatalities per year** |
|---|---|---|---|---|
| Collision train-object | 1,1E-7 | 4,3E-9 | 0,21 | 1,160 |

As described in chapter 2.5.3.2 the risk assessment at hand focuses on presumable changes of either the specific accident rate ($\Delta\lambda_a$ per train km) and / or the expected consequences given in fatalities per year. Due to the fact that those values could not be determined by the evaluation of statistical data [59][60], estimations by expert judgement have been required. The reasons and underlying thoughts / considerations regarding the taken estimations are described in the following for both system variants. For all blocks displayed in green colour in the following diagrams, the available statistics [12] [13] include informations regarding frequency of occurrence and / or consequences. On the other hand elements of the diagrams (displayed in white colour), may influence either the hazard rate or the consequences but the influence of these elements could not be quantified by the available statistics [12] [13].

Figure 18 combines a fault tree to show causes which might lead to collisions train-object as well as an event tree to display potential consequences. The diagram is related to both system-variants 1 and 2.
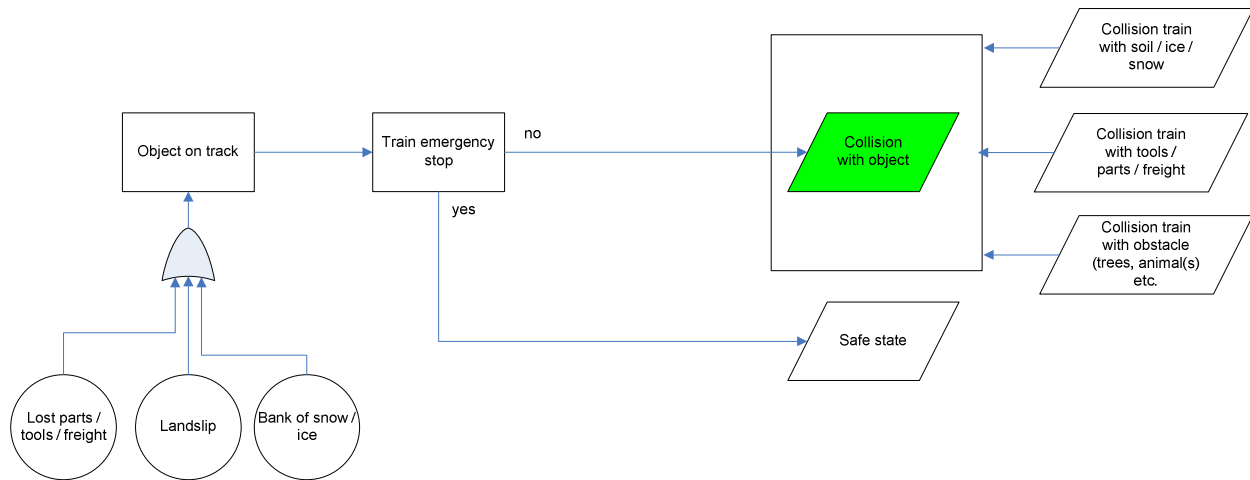
Figure 18: FTA / ETA system-variant 1, object on track

System-variant 1:

Collisions train-objects are mainly caused by environmental / climatical situations or human failures. Human failures in this context may be on one hand lost or forgotten parts / tools mainly related to repair- and maintenance activities and on the other hand lost freight or lost train-parts. Heavy snowfall and very low temperatures are the main reasons for collisions with banks of snow and / or ice. Landslip and /or falling rocks represent another main cause for Top-Event 3. The specific Norwegian environmental / climatical situations are supposed to be responsible for a higher accident rate for "collision with object" compared to the European average (see Table 4 and Table 5). Regarding the causes displayed in Figure 18 a differentiation between system-variant 1 and the existing railway system in Norway seems not to be required. As a first consideration in this phase of a risk assessment, a factor 1 for the accident rate of collision train-object seems to be justifiable and sufficient.

$$\Delta\lambda_A = 1,0$$

The fatality rate per collision train to object is supposed to be higher in a High Speed Rail system as in the existing Norwegian Rail system. As for other Top-Events (derailment, collision train-train) reasons may be on one hand higher kinetic energy in case of collision due to the mass ratio (estimated to 1,5 for new high speed trains compared to conventional passenger trains), the higher average speed (estimated 120 km/h for system-variant 1 compared to estimated 50 km/h in the existing net) and on the other hand the presumed higher number of potentially affected persons (estimated 400 passengers in high speed trains compared to estimated 100 passengers in conventional passenger trains).

$$\Delta\lambda_{F\,Top2} = 1,5 \cdot \frac{120^2}{50^2} \cdot \frac{400}{100}$$

An estimated increase of the fatality rate as shown in the formula above results in an order of magnitude of about:

$$\Delta\lambda_F = 35$$

System-variant 2:

The accident rate for collision train-object in system-variant 2 is supposed to be lower as in the existing net. The exclusively operation of modern high speed trains should lead to a perceptible decreased probability of lost train-parts. The loosening of freight can be more or less excluded and due to less maintenance work at the more stable track the probability of lost or forgotten

tools / parts should also lead to a reduced accident rate. As for other Top-Events, respectively their potential causes the problem is the missing quantification of these aspects due to missing data.  As a first consideration in this phase of a risk assessment, a reduction by the factor 2 for the accident rate of collision train-object seems to be justifiable and sufficient.

$$\Delta\lambda_A = 0,5$$

The fatality rate per collision train to objects is supposed to be even higher in as it has been estimated for the system-variant 1. Analogous to the evaluation of system-variant 1 the major factors influencing the consequences are supposed to be the resulting kinetic energy and the exposed passengers.

$$\Delta \lambda_{F\,Top2} = 1,5 \cdot \frac{250^2}{50^2} \cdot \frac{400}{100}$$

An estimated increase as shown in the formula above results in an order of magnitude of about:

$$\Delta\lambda_F = 150$$

Table 19 gives an overview of the parameters as well as the estimated values and the calculated risk given in fatalities per year for both system-variants, based on the assumption of supposed 5% additive train kilometres for a new high-speed rail system in Norway.

Table 19: Risk estimation, Top-Event 3

| Top-Event 3: Collision train-object | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rail-System | $\lambda_a$ per train km | $\Delta\lambda_{a\text{-hs1}}$ | $\lambda_a$ per train km (HSR) | Fatalities per accident | $\Delta\lambda_{f\text{-hs1}}$ | Fatalities per accident (new) | Fatalities per year |
| Existing system | 1,1E-7 | - | - | 0,21 | - | - | **1,160** |
| System-Variant 1 | 1,1E-7 | 1 | 1,1E-7 | 0,21 | 35 | 7,29 | **+ 2,079** |
| System-Variant 2 | 1,1E-7 | 0,50 | 5,7E-8 | 0,21 | 150 | 31,62 | **+ 4,513** |

As an important further conclusion of the calculation the relatively high influence of Top-Event 3 "collision train-object" to the overall residual risk of a potential new high speed rail system can be stated.

Considering the percentaged distibution evaluated by European data (see Table 6) the resulting collective risk as shown in Table 19 can be allocated to the different groups of affected persons as described in Table 20.

Table 20: Distribution of collective risk, Top-Event 3

| Top-Event 3: Collision train-object | | | | | |
|---|---|---|---|---|---|
| **Persons** | **Fatalities per year** | **Distribution** | **Fatalities per year, existing rail net** | **Fatalities per year, System-variant 1** | **Fatalities per year, System-variant 2** |
| others | | 73,9% | 0,854 | 2,390 | 4,189 |
| Passengers | 1,160 | 11,6% | 0,134 | 0,375 | 0,657 |
| Personal | | 14,5% | 0,168 | 0,469 | 0,822 |
| | | | **1,160** | **3,235** | **5,668** |

The individual risk depends on the number of exposed / affected persons.

Table 21: Distribution of individual risk, Top-Event 3

| Top-Event 3: Collision train-object | | | | |
|---|---|---|---|---|
| **Persons** | **Number of exposed / affected persons** | **Individual risk [Fatalities / person * year]** | | |
| | | **existing rail net** | **System-variant 1** | **System-variant 2** |
| others | 3.000.000 | 2,85E-07 | 7,97E-07 | 1,40E-06 |
| Passengers | 3.000.000 | 4,47E-08 | 1,25E-07 | 2,19E-07 |
| Personal | 7.500 | 2,23E-05 | 6,25E-05 | 1,10E-04 |
| | | **2,27E-05** | **6,35E-05** | **1,11E-04** |

In order to minimize existing uncertainties of the risk assessment at hand it is essential to continue the analysis regarding expected changes of the specific accident rates ($\Delta\lambda_a$) and the expected consequences given in fatalities per year by evaluation of more detailed data as they are given in [12] [13].

### 2.5.3.10.4 Top-Event 4, Fire

"Fire" is identified (see chapter 2.5.3.1) as the Top-Event 4. Norwegian statistics [13] as well as the available European data [12] do only specify „Fire in rolling stock". The data as shown in Table 22 have been evaluated for the risk assessment of Top-Event 4.

Table 22: Top-Event 4, statistical data [13]

| **Top-Event** | **$\lambda_a$ per train km** | **Fatality rate per train km** | **Fatalities per accident** | **Fatalities per year** |
|---|---|---|---|---|
| Fire in rolling stock | 4,3E-8 | 1,5E-10 | 0,02 | 0,049 |

As described in chapter 2.5.3.2 the risk assessment at hand focuses on presumable changes of either the specific accident rate ($\Delta\lambda_a$) and / or the expected consequences given in fatalities per year. Due to the fact that those values could not be determined by the evaluation of statistical data, estimations by expert judgement have been required. The reasons and underlying thoughts / considerations regarding the taken estimations are described in the following for both system variants. For all blocks displayed in green colour in the following diagrams, the available statistics [12] [13] include informations regarding frequency of occurrence and / or

consequences. On the other hand elements of the diagrams (displayed in white colour), may influence either the hazard rate or the consequences but the influence of these elements could not be quantified by the available statistics [12] [13].

Figure 19 and Figure 20 combine fault trees to show causes which might lead to fire as well as event trees to display potential consequences. The diagrams are related to both system-variants 1 and 2.
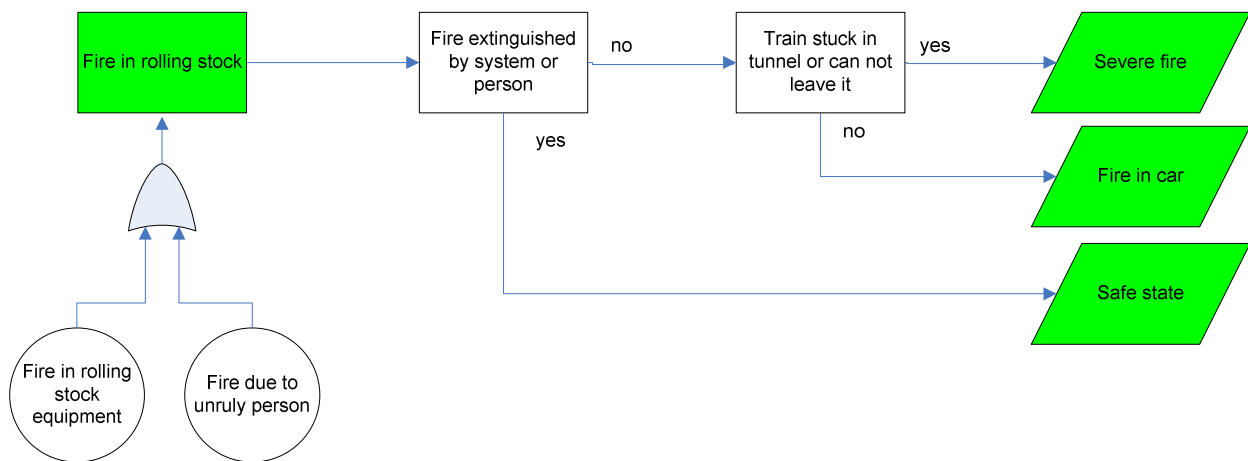


Figure 19: FTA / ETA system-variant 1/2, fire in rolling stock
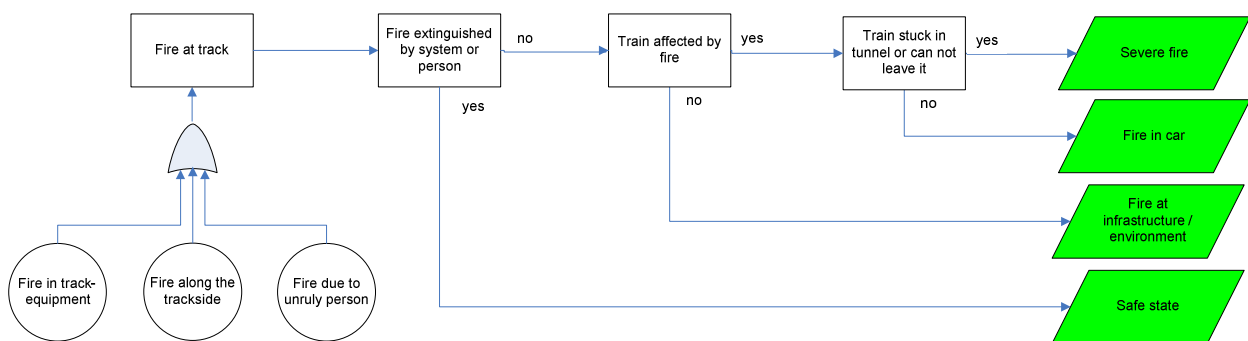


Figure 20: FTA / ETA system-variant 1/2, fire at track

System-variant 1:

Fires in rolling stock or at track are mainly caused by overheating of technical equipment and / or leakage of easily flammable substances (e.g. fuel). The major contingent is supposed to be human misbehaviour (e.g. smoking or malicious arson), but the available data [12] [13] do not include information concerning the detected causes of fires in the past. A higher number of passengers (estimated 400 passengers in high speed trains compared to estimated 100 passengers in conventional passenger trains) may implicate a higher risk for fire caused by persons. As a first consideration in this phase of a risk assessment, a factor 4 for the accident rate of fire in rolling stock seems to be justifiable and sufficient.

$\Delta\lambda_A = 4,0$

The fatality rate in case of fire in rolling stock is supposed to be higher in system-variant 1 as in the existing Norwegian Rail system due to the presumed higher number of potentially affected persons (estimated 400 passengers in high speed trains compared to estimated 100 passengers in conventional passenger trains). Another aspect is the design of modern high speed trains which is typically represented by contineopusly open compartments. This aspect which may increase the risk of expansion of fire to other vehicles still can not be quantified on base of the evaluated statistics [12] [13] and therefore an estimated increase of factor 4 (based on the supposed number of passengers) for the fatality rate seems to be justifiable and sufficient.

$\Delta\lambda_F = 4,0$

System-variant 2:

Considering the aspects described above for the system-variant 1 a factor 4 (ratio of exposed number of passengers) for the accident rate of fire in rolling stock in system-variant 2 seems to be justifiable and sufficient.

$\Delta\lambda_A = 4,0$

The fatality rate in case of fire in rolling stock is supposed to be higher in system-variant 2 as in the existing Norwegian Rail system due to the presumed higher number of potentially affected persons (estimated 400 passengers in high speed trains compared to estimated 100 passengers in conventional passenger trains) and the design of modern high speed trains with contineopusly open compartments. This aspect as described before may increase the risk of expansion of fire to other vehicles. On the other hand modern high speed trains are rigged with fire alarm- and extinguishing systems. Another factor which may increase the fatality rate is the supposed higher percentage of track inside tunnels. A quantification of these aspects has not been possible on base of the evaluated statistics [12] [13]  and therefore an estimated increase of factor 8 (factor 4 based on the supposed number of passengers and factor 2 considering the higher contingent of tunnels) for the fatality rate seems to be justifiable and sufficient.

$\Delta\lambda_F = 8,0.$

Table 23 gives an overview of the parameters as well as the estimated values and the calculated risk given in fatalities per year for both system-variants, based on the assumption of supposed 5% additive train kilometres for a new high-speed rail system in Norway.

Table 23: Risk estimation, Top-Event 4

| Top-Event 2: Fire in rolling stock | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rail-System | $\lambda_a$ per train km | $\Delta\lambda_{a\text{-}hs1}$ | $\lambda_a$ per train km (HSR) | Fatalities per accident | $\Delta\lambda_{f\text{-}hs1}$ | Fatalities per accident (new) | Fatalities per year |
| Existing system | 4,3E-8 | - | - | 0,02 | - | - | **0,049** |
| System-Variant 1 | 4,3E-8 | 4,00 | 1,7E-7 | 0,02 | 4,00 | 0,10 | **+ 0,041** |
| System-Variant 2 | 4,3E-8 | 4,00 | 1,7E-7 | 0,02 | 8,00 | 0,19 | **+ 0,082** |

As an important further conclusion of the calculation the minor influence of Top-event 4 "Fire" to the overall residual risk of a potential new high speed rail system can be stated.

Considering the percentaged distibution evaluated by European data (see Table 6) the resulting collective risk as shown in Table 23 can be allocated to the different groups of affected persons as described in Table 24.

Table 24: Distribution of collective risk, Top-Event 4

| Top-Event 4: Fire | | | | | |
|---|---|---|---|---|---|
| Persons | Fatalities per year | Distribution | Fatalities per year, existing rail net | Fatalities per year, System-variant 1 | Fatalities per year, System-variant 2 |
| others | | 8,9% | 0,004 | 0,008 | 0,012 |
| Passengers | 0,049 | 89,4% | 0,044 | 0,081 | 0,117 |
| Personal | | 1,6% | 0,001 | 0,001 | 0,002 |
| | | | **0,049** | **0,090** | **0,131** |

The individual risk depends on the number of exposed / affected persons.

Table 25: Distribution of individual risk, Top-Event 4

| Top-Event 4: Fire | | | | |
|---|---|---|---|---|
| Persons | Number of exposed / affected persons | Individual risk [Fatalities / person * year] | | |
| | | existing rail net | System-variant 1 | System-variant 2 |
| others | 3.000.000 | 1,46E-09 | 2,67E-09 | 3,89E-09 |
| Passengers | 3.000.000 | 1,46E-08 | 2,68E-08 | 3,91E-08 |
| Personal | 7.500 | 1,05E-07 | 1,92E-07 | 2,80E-07 |
| | | **1,21E-07** | **2,22E-07** | **3,23E-07** |

In order to minimize existing uncertainties of the risk assessment at hand it is essential to continue the analysis regarding expected changes of the specific accident rates ($\Delta\lambda_a$) and the expected consequences given in fatalities per year by evaluation of more detailed data as they are given in [12] [13].

### 2.5.3.10.5 Top-Event 5, passenger injured at platform

"Passenger injured at platform" is defined as a Top-Event by JBV [10] and it is identified (see chapter 2.5.3.1) as the Top-Event 5 in this risk assessment. Due to no data related to "Passenger injured at platform" in Norwegian statistics [13] the accident rate evaluated in [12] , which is shown in Table 26, has been used as the basis for the risk assessment for Top-Event 5.

Table 26: Top-Event 5, statistical data [13]

| Top-Event | $\lambda_a$ per train km | Fatality rate per train km | Fatalities per accident | Fatalities per year |
|---|---|---|---|---|
| Passenger injured at platform | 1,7E-7 | 8,1E-8 | 0,48 | 3,891 |

As described in chapter 2.5.3.2 the risk assessment at hand focuses on presumable changes of either the specific accident rate ($\Delta\lambda_a$ per train km) and / or the expected consequences given in fatalities per year. Due to the fact that those values could not be determined by the evaluation of statistical data [59][60], estimations by expert judgement have been required. The reasons and underlying thoughts / considerations regarding the taken estimations are described in the following for both system variants. For all blocks displayed in green colour in the following diagrams, the available statistics [12] [13] include informations regarding frequency of occurrence and / or consequences. On the other hand elements of the diagrams (displayed in white colour), may influence either the hazard rate or the consequences but the influence of these elements could not be quantified by the available statistics [12] [13].

Figure 21 and Figure 22 combine fault trees to show causes which might lead to persons injured at platform as well as event trees to display potential consequences. The diagrams are related to both system-variants 1 and 2.
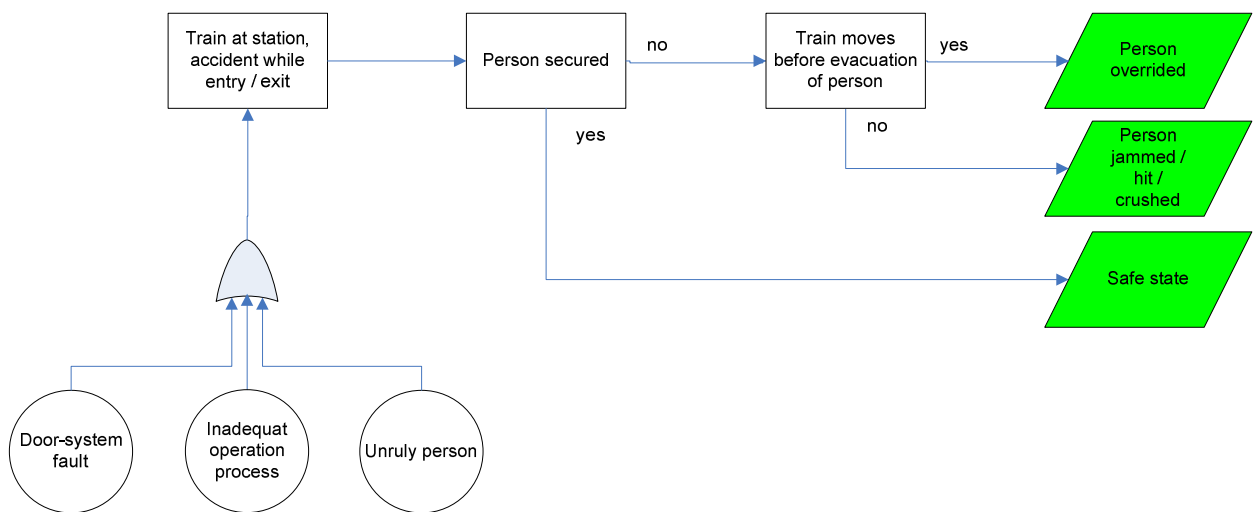


Figure 21: FTA / ETA system-variant 1/2, person injured at platform while entry /exit
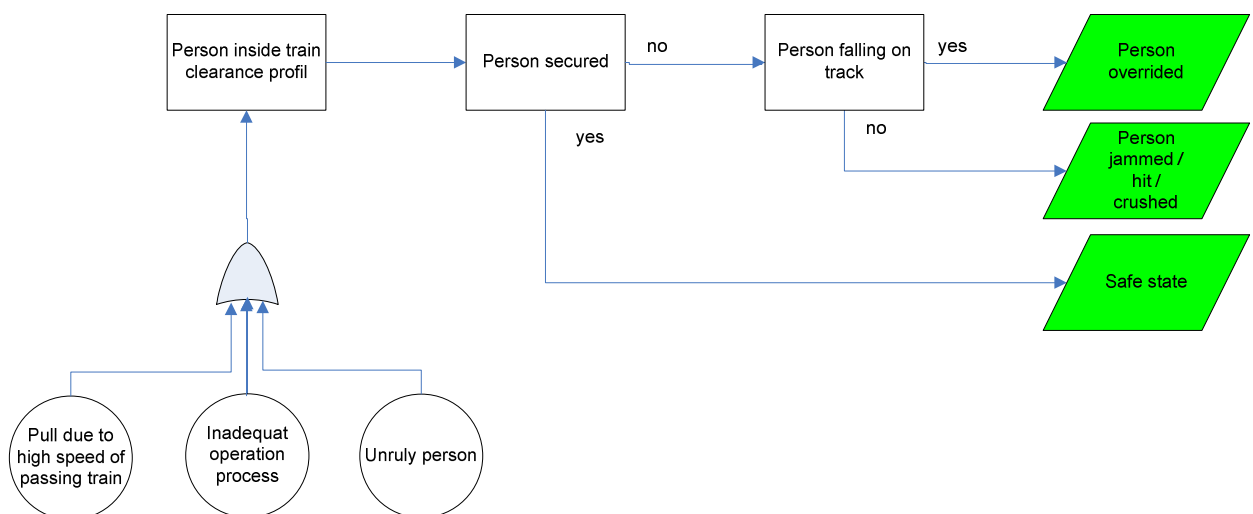


Figure 22: FTA / ETA system-variant 1/2, person injured at platform by passing train

System-variant 1:

As statistics show the most injuries at platforms are related to entries / exits of passengers. Causes can be inadequate operation processes / human failures as well as technical failures of the door system and its monitoring equipment. Regarding these aspects a differentiation between system-variant 1 compared to the existing railway net does not seem to be required. The second case, persons may come inside the train clearance profil can also be caused by different aspects as shown in figure 22. High speed of passing trains can lead to pulls at the platform. Especially small children and older persons may be affected by this scenario. Anyway a quantification of a potential increase of risk is not possible at this phase of the risk assessment and therefore as a first consideration a factor 1 for the accident rate of "persons injured at platform" seems to be justifiable and sufficient.

$$\Delta\lambda_A = 1,0$$

The fatality rate for "persons injured at platform" is also not supposed to be higher in system-variant 1 and therefore a factor 1 for a potential change of the fatality rate seems to be justifiable and sufficient.

$$\Delta\lambda_F = 1,0$$

System-variant 2:

The accident rate in system-variant 2 is influenced by different aspects:

- A reduced number of stops of high speed trains and so less entries / exits may decrease the accident rate;

- Longer stops and special operation processes may decrease the accident rate;

- Suction at platform is expected to be higher and may increase the accident rate.

These potential causes are displayed in white colour in figure 21 and 22 and can not be quantifed by the evaluation of the available data. As first estimation for the change of the accident rate of "persons injured at platform" a reduction by factor 10 in system-variant 2 seems to be justifiable and sufficient.

$$\Delta\lambda_A = 0,1$$

The fatality rate for "persons injured at platform" is also not supposed to be higher in system-variant 2 and therefore a factor 1 for a potential change of the fatality rate seems to be justifiable and sufficient.

$$\Delta\lambda_F = 1,0$$

Table 27 gives an overview of the parameters as well as the estimated values and the calculated risk given in fatalities per year for both system-variants, based on the assumption of supposed 5% additive train kilometres for a new high-speed rail system in Norway.

Table 27: Risk estimation, Top-Event 5

| Top-Event 5: Persons injured at platform | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rail-System | $\lambda_a$ per train km | $\Delta\lambda_{a\text{-}hs1}$ | $\lambda_a$ per train km (HSR) | Fatalities per accident | $\Delta\lambda_{f\text{-}hs1}$ | Fatalities per accident (new) | Fatalities per year |
| Existing system | 1,7E-7 | - | - | 0,48 | - | - | **3,891** |
| System-Variant 1 | 1,7E-7 | 1,00 | 1,7E-7 | 0,48 | 1,00 | 0,48 | **+ 0,203** |
| System-Variant 2 | 1,7E-7 | 0,10 | 1,7E-8 | 0,48 | 1,00 | 0,48 | **+ 0,020** |

As an important further conclusion of the calculation the minor influence of Top-event 5 "Persons injured at platform" to the overall residual risk of a potential new high speed rail system can be stated.

Considering the percentaged distibution evaluated by European data (see Table 6) the resulting collective risk as shown in Table 27 can be allocated to the different groups of affected persons as described in Table 28.

Table 28: Distribution of collective risk, Top-Event 5

| Top-Event 5: Persons injured at platform | | | | | |
|---|---|---|---|---|---|
| Persons | Fatalities per year | Distribution | Fatalities per year, existing rail net | Fatalities per year, System-variant 1 | Fatalities per year, System-variant 2 |
| others | | 86,6% | 3,370 | 3,545 | 3,387 |
| Passengers | 3,891 | 9,3% | 0,362 | 0,381 | 0,364 |
| Personal | | 4,1% | 0,160 | 0,168 | 0,160 |
| | | | **3,891** | **4,094** | **3,911** |

The individual risk depends on the number of exposed / affected persons.

Table 29: Distribution of individual risk, Top-Event 5

| Top-Event 5: Persons injured at platform | | | | |
|---|---|---|---|---|
| Persons | Number of exposed / affected persons | Individual risk [Fatalities / person * year] | | |
| | | existing rail net | System-variant 1 | System-variant 2 |
| others | 3.000.000 | 1,12E-06 | 1,18E-06 | 1,13E-06 |
| Passengers | 3.000.000 | 1,21E-07 | 1,27E-07 | 1,21E-07 |
| Personal | 7.500 | 2,13E-05 | 2,24E-05 | 2,14E-05 |
| | | **2,25E-05** | **2,37E-05** | **2,26E-05** |

In order to minimize existing uncertainties of the risk assessment at hand it is essential to continue the analysis regarding expected changes of the specific accident rates ($\Delta\lambda_a$) and the

expected consequences given in fatalities per year by evaluation of more detailed data as they are given in [12] [13].

### 2.5.3.10.6 Top-Event 6, Passenger injured at level crossing

"Passenger injured at level crossing" is defined as a Top-Event by JBV [10] and it is identified (see chapter 2.5.3.1) as the Top-Event 6 in this risk assessment. On base of Norwegian statistics [13] and the data related to "Passenger injured at level crossing" the parameters for the risk assessment of Top-Event 6 as shown in Table 30 have been evaluated.

Table 30: Top-Event 5, statistical data [13]

| Top-Event | $\lambda_a$ per train km | Fatality rate per train km | Fatalities per accident | Fatalities per year |
|---|---|---|---|---|
| Passenger injured at level crossing | 3,3E-8 | 8,7E-8 | 0,63 | 0,982 |

As described in chapter 2.5.3.2 the risk assessment at hand focuses on presumable changes of either the specific accident rate ($\Delta\lambda_a$) and / or the expected consequences given in fatalities per year. Due to the fact that those values could not be determined by the evaluation of statistical data [59][60], estimations by expert judgement have been required. The reasons and underlying thoughts / considerations regarding the taken estimations are described in the following for both system variants. For all blocks displayed in green colour in the following diagrams, the available statistics [12] [13] include informations regarding frequency of occurrence and / or consequences. On the other hand elements of the diagrams (displayed in white colour), may influence either the hazard rate or the consequences but the influence of these elements could not be quantified by the available statistics [12] [13].

Figure 23 and Figure 24 combine fault trees to show causes which might lead to persons injured at platform as well as event trees to display potential consequences. The Top-Event 6 and so the shown diagram is only related to system-variant 1.
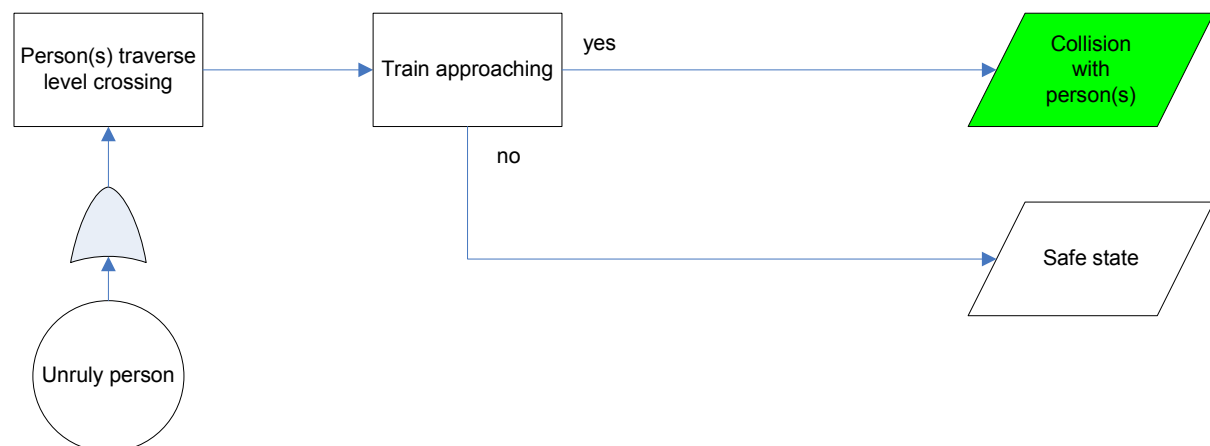


Figure 23: FTA / ETA system-variant 1, person(s) traverse level crossing
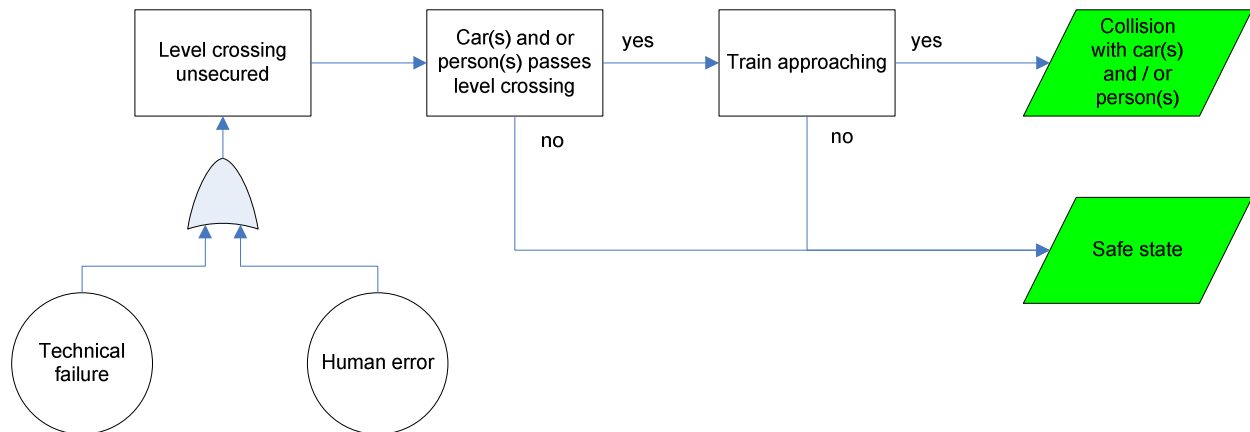
Figure 24: FTA / ETA system-variant 1, level crossing unsecured

As described before, accidents at level crossing can be excluded for system-variant 2 due to regulations which do not allow installing level crossing at new high speed rail systems. This means in the context with system-variant 1 that only the actual existing cross levels have to be considered. The accident rate may be influenced by the following aspects:

- A increased average speed of passing trains may increase the accident rate;
- The fast approaching of trains in combination with a reduced noise level may increase the accident rate.

Again these aspects can not be quantified by the evaluation of the available data and a significant change of the accident rate compared to the existing railway net in Norway does not seem to be required.

$$\Delta\lambda_A = 1,0$$

The fatality rate for "persons injured at level crossings" is also not supposed to be higher in system-variant 1 and therefore a factor 1 for a potential change of the fatality rate seems to be justifiable and sufficient.

$$\Delta\lambda_F = 1,0$$

Table 31 gives an overview of the parameters as well as the estimated values and the calculated risk given in fatalities per year for both system-variants, based on the assumption of supposed 5% additive train kilometres for a new high-speed rail system in Norway.

Table 31: Risk estimation, Top-Event 6

| Top-Event 6: Persons injured at level crossings | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rail-System | $\lambda_a$ per train km | $\Delta\lambda_{a-hs1}$ | $\lambda_a$ per train km (HSR) | Fatalities per accident | $\Delta\lambda_{f-hs1}$ | Fatalities per accident (new) | Fatalities per year |
| Existing system | 3,3E-8 | - | - | 0,63 | - | - | **0,982** |
| System-Variant 1 | 3,3E-8 | 1,00 | 3,3E-8 | 0,63 | 1,00 | 0,63 | **+ 0,051** |

HSR Assessment Norway, Phase 3
Risk and Safety Analysis
Page 62 of (147)

As an important further conclusion of the calculation the minor influence of Top-event 6 "Persons injured at level crossing" to the overall residual risk of a potential new high speed rail system can be stated.

Considering the percentaged distribution evaluated by European data (see Table 6) the resulting collective risk as shown in Table 31 can be allocated to the different groups of affected persons as described in Table 32.

Table 32: Distribution of collective risk, Top-Event 6

| Top-Event 6: Persons injured at level crossing | | | | | |
|---|---|---|---|---|---|
| Persons | Fatalities per year | Distribution | Fatalities per year, existing rail net | Fatalities per year, System-variant 1 | Fatalities per year, System-variant 2 |
| others | | 99,1% | 0,974 | 1,025 | not applicable |
| Passengers | 0,982 | 0,2% | 0,002 | 0,002 | not applicable |
| Personal | | 0,6% | 0,006 | 0,006 | not applicable |
| | | | 0,982 | 1,033 | not applicable |

The individual risk depends on the number of exposed / affected persons.

Table 33: Distribution of individual risk, Top-Event 6

| Top-Event 6: Persons injured at level crossing | | | | |
|---|---|---|---|---|
| Persons | Number of exposed / affected persons | Individual risk [Fatalities / person * year] | | |
| | | existing rail net | System-variant 1 | System-variant 2 |
| others | 3.000.000 | 3,25E-07 | 3,42E-07 | not applicable |
| Passengers | 3.000.000 | 6,55E-10 | 6,89E-10 | not applicable |
| Personal | 7.500 | 7,86E-07 | 8,27E-07 | not applicable |
| | | 1,11E-06 | 1,17E-06 | not applicable |

In order to minimize existing uncertainties of the risk assessment at hand it is essential to continue the analysis regarding expected changes of the specific accident rates ($\Delta\lambda_a$) and the expected consequences given in fatalities per year by evaluation of more detailed data as they are given in [12] [13].

### 2.5.3.10.7 Top-Event 7, Person injured at track side

"Person injured at track side" is defined as a Top-Event by JBV [10] and it is identified (see chapter 2.5.3.1) as the Top-Event 7 in this risk assessment. On base of Norwegian statistics [13] and the data related to "Person injured at track side" the parameters for the risk assessment of Top-Event 7 as shown in Table 34 have been evaluated.

Table 34: Top-Event 7, statistical data [13]

| Top-Event | $\lambda_a$ per train km | Fatality rate per train km | Fatalities per accident | Fatalities per year |
|---|---|---|---|---|
| Passenger injured at track side | 5,5E-8 | 1,5E-7 | 0,72 | 1,900 |

As described in chapter 2.5.3.2 the risk assessment at hand focuses on presumable changes of either the specific accident rate ($\Delta\lambda_a$) and / or the expected consequences given in fatalities per year. Due to the fact that those values could not be determined by the evaluation of statistical data [59][60], estimations by expert judgement have been required. The reasons and underlying thoughts / considerations regarding the taken estimations are described in the following for both system variants. For all blocks displayed in green colour in the following diagrams, the available statistics [12] [13] include informations regarding frequency of occurrence and / or consequences. On the other hand elements of the diagrams (displayed in white colour), may influence either the hazard rate or the consequences but the influence of these elements could not be quantified by the available statistics [12] [13].

Figure 25 and Figure 26 combine fault trees to show causes which might lead to persons injured at platform as well as event trees to display potential consequences. The shown diagrams are related to both system-variants 1 and 2.
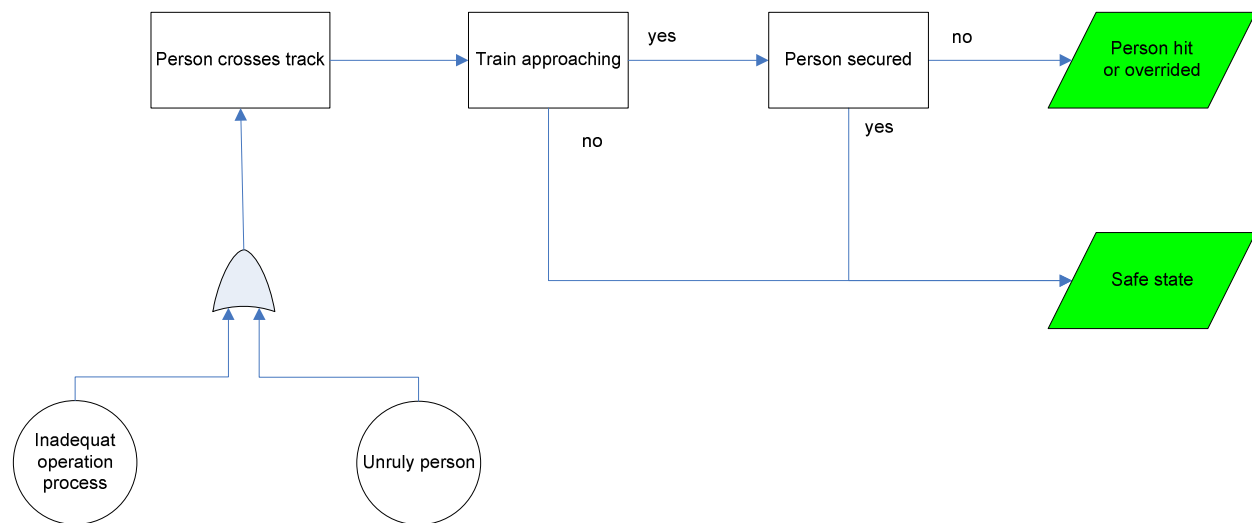


Figure 25: FTA / ETA system-variant 1/2, person crosses track
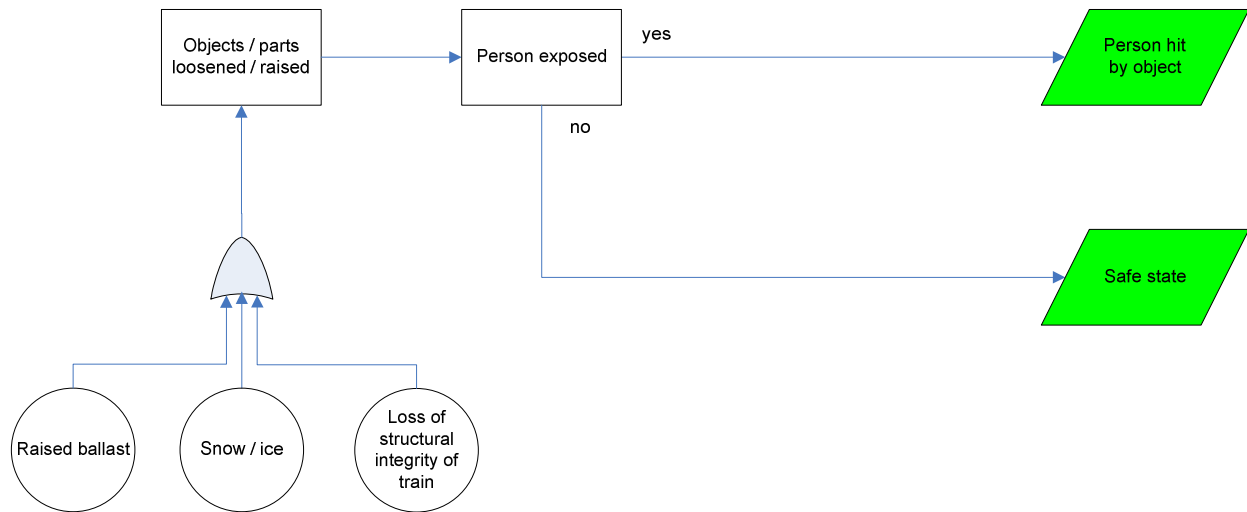
Figure 26: FTA / ETA system-variant 1/2, objects / parts loosened / raised

System-variant 1:

As shown in the diagrams above loosened parts or falling objects like snow represent potential causes for "persons injured at track side". These aspects are not supposed to be different in system-variant 1 compared to the existing rail net. In contrast higher speed of passing high speed trains may lead to more raised ballast, but a significant change of the accident rate seems not to be required.

$$\Delta\lambda_A = 1,0$$

The main aspect concerning the fatality rate is the precence of persons on or beside the track when trains are approaching / passing. The higher speed of high speed trains and their reduced noice level may increase the accident rate, but in this phase of the risk assessment a significant change of it seems not to be required.

$$\Delta\lambda_F = 1,0$$

System-variant 2:

The system-variant 2 is characterized by a more or less separated track. Due to this a reduction of the accident rate seems to be justifiable. The grad (factor) of the reductions depends massively on the technical realization. A reduction of the accident rate for the system-variant 2 by factor 2 seems to be sufficient at this phase of the risk assessment.

$$\Delta\lambda_A = 0,5$$

As described before, the higher speed of high speed trains and their reduced noice level may also increase the accident rate in system-variant 2, but in this phase of the risk assessment a significant change of accident rate seems not to be required.

$$\Delta\lambda_F = 1,0$$

Table 35 gives an overview of the parameters as well as the estimated values and the calculated risk given in fatalities per year for both system-variants, based on the assumption of supposed 5% additive train kilometres for a new high-speed rail system in Norway.

Table 35: Risk estimation, Top-Event 7

| Top-Event 7: Person injured at track side | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rail-System | $\lambda_a$ per train km | $\Delta\lambda_{a\text{-}hs1}$ | $\lambda_a$ per train km (HSR) | Fatalities per accident | $\Delta\lambda_{f\text{-}hs1}$ | Fatalities per accident (new) | Fatalities per year |
| Existing system | 5,5E-8 | - | - | 0,72 | - | - | **1,900** |
| System-Variant 1 | 5,5E-8 | 1,00 | 5,5E-8 | 0,72 | 1,00 | 0,72 | **+ 0,099** |
| System-Variant 2 | 5,5E-8 | 0,50 | 2,7E-8 | 0,72 | 1,00 | 0,72 | **+ 0,049** |

As an important further conclusion of the calculation the minor influence of Top-event 7 "Person injured at track side" to the overall residual risk of a potential new high speed rail system can be stated.

Considering the percentaged distibution evaluated by European data (see Table 6) the resulting collective risk as shown in Table 35 can be allocated to the different groups of affected persons as described in Table 36.

Table 36: Distribution of collective risk, Top-Event 7

| Top-Event 7: Person injured at track side | | | | | |
|---|---|---|---|---|---|
| Persons | Fatalities per year | Distribution | Fatalities per year, existing rail net | Fatalities per year, System-variant 1 | Fatalities per year, System-variant 2 |
| others | | 95,7% | 1,818 | 1,913 | 1,865 |
| Passengers | 1,900 | 2,3% | 0,044 | 0,046 | 0,045 |
| Personal | | 2,0% | 0,038 | 0,040 | 0,039 |
| | | | **1,900** | **1,999** | **1,949** |

The individual risk depends on the number of exposed / affected persons.

Table 37: Distribution of individual risk, Top-Event 7

| Top-Event 7: Person injured at track side | | | | |
|---|---|---|---|---|
| Persons | Number of exposed / affected persons | Individual risk [Fatalities / person * year] | | |
| | | existing rail net | System-variant 1 | System-variant 2 |
| others | 3.000.000 | 6,06E-07 | 6,38E-07 | 6,22E-07 |
| Passengers | 3.000.000 | 1,46E-08 | 1,53E-08 | 1,49E-08 |
| Personal | 7.500 | 5,07E-06 | 5,33E-06 | 5,20E-06 |
| | | **5,69E-06** | **5,98E-06** | **5,83E-06** |

In order to minimize existing uncertainties of the risk assessment at hand it is essential to continue the analysis regarding expected changes of the specific accident rates ($\Delta\lambda_a$) and the expected consequences given in fatalities per year by evaluation of more detailed data as they are given in [12] [13].

### 2.5.3.10.8 Top-Event 8, Other accidents

"Other accidents" is identified (see chapter 2.5.3.1) as the Top-Event 8 in this risk assessment. The risk assessment concerning Top-Event 8 focuses on electrocution accidents and dangerous goods incidents. Accidents in warehouses, workshops and depots are excluded due to the fact that they are not captured in the available data [12][13].

Table 38: Top-Event 8, statistical data [13]

| Top-Event | $\lambda_a$ per train km | Fatality rate per train km | Fatalities per accident | Fatalities per year |
|---|---|---|---|---|
| Other hazards | 1,2E-08 | 6,9E-09 | 0,60 | 0,333 |

As described in chapter 2.5.3.2 the risk assessment at hand focuses on presumable changes of either the specific accident rate ($\Delta\lambda_a$) and / or the expected consequences given in fatalities per year. Due to the fact that those values could not be determined by the evaluation of statistical data [59][60], estimations by expert judgement have been required. The reasons and underlying thoughts / considerations regarding the taken estimations are described in the following for both system variants. For all blocks displayed in green colour in the following diagrams the available statistics [12] [13] include informations regarding frequency of occurrence and / or consequences. On the other hand elements of the diagrams (displayed in white colour) may influence either the hazard rate or the consequences but the influence of these elements could not be quantified by the available statistics [12] [13].

Figure 27 and Figure 28 combine fault trees to show causes which might lead to an accident as well as event trees to display potential consequences. The diagrams are related to both system-variants 1 and 2.
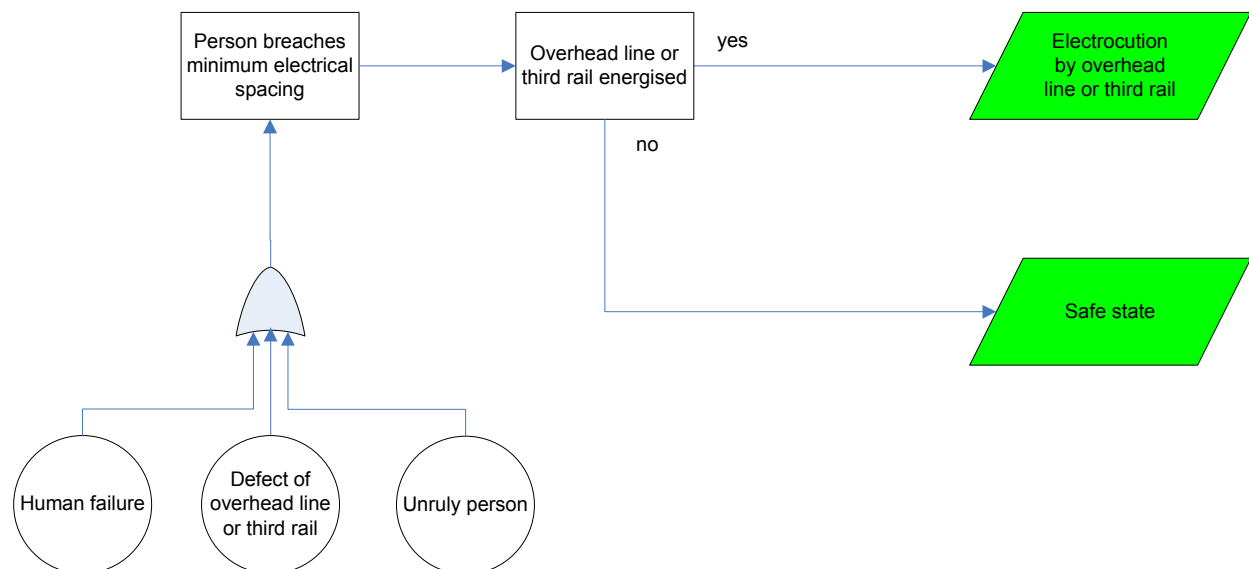


Figure 27: FTA / ETA system-variant 1/2, electrocution accidents
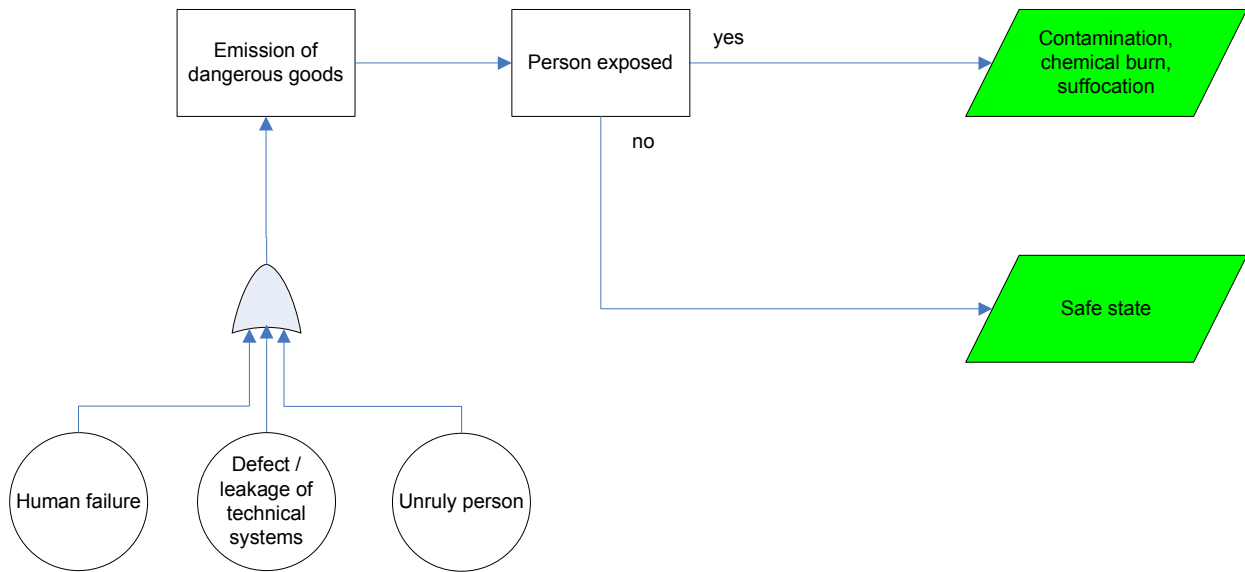
Figure 28: FTA / ETA system-variant 1/2, dangerous goods accidents

System-variant 1:

As the above figures show, electrocution accidents and dangerous good incidents may be caused by technical failures or human failures. It is supposed that human failures cause the majority of accidents. A higher number of passengers (estimated 400 passengers in high speed trains compared to estimated 100 passengers in conventional passenger trains) may implicate a higher risk regarding dangerous good incidents, but it seems not to be required to increase the accident rate due to this aspect. A differentiation between system-variant 1 and the existing net regarding electrocution accidents is also not advisable. As a first consideration in this phase of a risk assessment, a factor 1 for the accident rate of fire in rolling stock seems to be justifiable and sufficient.

$$\Delta\lambda_A = 1,0$$

The fatality rate in case of fire in rolling stock is supposed to be approximately the same in system-variant 1 as in the existing Norwegian Rail. The presumed higher number of potentially affected persons (estimated 400 passengers in high speed trains compared to estimated 100 passengers in conventional passenger trains) is not supposed to influence the fatality rate significantly and therefore an estimated factor 1 for the fatality rate seems to be justifiable and sufficient.

$$\Delta\lambda_F = 1,0$$

System-variant 2:

The accident rate in system-variant 2 may be lower than in system-variant 1 and the existing railway system in Norway, due to the fact that the contingent of potential dangerous goods or substances in high-speed trains is less than in mixed traffic with wagon trains. More secured tracks in system-variant 2 should reduce the probability of electrocution accidents of $3^{rd}$ persons, but anyway, both aspects can not be quantified due to missing data. As a conservative estimation in this phase of a risk assessment, a factor 1 for the accident rate of other hazards seems to be justifiable and sufficient.

$$\Delta\lambda_A = 1,0$$

The fatality rate for other hazards may be lower in system-variant 2 as in the existing Norwegian Rail due to the exclusion of dangerous goods incidents in the context with freight trains. Considering that the majority of serious accidents is related to electrocution and not to dangerous goods, a significant change of the fatality rate seems not to be required. As a conservative estimation in this phase of a risk assessment, a factor 1 for the fatality rate of other hazards seems to be justifiable and sufficient.

$$\Delta\lambda_F = 1,0$$

Table 39 gives an overview of the parameters as well as the estimated values and the calculated risk given in fatalities per year for both system-variants, based on the assumption of supposed 5% additive train kilometres for a new high-speed rail system in Norway.

Table 39: Risk estimation, Top-Event 8

| Top-Event 8: other hazards | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rail-System | $\lambda_a$ per train km | $\Delta\lambda_{a-hs1}$ | $\lambda_a$ per train km (HSR) | Fatalities per accident | $\Delta\lambda_{f-hs1}$ | Fatalities per accident (new) | Fatalities per year |
| Existing system | 1,2E-8 | - | - | 0,60 | - | - | **0,333** |
| System-Variant 1 | 1,2E-8 | 1,00 | 1,2E-8 | 0,60 | 1,00 | 0,60 | **+ 0,017** |
| System-Variant 2 | 1,2E-8 | 1,00 | 1,2E-8 | 0,60 | 1,00 | 0,60 | **+ 0,017** |

As an important further conclusion of the calculation the minor influence of Top-event 8 "opther hazards" to the overall residual risk of a potential new high speed rail system can be stated.

Considering the percentaged distibution evaluated by European data (see Table 6) the resulting collective risk as shown in Table 39 can be allocated to the different groups of affected persons as described in Table 40.

Table 40: Distribution of collective risk, Top-Event 8

| Top-Event 8: other hazards | | | | | |
|---|---|---|---|---|---|
| Persons | Fatalities per year | Distribution | Fatalities per year, existing rail net | Fatalities per year, System-variant 1 | Fatalities per year, System-variant 2 |
| others | | 91,9% | 0,306 | 0,322 | 0,322 |
| Passengers | 0,333 | 3,6% | 0,012 | 0,013 | 0,013 |
| Personal | | 4,5% | 0,015 | 0,016 | 0,016 |
| | | | **0,333** | **0,350** | **0,350** |

The individual risk depends on the number of exposed / affected persons.

Table 41: Distribution of individual risk, Top-Event 8

| Top-Event 8: other hazards | | | | |
|---|---|---|---|---|
| Persons | Number of exposed / affected persons | Individual risk [Fatalities / person * year] | | |
| | | existing rail net | System-variant 1 | System-variant 2 |
| others | 3.000.000 | 1,02E-07 | 1,07E-07 | 1,07E-07 |
| Passengers | 3.000.000 | 4,00E-09 | 4,20E-09 | 4,20E-09 |
| Personal | 7.500 | 2,00E-06 | 2,10E-06 | 2,10E-06 |
| | | **2,10E-06** | **2,21E-06** | **3,23E-07** |

In order to minimize existing uncertainties of the risk assessment at hand it is essential to continue the analysis regarding expected changes of the specific accident rates ($\Delta\lambda_a$) and the expected consequences given in fatalities per year by evaluation of more detailed data as they are given in [12] [13].

## 2.6 Sensitivity analysis

The following equation (risk model for collective risk) provides the basis for a sensitivity analysis.

$$R_C = \sum_1^8 \Delta\lambda_{A\,Top\,i} \cdot \lambda_{A\,Top\,i} \cdot \Delta\lambda_{F\,Top\,i} \cdot \lambda_{F\,Top\,i}$$

$\lambda_{A\,Top\,i}$ = Accident rate (for a specific Top-Event i)

$\lambda_{F\,Top\,i}$ = Fatality rate (for a specific Top-Event i)

By systematically changing parameters in the model to determine the effects of such changes the level of uncertainty and robustness of the model is analyzed. As already discussed in the previous chapters the Top-Event "collision train-train" does not have a significant influence to the overall residual risk and is therefore taken out of consideration for the sensitivity analysis. The Top-Event "other accidents" is also not considered here because of the general uncertainty which accidents are included in the available statistics.

Therefore the risk model for the sensibility analysis reduces to the following equation:

$$R_C = \sum_1^6 \Delta\lambda_{A\,Top\,i} \cdot \lambda_{A\,Top\,i} \cdot \Delta\lambda_{F\,Top\,i} \cdot \lambda_{F\,Top\,i}$$

The following tables classifiy each influencing parameter to a particular level of uncertainty:

Table 42: Level of uncertainty for each influencing parameter of the collective risk model (system variant 1)

| Top-Event | $\Delta\lambda_{a\text{-}hs1}$ | Level of uncertainty | Parameter variation | $\Delta\lambda_{f\text{-}hs1}$ | Level of uncertainty | Parameter variation |
|---|---|---|---|---|---|---|
| Collision train-object | 1 | medium | 0,5..1 | 35 | high | 3,5..50 |
| Derailment | 1 | high | 0,1..2 | 35 | high | 10..50 |
| Passenger injured at platform | 1 | medium | 0,5..1 | 1 | low | - |
| Person injured at level crossing | 1 | medium | 0,5..1 | 1 | low | - |
| Person injured at track side | 1 | medium | 0,5..1,5 | 1 | low | - |
| Fire in rolling stock | 4 | high | 0,4..4 | 4 | high | 0,4..10 |

Table 43: Level of uncertainty for each influencing parameter of the collective risk model (system variant 2)

| Top-Event | $\Delta\lambda_{a\text{-}hs1}$ | Level of uncertainty | Parameter variation | $\Delta\lambda_{f\text{-}hs1}$ | Level of uncertainty | Parameter variation |
|---|---|---|---|---|---|---|
| Collision train-object | 0,5 | high | 0,05..1 | 150 | high | 10..300 |
| Derailment | 0,5 | high | 0,05..0,5 | 150 | high | 20..300 |
| Passenger injured at platform | 0,1 | medium | 0,05..0,5 | 1 | low | - |
| Person injured at level crossing | 0 | low | - | 0 | low | - |
| Person injured at track side | 0,5 | medium | 0,1..2 | 1 | low | - |
| Fire in rolling stock | 4 | high | 0,4..4 | 8 | high | 0,8..10 |

The accumulated results of the sensitivity analysis are shown in the following diagram for the two system variants (collective risk):
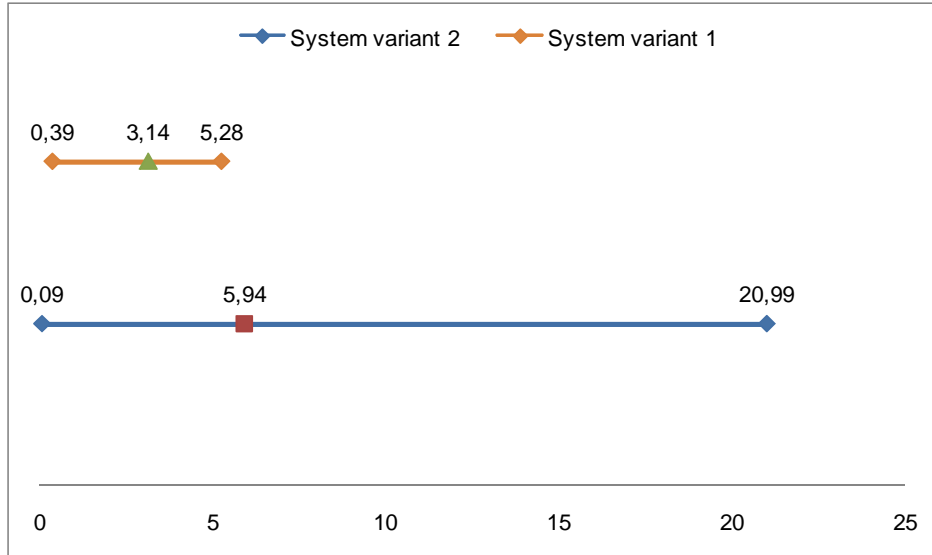


Figure 29: Range of collective risks

The range of possible outcomes is huge because of the high level of uncertainty of many influencing parameters as discussed before. If all parameters are at the low end of the range (most optimistic scenario) the collective risk for system variant 1 would be lower than a scenario with conventional passenger trains (0,45 equivalent fatalities per year) and the most optimistic scenario for system variant 2 is even lower adding negligible risk to the current situation.

The main drivers of the risk are the two accident scenarios derailment and collision train-object as can be seen in the following two diagrams:
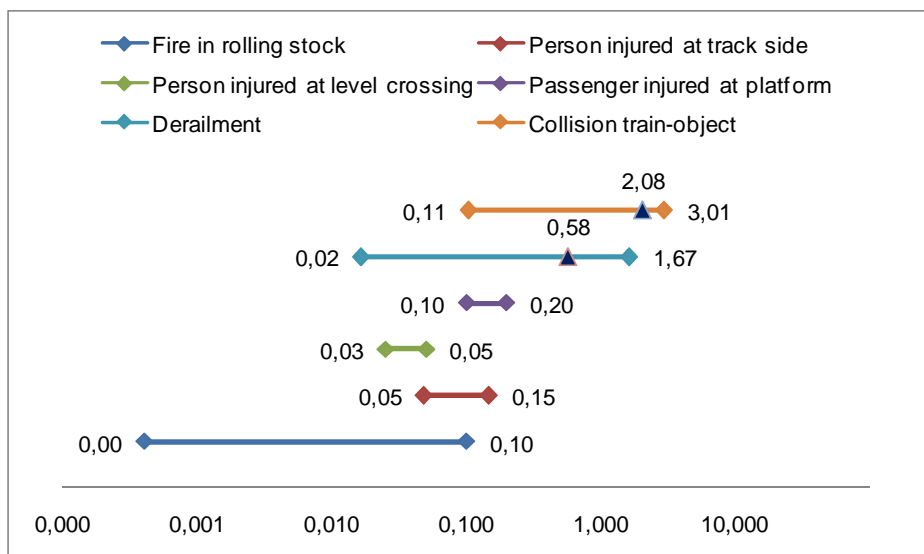


Figure 30: Results of the sensitivity analysis for each Top-Event (system variant 1)
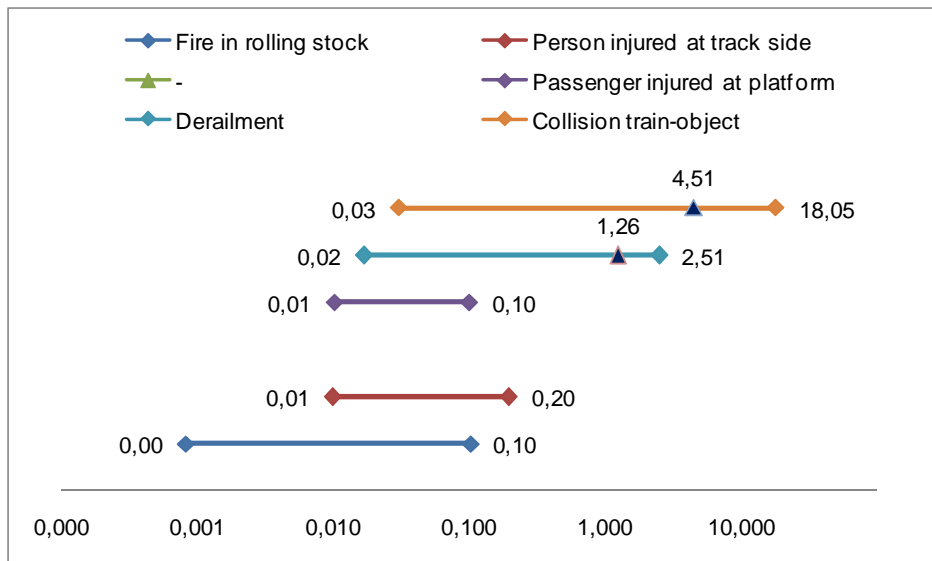
Figure 31: Results of the sensitivity analysis for each Top-Event (system variant 2)

To keep the above values in context, analysing the ICE accident statistics in Germany reveals the following:

The point estimates of the proposed risk model for derailment (system variant 1) for Norway is predicted to be twice as high as the risk in Germany (8 accidents recorded with 110 equivalent fatalities) whereas the risk for collision train-object is predicted to be higher by a factor of 1.000 (Germany: 6 accidents recorded with 1 equivalent fatality)! Especially 1 severe accident collision train-object in 2008 (collision with a herd of sheep with a speed of 215km/h, 12 of 14 cars derailed, has had only mild consequences mainly because the derailed train approached a tunnel and was therefore kept on track) could have changed the picture massively and the risk difference between the predicted model and statistical evidence would be only a factor of 8 instead of 1.000.

Analysing the different accident scenarios from different sources of statistics and here especially derailments and collisions, the distribution of fatalities per accident follow a power-law model. This means that very few accidents cause the majority of fatalities. Finding the parameters of the power-law model for the fatality distribution over the different accident scenarios for a high-speed network could lead to a lower uncertainty regarding the proposed risk model.

## 2.7   Summary of results of the generic risk model

Chapters 2.5.3.10.1 to 2.5.3.10.8 include detailed descriptions regarding the underlying model for the estimation / calculation of the residual risk (collective and individual risk) for every defined Top-Event. Table 44 subsumes the results and gives an overview of the residual risks determined by point estimation of the two different potential high-speed system variants (see chapter 2.4) as well as the status quo[2] concerning the risk in the Norwegian railway system (existing net).

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[2] Values for collective and individual risk evaluated on basis of ERADIS-statistics

Table 44: Residual risk related to Top-Events, overview

| Top-Event | Residual Risk[3] | Existing Net | System-Variant 1 | System-Variant 2 |
|---|---|---|---|---|
| Derailment | Collective risk | 0,322 | 0,900 | 1,578 |
| | Individual risk | 6,95E-06 | 1,95E-05 | 3,41E-05 |
| Collision train-train | Collective risk | 0,042 | 0,118 | 0,045 |
| | Individual risk | 3,61E-06 | 1,01E-05 | 3,89E-06 |
| Collision train-object | Collective risk | 1,155 | 3,235 | 5,668 |
| | Individual risk | 2,27E-05 | 6,35E-05 | 1,11E-04 |
| Fire | Collective risk | 0,049 | 0,090 | 0,131 |
| | Individual risk | 1,21E-07 | 2,22E-07 | 3,23E-07 |
| Passenger injured at platform | Collective risk | 3,891 | 4,094 | 3,911 |
| | Individual risk | 2,25E-05 | 2,37E-05 | 2,26E-05 |
| Level crossing accidents | Collective risk | 0,982 | 1,033 | Not applicable |
| | Individual risk | 1,11E-06 | 1,17E-06 | Not applicable |
| Person injured at track side | Collective risk | 1,900 | 1,999 | 1,949 |
| | Individual risk | 5,69E-06 | 5,98E-06 | 5,83E-06 |
| Other accidents | Collective risk | 0,333 | 0,350 | 0,350 |
| | Individual risk | 2,10E-06 | 2,21E-06 | 2,21E-06 |

In Table 45 the results regarding the estimated residual collective risk[4] for the different groups of persons are subsumed.

Table 46 shows the determined residual collective risk-values for the different rail-systems und benchmarks the point estimated results as well as the lower end estimations (see also chapter 2.10) with the tolerable number of 11 fatalities per year defined by JBV (see chapter 2.5.1.2).

Table 45: Residual collective risk, overview

| Rail-System | Residual collective risk for passengers | Residual collective risk for 3rd persons | Residual collective risk for personal |
|---|---|---|---|
| Existing Net | 0,677 | 7,531 | 0,465 |
| System-Variant 1 | 1,120 | 9,778 | 0,920 |
| System-Variant 2 | 1,555 | 11,733 | 1,327 |

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[3] Values for collective risk are given as "Equivalent fatalities / year", values for individual risk are given as "Equivalent fatalities / person * year"

[4] Values for collective risk are given as "Equivalent fatalities / year"

Table 46: Residual collective risk, point estimate overview

| Rail-System | Residual collective risk, overall, point estimation | Residual collective risk, overall, lower end | Comment |
|---|---|---|---|
| Existing Net | 8,674 | - | JBVs collective risk criteria fulfilled |
| System-Variant 1 | 11,818 | 8,731 | JBVs collective risk criteria fulfilled considering lower end risk estimation. Slightly exceedance of criteria by point estimate |
| System-Variant 2 | 14,615 | 8,764 | JBVs collective risk criteria fulfilled considering lower end risk estimation. Significant exceedance of criteria by point estimate |

An extrapolation of the collective risk of the Norwegian railway net assuming 5% additional mixed traffic as in the existing railway net results in an expected higher residual collective risk (9,125 equivalent fatalities per year) compared to the lower end estimations shown in the above table.

JBV's risk acceptance criteria regarding personal (1st persons) is defined as less than 12,5 fatalities / 100.000.000 working hours (see chapter 2.5.1.2), respectively 1,25E-07 fatalities / working hour. As Table 47 shows this risk criteria is fulfilled for both assumed system-variants.

Table 47: Residual collective risk of personal[5], overview

| Rail-System | Residual collective risk for personal [EqFa / year] | Residual collective risk for personal [EqFa / working hrs] | Comment |
|---|---|---|---|
| Existing Net | 0,465 | 3,45E-08 | JBVs individual risk criteria for 1st persons fulfilled |
| System-Variant 1 | 0,920 | 6,81E-08 | JBVs individual risk criteria for 1st persons fulfilled |
| System-Variant 2 | 1,327 | 9,83E-08 | JBVs individual risk criteria for 1st persons fulfilled |

Table 48 shows the estimated residual individual risk-values[6] for the different rail-systems and benchmarks the results with the respective boundary value (0,0001 fatalities / person * year) by JBV (see chapter 2.5.1.2).

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[5] Residual collective risk for personal based on assumed 13,5 Mio. working hours per year

[6] Values for individual risk are given as "Equivalent fatalities / person * year"

Table 48: Residual individual risk of passengers and 3$^{rd}$ persons, overview

| Rail-System | Residual individual risk, passengers & 3rd persons | Residual individual risk for passengers | Residual individual risk for 3rd persons | Comment |
|---|---|---|---|---|
| **Existing Net** | 2,74E-06 | 2,26E-07 | 2,51E-06 | JBVs individual risk criteria fulfilled |
| **System-Variant 1** | 3,63E-06 | 3,73E-07 | 3,26E-06 | JBVs individual risk criteria fulfilled |
| **System-Variant 2** | 4,43E-06 | 5,18E-07 | 3,91E-06 | JBVs individual risk criteria fulfilled |

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## 2.8   Corridor-specific Risk Assessment (Phase 3)

For the corridor-specific risk assessment the Risk model is adapted to the corridors Ø2P, S2P, H1P and BS1P. To determine the fatality rates the individual sections of the corridors have been examined: The velocity on the respective sections and the expected number of passengers have been calculated and used in the already known formula (chapter 2.5) for calculating the fatality rate:

$$\Delta \lambda_F = \frac{m_{HSR}}{m_{ConventionalRail}} \cdot \frac{v_{HSR}^{\;2}}{v_{ConventionalRail}^{\;2}} \cdot \frac{\#Passenger_{HSR}}{\#Passenger_{ConventionalRail}}$$

The fatality rate for one corridor consists of the individual rates of the various sections. The exact results for the corridor Ø2P are shown in paragraph 2.8.1, Table 51 to Table 56. The results of the remaining corridors S2P, H1P and BS1P are subsumed in the respective paragraphs.

### 2.8.1   Corridor Ø2P

Corridor Ø2P goes from Oslo to Trondheim (Figure 32). The total length is 409.5km, 60% of the route pass through tunnels, 5% over bridges. On the largest part of the route there will be mixed traffic, i.e. the track will be used by high speed trains, regional trains and freight trains together. Only the section from Gardermoen to Vallset will be used exclusively by high speed trains.
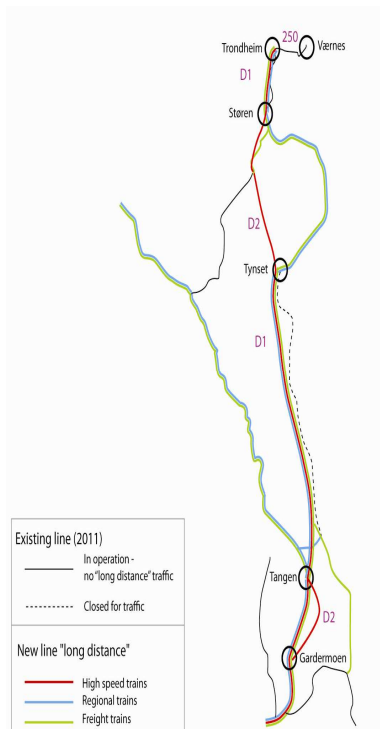


Figure 32: Ø2P

The speeds and the expected number of passengers for the individual sections of corridor Ø2P are shown in Table 49:

Table 49: Speeds and number of passengers for individual sections of corridor Ø2P

| Section | avg speed | # Passenger | | | | | |
|---------|-----------|------|------|------|------|------|------|
| Oslo – Gardermon | 152,4 km/h | 2024 | 170 | 2043 | 204 | 2060 | 242 |
| Gardermoen – Vallset | 225,7 km/h | | | | | | |
| Vallset - Elverum Parkway | 225,7 km/h | | | | | | |
| Elverum Parkway – Tynset | 276,0 km/h | | | | | | |
| Tynset - Trondheim/Lerkendal | 246,1 km/h | | | | | | |
| Trondheim/Lerkendal - | 161,1 km/h | | | | | | |

In Table 50 there are given the increase factors respectively the reduction factors of variant 1 (mixed traffic) and variant 2 (High Speed Rail only) for calculating the accident rates: If the track will be used by high speed trains, regional trains and freight trains together the increase/reduction factors of variant 1 are used for the calculation of the accident rates, if the track will be used exclusively by high speed trains the increase/reduction factors of variant 2 are used for calculating the accident rates. The attributes of these variants are in principle the same as in chapter 2.4, but differ in following points:

Top event "Passenger injured at platform" is no longer considered to preserve consistency as these types of accidents are handled differently in the statistics. Consequently the number of fatalities is reduced by **3,891** for Norway in comparison to the "Existing rail net" from chapter 2.5. Nonetheless there is certain evidence that platform related accidents like slips, trips and falls on the platform itself as well as accidents during the processes of entering and exiting the train - even if minor injuries outweigh severe injuries and fatalities - play a role in the overall residual risk. This is especially true for commuter trains where the passenger traffic during boarding in peak times is substantial. High speed train boarding processes are relatively safe in comparison and the risk associated with boarding is insignificant.

Table 50: Increase factors respectively reduction factors of mixed traffic (hs1) and HSR only (hs2) for calculating the accident rates

| Top Event | $\Delta\lambda_{a-hs1}$ | $\Delta\lambda_{a-hs2}$ |
|-----------|------------|------------|
| Collision train-object | 1,00 | 0,50 |
| Collision train-train | 1,00 | 0,01 |
| Derailment | 1,00 | 0,50 |
| Other | 1,00 | 1,00 |
| Passenger injured at platform[7] | - | - |
| Person injured at level crossing[8] | - | - |
| Person injured at track side | 1,00 | 0,50 |
| Fire in rolling stock | 4,00 | 4,00 |

In Table 51 to Table 56 the resulting increase factors for calculating the fatality rates are shown for the individual sections of corridor Ø2P for the years 2024, 2043 and 2060. Listed are only the factors for the top events which differ from the factors from the basic risk model, see chapter 2.5.3.10. These top events are "Collision train-object", "Collision train-train" and "Derailment": The specific average speed as well as the number of passenger for the corresponding section is considered, for top event "Collision train-object" furthermore there is integrated a reduction

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[7] Accidents at platforms with train not moving (stations) are no longer reported in.

[8] No levelcrossing allowed at speeds higher 160km/h.

factor of 0.25 as other evaluations of Norwegian data have shown that the fatality rate is not significantly effected by the kinetic energy.

Table 51: Increase factors for calculating the fatality rates for the years 2024, 2043 and 2060, Oslo – Gardermon

| Top Event | $\Delta\lambda_{f\text{-}hs1}$2024 | $\Delta\lambda_{f\text{-}hs1}$2043 | $\Delta\lambda_{f\text{-}hs1}$2060 |
|---|---|---|---|
| Collision train-object | 2,63 | 3,16 | 3,75 |
| Collision train-train | 10,53 | 12,63 | 14,98 |
| Derailment | 10,53 | 12,63 | 14,98 |

Table 52: Increase factors for calculating the fatality rates for the years 2024, 2043 and 2060, Gardermoen – Vallset

| Top Event | $\Delta\lambda_{f\text{-}hs2}$2024 | $\Delta\lambda_{f\text{-}hs2}$2043 | $\Delta\lambda_{f\text{-}hs2}$2060 |
|---|---|---|---|
| Collision train-object | 5,77 | 6,93 | 8,22 |
| Collision train-train | 23,09 | 27,71 | 32,87 |
| Derailment | 23,09 | 27,71 | 32,87 |

Table 53: Increase factors for calculating the fatality rates for the years 2024, 2043 and 2060, Vallset - Elverum Parkway

| Top Event | $\Delta\lambda_{f\text{-}hs1}$2024 | $\Delta\lambda_{f\text{-}hs1}$2043 | $\Delta\lambda_{f\text{-}hs1}$2060 |
|---|---|---|---|
| Collision train-object | 5,77 | 6,93 | 8,22 |
| Collision train-train | 23,09 | 27,71 | 32,87 |
| Derailment | 23,09 | 27,71 | 32,87 |

Table 54: Increase factors for calculating the fatality rates for the years 2024, 2043 and 2060, Elverum Parkway – Tynset

| Top Event | $\Delta\lambda_{f\text{-}hs1}$2024 | $\Delta\lambda_{f\text{-}hs1}$2043 | $\Delta\lambda_{f\text{-}hs1}$2060 |
|---|---|---|---|
| Collision train-object | 8,63 | 10,36 | 12,29 |
| Collision train-train | 34,53 | 41,43 | 49,15 |
| Derailment | 34,53 | 41,43 | 49,15 |

Table 55: Increase factors for calculating the fatality rates for the years 2024, 2043 and 2060, Tynset - Trondheim/Lerkendal

| Top Event | $\Delta\lambda_{f\text{-}hs1}$2024 | $\Delta\lambda_{f\text{-}hs1}$2043 | $\Delta\lambda_{f\text{-}hs1}$2060 |
|---|---|---|---|
| Collision train-object | 6,87 | 8,24 | 9,77 |
| Collision train-train | 27,47 | 32,96 | 39,10 |
| Derailment | 27,47 | 32,96 | 39,10 |

Table 56: Increase factors for calculating the fatality rates for the years 2024, 2043 and 2060, Trondheim/Lerkendal - Værnes

| Top Event | $\Delta\lambda_{f\text{-}hs1}$2024 | $\Delta\lambda_{f\text{-}hs1}$2043 | $\Delta\lambda_{f\text{-}hs1}$2060 |
|---|---|---|---|
| Collision train-object | 2,94 | 3,53 | 4,19 |
| Collision train-train | 11,77 | 14,12 | 16,75 |
| Derailment | 11,77 | 14,12 | 16,75 |

With the assumptions above regarding velocity and number of passengers the following number of fatalities is given. Table 57 shows the fatalities per year for the years 2024, 2043 and 2060 for conventional rail in Norway as well as in corridor Ø2P devided into 3rd persons (others), passengers and staff without and with annual safety improvement factor (see chapter 2.9). This listing is analogously to the "Existing rail net" and the "supposed 5% additive train kilometres for a new high-speed rail system in Norway" (see chapter 2.5).

Table 57: Expected fatalities without and with improvement factor for the years 2024, 2043 and 2060 for corridor Ø2P

| Fatalities per year | 2024 | | |
| | Norway | O2P | Norway + O2P |
|---|---|---|---|
| other | 4,16 | 2,44 | 6,60 |
| passenger | 0,32 | 0,71 | 1,03 |
| staff | 0,31 | 0,59 | 0,90 |
| total | 4,78 | 3,74 | 8,52 |
| with improvement factor | **4,34** | **2,66** | **7,00** |

| Fatalities per year | 2043 | | |
| | Norway | O2P | Norway + O2P |
|---|---|---|---|
| other | 4,16 | 2,84 | 7,01 |
| passenger | 0,32 | 0,82 | 1,14 |
| staff | 0,31 | 0,71 | 1,01 |
| total | 4,78 | 4,37 | 9,15 |
| with improvement factor | **3,95** | **1,96** | **5,91** |

| Fatalities per year | 2060 | | |
| | Norway | O2P | Norway + O2P |
|---|---|---|---|
| other | 4,16 | 3,30 | 7,46 |
| passenger | 0,32 | 0,94 | 1,26 |
| staff | 0,31 | 0,83 | 1,14 |
| total | 4,78 | 5,08 | 9,86 |
| with improvement factor | **3,75** | **1,53** | **5,28** |

## 2.8.2  Corridor S2P

Corridor S2P goes from Oslo to Stavanger (Figure 33). The total length is 330.1km, 58% of the route pass through tunnels, 11% over bridges. On the largest part of the route there will be mixed traffic, only the sections from Drammen to Porsgrunn and from Egersund to Sandnes will be used exclusively by high speed trains.



Figure 33: S2P

The speeds and the expected number of passengers for the individual sections of corridor S2P are shown in Table 58:

Table 58: Speeds and number of passengers for individual sections of corridor S2P

| Section | avg speed | # Passenger | | | | | |
|---|---|---|---|---|---|---|---|
| Stavanger – Sandnes | 81,5 km/h | **2024** | 165 | **2043** | 193 | **2060** | 222 |
| Sandnes – Egersund | 206,1 km/h | | | | | | |
| Egersund – Mandal | 277,7 km/h | | | | | | |
| Mandal – Kristiansand | 197,1 km/h | | | | | | |
| Kristiansand – Arendal | 222,7 km/h | | | | | | |
| Arendal – Porsgrunn | 242,4 km/h | | | | | | |
| Porsgrunn – Drammen | 230,8 km/h | | | | | | |
| Drammen – Oslo | 79,4 km/h | | | | | | |

Table 59 shows the fatalities per year for the years 2024, 2043 and 2060 for conventional rail in Norway as well as in corridor S2P devided into 3$^{rd}$ persons (others), passengers and staff without and with annual safety improvement factor (see paragraph 2.9).

Table 59: Expected fatalities without and with improvement factor for the years 2024, 2043 and 2060 for corridor S2P

| Fatalities per year | 2024 | | |
|---|---|---|---|
| | Norway | S2P | Norway + S2P |
| other | 4,16 | 1,81 | 5,97 |
| passenger | 0,32 | 0,57 | 0,88 |
| staff | 0,31 | 0,41 | 0,71 |
| total | 4,78 | 2,79 | 7,57 |
| with improvement factor | **4,34** | **1,98** | **6,33** |

| Fatalities per year | 2043 | | |
|---|---|---|---|
| | Norway | S2P | Norway + S2P |
| other | 4,16 | 2,06 | 6,22 |
| passenger | 0,32 | 0,63 | 0,95 |
| staff | 0,31 | 0,48 | 0,78 |
| total | 4,78 | 3,16 | 7,95 |
| with improvement factor | **3,95** | **1,42** | **5,37** |

| Fatalities per year | 2060 | | |
|---|---|---|---|
| | Norway | S2P | Norway + S2P |
| other | 4,16 | 2,31 | 6,47 |
| passenger | 0,32 | 0,70 | 1,01 |
| staff | 0,31 | 0,55 | 0,85 |
| total | 4,78 | 3,55 | 8,33 |
| with improvement factor | **3,75** | **1,07** | **4,82** |

### 2.8.3  Corridor H1P

Corridor H1P goes from Bergen to Oslo (Figure 34). The total length is 354km, 63% of the route pass through tunnels, 9% over bridges. On the entire route there will be mixed traffic, so for the calculation of the accident rates only the increase/reduction factors of variant 1 are used.



Figure 34: H1P

The speeds and the expected number of passengers for the individual sections of corridor H1P are shown in Table 60:

Table 60: Speeds and number of passengers for individual sections of corridor H1P

| Section | avg speed | # Passenger | | | | | |
|---|---|---|---|---|---|---|---|
| Bergen – Odda | 197,6 km/h | 2024 | 110 | 2024 | 131 | 2024 | 152 |
| Odda – Roldal | 155,2 km/h | | | | | | |
| Roldal – Kongsberg | 258,4 km/h | | | | | | |
| Kongsdal – Drammen | 255,4 km/h | | | | | | |
| Drammen – Oslo | 79,4 km/h | | | | | | |

Table 61 shows the fatalities per year for the years 2024, 2043 and 2060 for conventional rail in Norway as well as in corridor H1P devided into 3rd persons (others), passengers and staff without and with annual safety improvement factor (see paragraph 2.9).

Table 61: Expected fatalities without and with improvement factor for the years 2024, 2043 and 2060 for corridor H1P

| 2024 Fatalities per year | Norway | H1P | Norway + H1P |
|---|---|---|---|
| other | 4,16 | 3,81 | 7,97 |
| passenger | 0,32 | 1,10 | 1,42 |
| staff | 0,31 | 0,84 | 1,15 |
| total | 4,78 | 5,75 | 10,54 |
| with improvement factor | **4,34** | **4,09** | **8,44** |

| 2043 Fatalities per year | Norway | H1P | Norway + H1P |
|---|---|---|---|
| other | 4,16 | 4,35 | 8,51 |
| passenger | 0,32 | 1,25 | 1,57 |
| staff | 0,31 | 0,99 | 1,30 |
| total | 4,78 | 6,59 | 11,38 |
| with improvement factor | **3,95** | **2,96** | **6,90** |

| 2060 Fatalities per year | Norway | H1P | Norway + H1P |
|---|---|---|---|
| other | 4,16 | 4,89 | 9,05 |
| passenger | 0,32 | 1,40 | 1,71 |
| staff | 0,31 | 1,15 | 1,46 |
| total | 4,78 | 7,43 | 12,21 |
| with improvement factor | **3,75** | **2,24** | **6,00** |

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### 2.8.4  Corridor BS1P

Corridor BS1P goes from Bergen to Stavanger (Figure 35). The total length is 230.1km, 63% of the route pass through tunnels, 6% over bridges. The entire route will be used exclusively by high speed trains, so for the calculation of the accident rates only the increase/reduction factors of variant 2 are used.
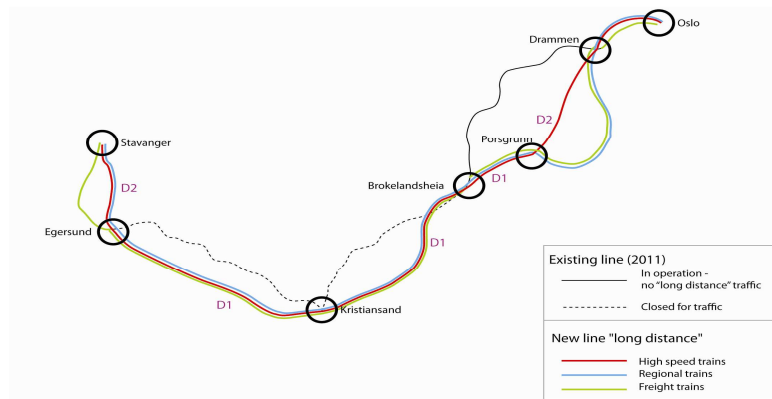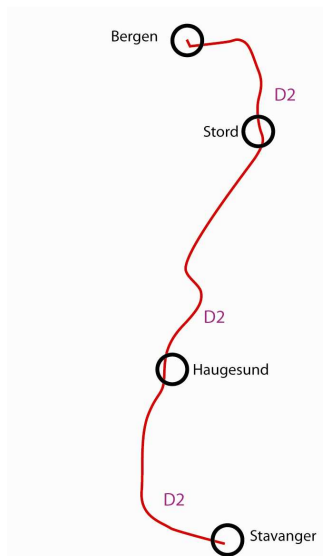


Figure 35: BS1P

The speeds and the expected number of passengers for the individual sections of corridor BS1P are shown in Table 62:

Table 62: Speeds and number of passengers for individual sections of corridor BS1P

| Section | avg speed | # Passenger | | | | | |
|---|---|---|---|---|---|---|---|
| Bergen – Haugesund | 192,5 km/h | 2024 | 64 | 2043 | 70 | 2060 | 76 |
| Haugesund – Stavanger | 192,9 km/h | | | | | | |

Table 63 shows the fatalities per year for the years 2024, 2043 and 2060 for conventional rail in Norway as well as in corridor BS1P devided into 3rd persons (others), passengers and staff without and with annual safety improvement factor (see paragraph 2.9).

Table 63: Expected fatalities without and with improvement factor for the years 2024, 2043 and 2060 for corridor BS1P

| Fatalities per year | 2024 | | |
|---|---|---|---|
| | Norway | BS1P | Norway + BS1P |
| other | 4,16 | 0,24 | 4,41 |
| passenger | 0,32 | 0,16 | 0,48 |
| staff | 0,31 | 0,03 | 0,34 |
| total | 4,78 | 0,44 | 5,22 |
| with improvement factor | **4,34** | **0,31** | **4,66** |

| Fatalities per year | 2043 | | |
|---|---|---|---|
| | Norway | BS1P | Norway + BS1P |
| other | 4,16 | 0,50 | 4,67 |
| passenger | 0,32 | 0,17 | 0,49 |
| staff | 0,31 | 0,09 | 0,40 |
| total | 4,78 | 0,77 | 5,55 |
| with improvement factor | **3,95** | **0,34** | **4,29** |

| Fatalities per year | 2060 | | |
|---|---|---|---|
| | Norway | BS1P | Norway + BS1P |
| other | 4,16 | 0,55 | 4,71 |
| passenger | 0,32 | 0,18 | 0,50 |
| staff | 0,31 | 0,10 | 0,41 |
| total | 4,78 | 0,83 | 5,61 |
| with improvement factor | **3,75** | **0,25** | **4,00** |

## 2.9   Annual safety improvement

Historical evidence shows that the overall safety levels of all transport systems increase over time due to application of various technical, procedural and legislative measures. To estimate the risk level in the future the safety level increase has to be considered.

The annual safety improvement is based on the statistical data from the annual reports concerning safety and accident statistics [13] published by the Norwegian national rail safety authority "Jernbaetilsynets". The statistical data of the last fifteen years has been evaluated and a regression curve (see Figure 36, y) that seems to fit the underlying data has been identified.

For the years until 2024 for conventional rail the improvement factor is estimated to be 0.8% per year, from 2024 - 2043 of 0.5% per year and from 2043 - 2060 of 0.3% whereas the increase in passenger traffic is already included

For the HSR the annual improvement is estimated to be 2.8% until 2024, 2.4% from 2024 - 2043 and 2.3% from 2043 - 2060 as the increase of accumulated passenger kilometres is not regarded on this.

By categorizing the annual fatalities it is assumed that a log-normal distribution is underlying. By calculating the parameters of the distribution Monte-Carlo simulation can be used to randomize potential outcomes. The diagram Figure 36 illustrates one of infinite possibilities for conventional rail.
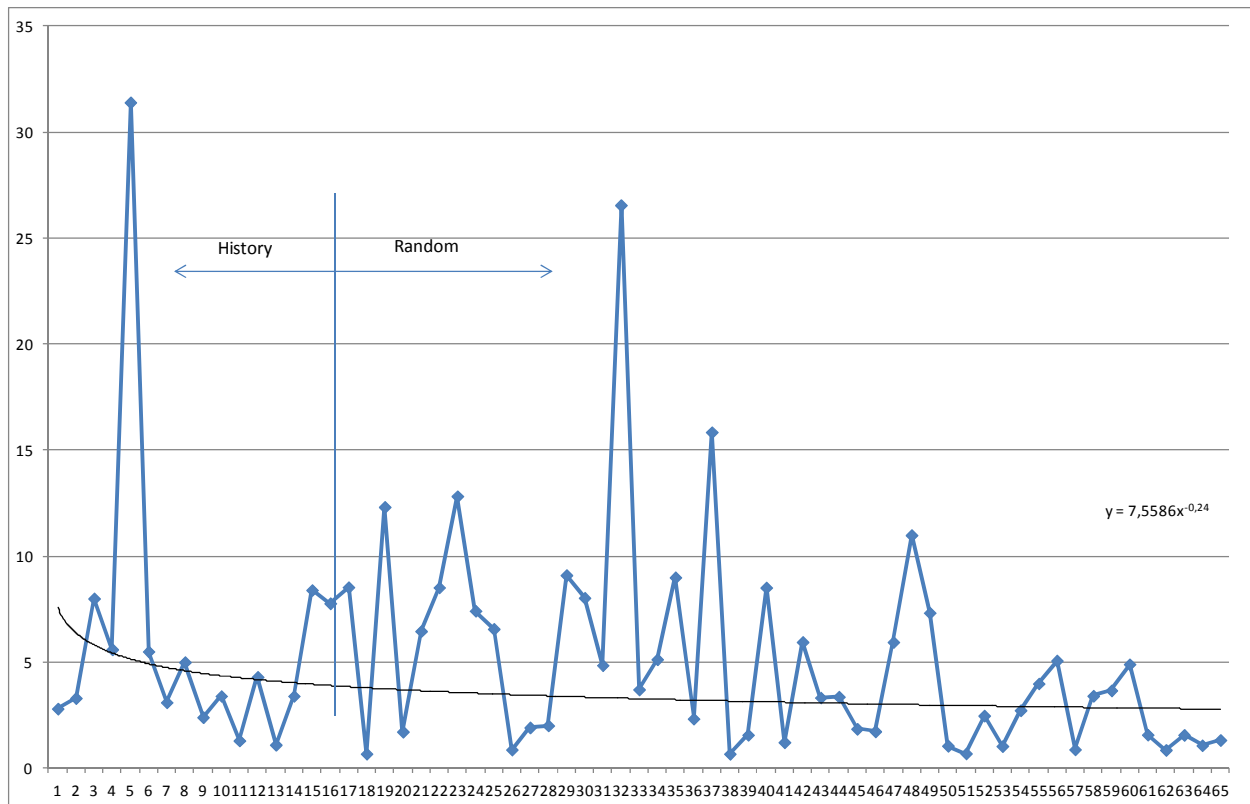


Figure 36: Fatalities per year from Monte Carlo simulation

The diagram Figure 37 in contrast is constructed and meant to indicate the significant difference in the expected distribution of annual fatalities. It is not based on statistical data but on expert judgement and rare incidents.
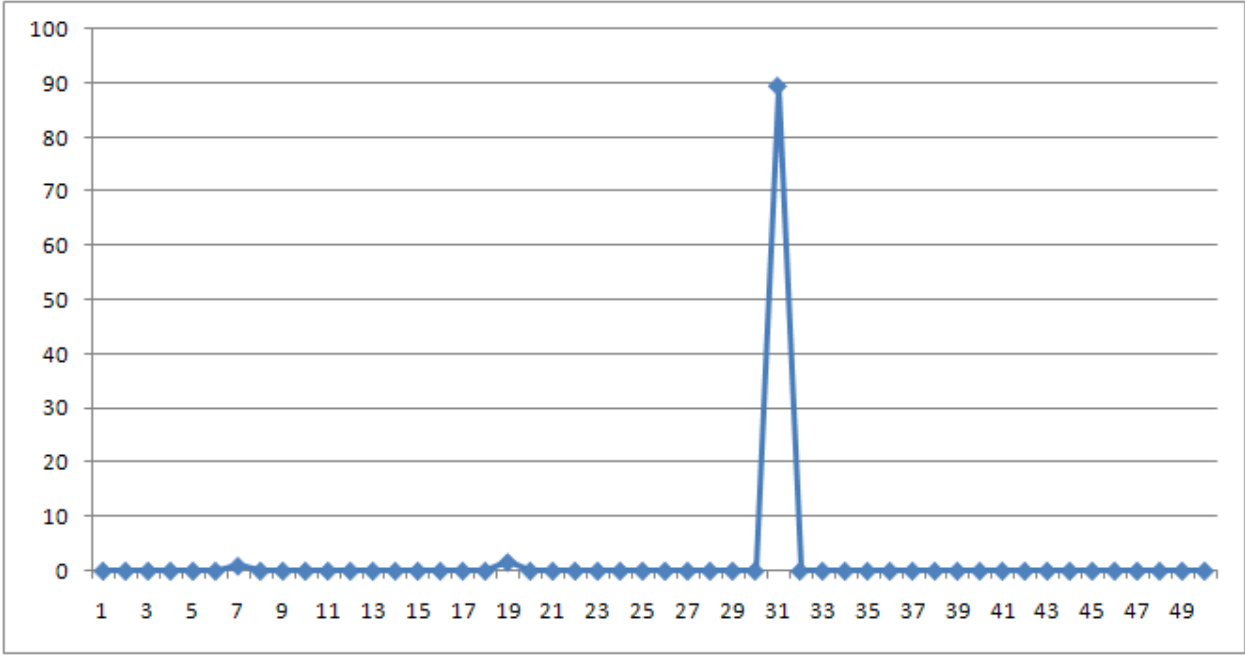


Figure 37: Fatalities per year HSR

## 2.10  Mitigation measures

As shown in chapter 2.6 there is a huge range of possible outcomes due to the high level of uncertainty of many influencing parameters. As the achieved safety level for the implementation of high speed corridors in the future depends substantially on the risk-mitigation measures implemented, this paragraph lists some considerations to take into account when planning new corridors. This listing is by no means exhaustive, but gives an impression of what should be undertaken for continuous improvement of safety.

Mitigation against probability and consequences for collision train-object

- Safety fences

- Obstacle detection via track sensors

- No track maintenance allowed during times in which trains are operating

- Prevention of vandalism

- Monitoring the track

- Safety equipment and methods should comply to state of the art

Mitigation against probability and consequences for fire in rolling stock / tunnel

- Emergency concept

- Incident management

- Fire detection and suspension systems

- Ventilation systems

- Emergency stations

- Monitoring the track

- Safety equipment , design and methods should comply to state of the art

Mitigation against probability for person injured at trackside

- Safety fences

- Monitoring the track

- Safety equipment and methods should comply to state of the art

Mitigation against probability for derailments

- Infrastructure maintenance regime

- Track geometry requirements

- Design of rolling stock

- Monitoring the track

- Safety equipment , design and methods should comply to state of the art

# 3   Subject – Safety and Security

## 3.0   Introduction

An important basis for decisions regarding possible future high-speed rail operations in Norway is the impact of such an operation on the total transport safety in society. This part of the Technical Safety Analysis therefore comprises of a comparative study concerning the effects on the total national transport safety due to the implementation of high-speed rail along four transport corridors in Norway.

- The model for the safety calculations was developed in the previous phase of the project - *HSR Assessment Norway, Phase II Technical and Safety Analysis*. In the previous phase the model was applied in a generic sense without consideration to corridor specific data. In the current phase corridor specific data have been made available due to the calculations of risk levels by Interfleet (see the risk assessment part) and a market, demand and revenue analysis by Atkins of four transport corridors.

### 3.0.1   Objectives & Scope

The overall objective of the study is to estimate the effect of a high-speed railway operation along four transport corridors on the total national transport safety. The four investigated HSR-corridors are:

- Oslo-Trondheim, Ø2P
- Oslo-Bergen, H1P
- Bergen-Stavanger, BS1P
- Oslo-Stavanger, S2P

This objective of the study is accomplished by analysing the following two scenarios for each corridor:

- Future safety level of transport with present relevant modes of transport.
- Future safety level of transport with high speed train operations.

The safety is expressed in terms of the expected total number of fatalities by all transport modes, such as railway transport, road transport and air transport. An economic valuation of the change in transport safety due to the implementation of high-speed rail operation is calculated as a function of the expected change in transport safety, expressed as the expected number of fatalities, and the value of a statistical life (VSL) used in Norway.

Additional safety factors that will follow from an introduction of a high-speed railway are assessed and included in the analysis. Examples of such factors are: possible increase in safety level for road traffic caused by more goods transported on the railways and fewer trucks occupying roads.

To accomplish the objectives, the study includes the following six major steps for each corridor:

- Estimation of the current transport safety level and development.
- Estimation of the future distributions between types of transport modes.
- Estimation of future transport safety levels without high-speed operations.

- Estimation of the future transport safety including high-speed operations.

- Estimation of changes in safety and the consequences of the changes.

- Uncertainty analysis.

The study thus results in an estimation of the total change in safety and its economic consequences for the Norwegian transport system (only journeys above 100 kilometres are included; see section 3.0.2) due to the implementation of HSR on the four different corridors.

### 3.0.2  Limitations

To calculate the total safety level before and after HSR implementation data on changes in passenger traffic for all relevant transport modes are necessary. Atkins has performed a market, demand and revenue analysis presenting the expected changes in traffic for trips longer than 100 kilometres. This means that the safety calculations for the Norwegian transport system represent the safety on journeys longer than 100 kilometres.

Furthermore Atkins has assumed that no competitive response from air, coach and conventional rail traffic will be taken if HSR is implemented. This means that no decreases in vehicle kilometres for these traffic modes are predicted to occur after HSR implementation (in the Atkins model). As a consequence, this may disadvantage the safety of HSR relative to other transport modes in the safety calculations.

The safety levels for car transport were calculated based on statistics representing all car transports, since no statistics concerning journeys by car longer than 100 kilometres specifically was available. Consequently, if it is the case that longer journeys by car are safer than shorter journeys per passenger kilometre, then the car safety levels are underestimated.

The Atkins model does not include changes in lorry traffic but a separate study has been performed to calculate the changes in lorry traffic. However, since this study only presents *changes* in lorry traffic it is not possible to calculate the total number of lorry related fatalities.

Finally, it is important to keep in mind that the transport prediction model used by Atkins was primarily developed to calculate the potential market for HSR service and not to model other transport modes in detail.

### 3.0.3  Definitions

| | |
|---|---|
| Passenger kilometres | - Number of passengers multiplied by the distance in km |
| Vehicle kilometres | - Number of vehicles multiplied by the distance in km |
| Fatality | - Fatality caused by the transport sector (Note: this is <u>not</u> equal to the term *equivalent fatality* which is the sum of fatalities and a normalised representation of the number of injured persons) |
| Road transport | - Car, coach and lorry traffic |
| Safety level | - Fatalities/passenger kilometres or fatalities/vehicle kilometres |
| RC | - Reference case, representing a scenario with current transport system |
| DS | - Do something, representing a scenario with implementation of HSR |

## 3.1  Input data

To determine the total safety level of the current transportation system and how this has developed over time, two main types of data have been collected for different types of transportation modes. The first type concerns the number of fatal accidents per year and the second the total quantity of transported person/passenger and vehicle kilometres per year.

The following sources of information were used:

- o  Statistics
- o  Atkins  [48]
- o  Significance [49]
- o  Interfleet, part 2 in this report

The sources of information for key categories of input parameters in calculations of the total national transport safety level are shown in Table 64. Input parameters from the category "Input: Safety level" were used to calculate and determine the safety level and yearly safety level change of the different transport modes (fatalities/passenger kilometres and fatalities/vehicle kilometres). Input parameters from the category "Input: Transported kilometres were used as starting values for the transported passenger and vehicle kilometres and to calculate the yearly transport change.

Table 64: The sources of information for calculations of safety levels.

| Transport mode | Input: Safety level | | | Input: Transported kilometres | |
|---|---|---|---|---|---|
| | Fatalities | Passenger kilometres | Vehicle kilometres | Passenger kilometres | Vehicle kilometr |
| HSR | I | A | A | A | A |
| Classic Rail | I | A | A, S | A | A, S |
| Car | SD | SD | SD | A | A |
| Coach | SD | SD | SD | A | A |
| Lorry | SD | - | SD | - | S |
| Air | SD | SD | - | A | - |

*A=Atkins, I=Interfleet, S=Significance and SD=statistical data*

The availability of data varies. For example, data concerning private car transports are quite extensive whereas data is limited for other transport modes.

Due to data limitations, interactions, and dependencies between different types of statistical information a number of simplifications and assumptions have been necessary. These are explained in the appropriate section below.

Statistics for transports in Norway have been collected from Statistisk sentralbyrå (SSB) and Jernbaneverket. In statistics from SSB concerning passenger kilometres only passengers that have starting point and final destination in Norway are included.

Due to limited or incomplete Norwegian transport data additional information has been gathered from Swedish and international data sources. Statistics concerning road and rail data from Trafikanalys, the Swedish Statistisk Centralbyrå (SCB) and Trafikverket (the Swedish Transport

Administration) were used to estimate historical road and rail transport safety development. International aviation statistics from ICAO (International Civil Aviation Organization) were used to estimate the historical safety development of air traffic.

## 3.2 Transports – statistical data

### 3.2.1 Types of data

Input values on safety levels, i.e. fatalities per billion passenger and vehicle kilometres, were based on statistical transport data for the following modes of transport:

- Road transport
    - Car
    - Coach
    - Lorry
- Air transport

The input values on transport data were taken from the market, demand and revenue analysis performed by Atkins. The historical data is presented below. Although not used as inputs in the safety calculations, transport information concerning conventional rail and ferry traffic is also presented below to provide an understanding of the development of transport volumes over time.

### 3.2.2 Evaluation of statistical data

To facilitate a display of the annual change of transport kilometres over available periods of historical data a Kendall slope factor analysis [24] was performed. All observed slope estimates $b_{i,j}$ between years $i$ and $j$ in the observation period were calculated as:

$$b_{i,j} = \frac{x_i - x_j}{i - j}$$

where $x_i$ and $x_j$ are the log-transformed measurements for years $i$ and $j$, and where $i < j$. The median $B$ of all $b_{i,j}$ provides an estimate of the annual change in %:

$$K = 100(1 - e^{-B})$$

### 3.2.3 Railway transport

In Norway railway transports accounts for a relatively small part of the total quantity of passenger kilometres. A comparison between railway transport and air transport during the last 20 years shows that the passenger kilometres on rail are 70 % of the air plane passenger kilometres. In Figure 38 the passenger kilometres during 1970-2010 is presented and in Figure 39 the railway vehicle kilometres during 2005-2009 is presented. The three year average trend line is inserted in the diagrams.
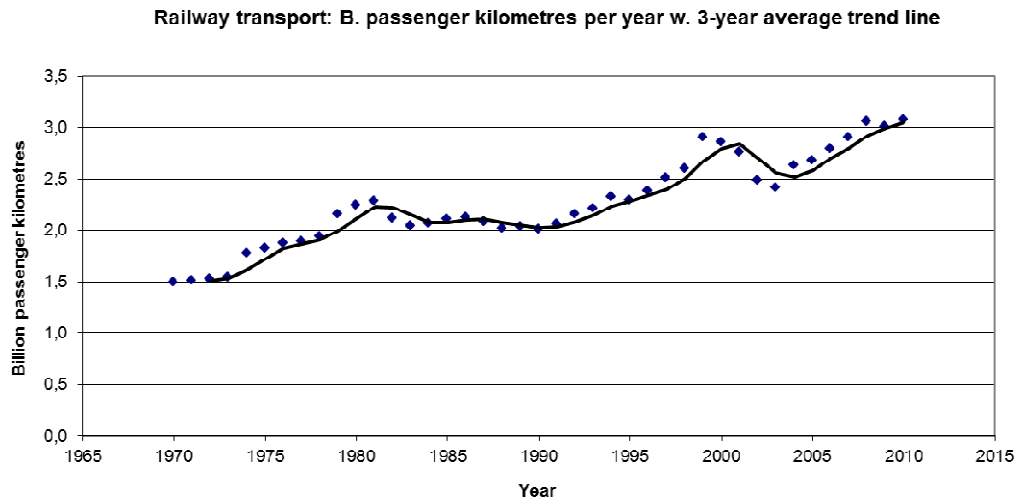
Figure 38: Billion railway passenger kilometres in Norway[9].


The statistical information shows that the current annual number of train passenger kilometres on conventional rail is 3.05 billion, expressed as a three-year mean value. The annual increase in passenger kilometres is according to the Kendall slope analysis 1.54 %.
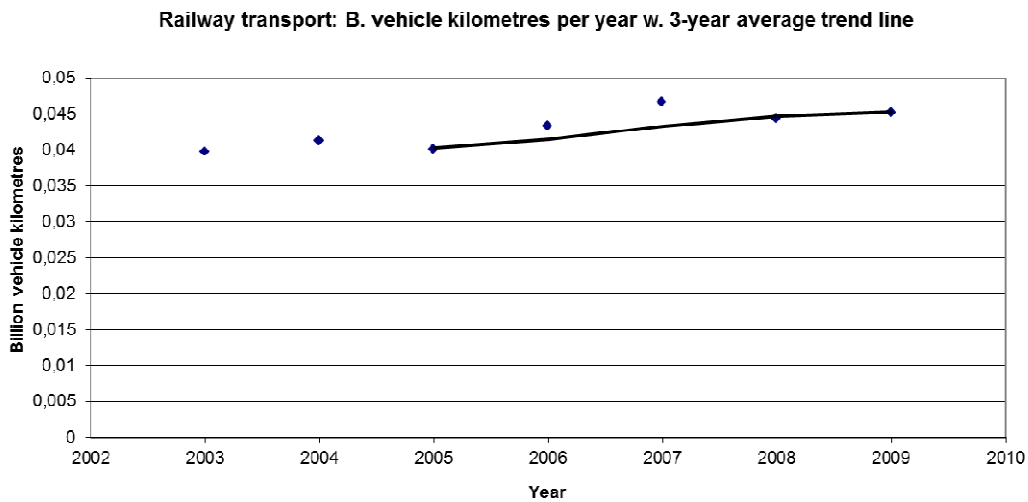



Figure 39: Billion railway vehicle kilometres in Norway.[10]


The current annual train vehicle kilometres on conventional rail was calculated to be 0.05 billion, expressed as a three-year mean value. This figure was used as a starting point on rail vehicle

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[9] Cp. [25].
[10] Cp. [26].

kilometres in the 0-alternative. The annual increase in train vehicle kilometres is according to the Kendall slope analysis 2.2 %.

### 3.2.4  Road transport

Road transports account for the largest part of the total amount of transported kilometres, concerning both passenger kilometres and vehicle kilometres, in Norway. The largest part of road passenger kilometres are made up of car transports (driver and passengers are counted) and a smaller quantity by coach transport. When looking at vehicle kilometres cars also make up the dominating part, although lorries contribute significantly.

#### 3.2.4.1  Car transport

Norwegian statistics for passenger kilometres in cars are available from 1970-2010. The statistics concerning car vehicle kilometres are more limited and were available only for the period 2005-2010. In Figure 40 the total passenger kilometres in cars in Norway is presented and Figure 41 displays the total car vehicle kilometres.
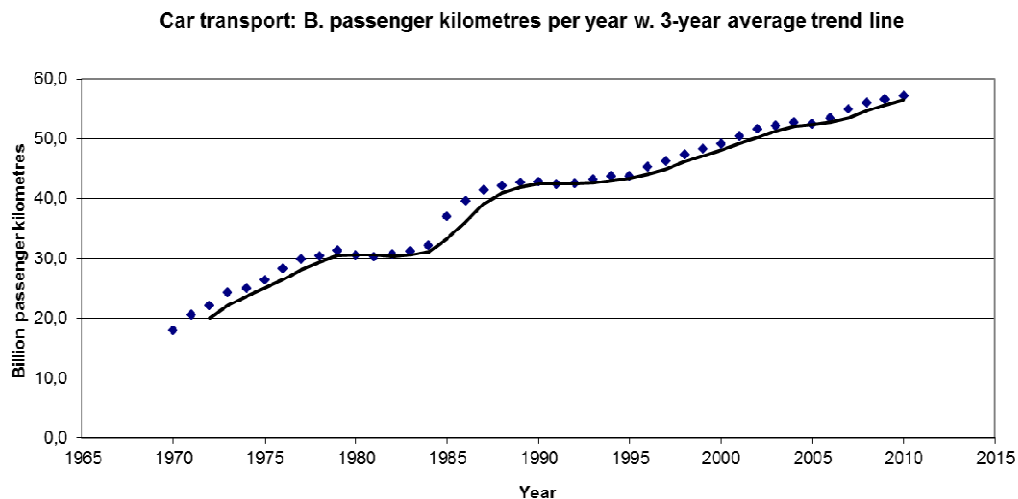


Figure 40: Billion passenger kilometres (driver and passenger) in cars on Norwegian roads.[11]

The current annual passenger kilometres of cars were calculated to be 56.51 billion, expressed as a three-year mean value. The annual increase in car passenger kilometres is according to the Kendall slope analysis 2.31 %.

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[11] Cp. [25].

Figure 41: Billion vehicle kilometres in cars on Norwegian roads.[12]

The current annual car vehicle kilometres were calculated to be 32.57 billion, expressed as a three-year mean value. The annual increase in car vehicle kilometres is according to the Kendall slope analysis 2.43 %. Since data concerning vehicle kilometres only consist of five years, 2005-2010, it should be noted that the annual increase is rather uncertain. The increase is approximately consistent with the annual increase of passenger kilometres, 2.31 %.

### 3.2.4.2   Coach transport

Norwegian statistics for passenger kilometres in coaches are available from the period 1970-2010. The statistics concerning coach vehicle kilometres are more limited and were only available from 2005-2010. In Figure 42 the total passenger kilometres in coaches in Norway is presented and Figure 6 displays the total coach vehicle kilometres.



Figure 42: Billion passenger kilometres in coaches on Norwegian roads.[13]

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[12] Cp. [27].
[13] Cp. [25].

The current annual passenger kilometres in coaches were calculated to be 4.42 billion, expressed as a three-year mean value. The annual increase in coach passenger kilometres for the last five years is according to the Kendall slope analysis 0.29 %.

**Bus transport: B. vehicle kilometres per year w. 3-year average trend line**
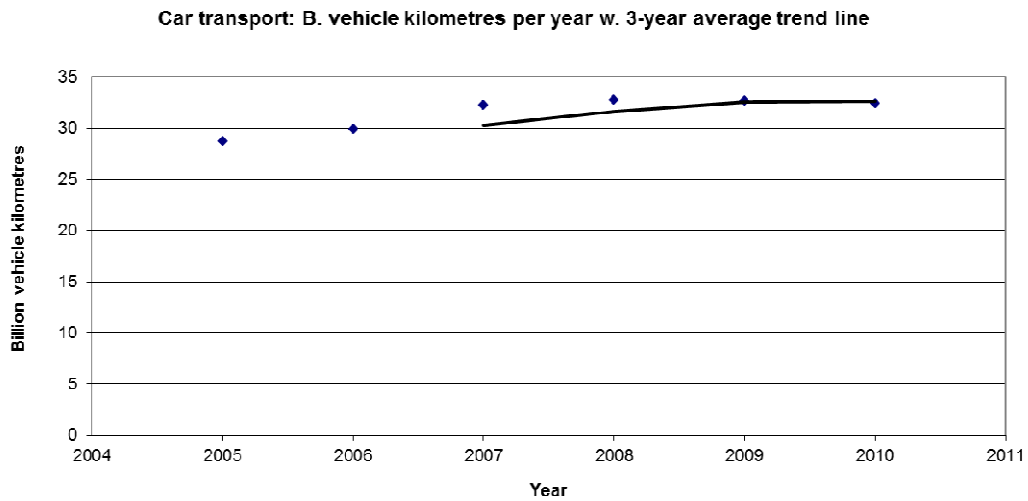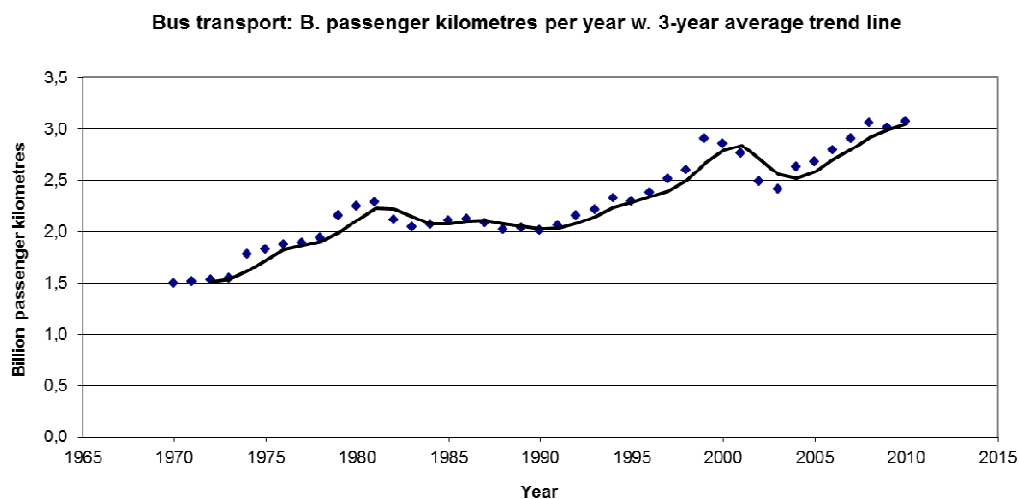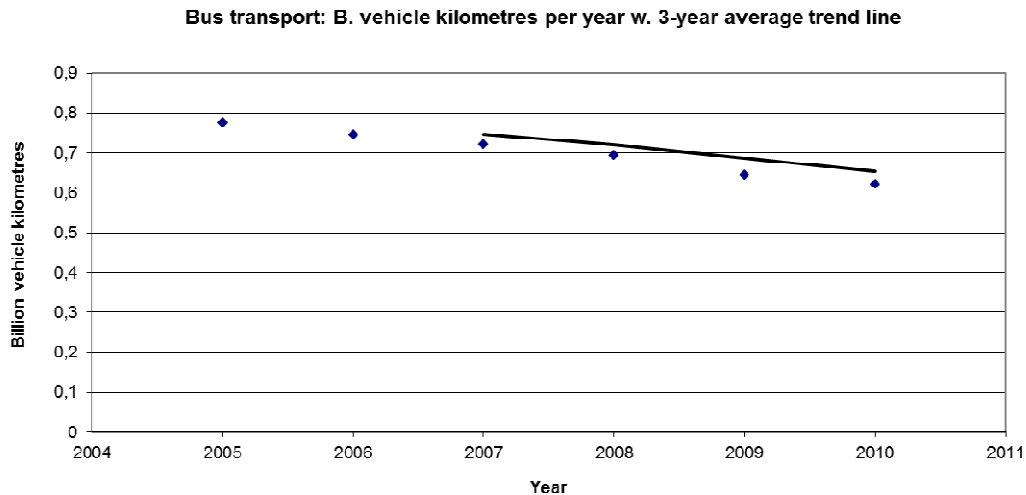


Figure 43: Billion vehicle kilometres in coaches on Norwegian roads.[14]

The current annual coach vehicle kilometres was calculated to be 0.65 billion, expressed as a three-year mean value. The annual change in coach vehicle kilometres for the last five years is according to the Kendall slope analysis -4.26 %. A decrease of this degree may seem somewhat unrealistic; perhaps the amount of seats in coaches has increased.

### 3.2.4.3   Lorry transport

No passengers (of note) use lorries as a modes of transport. Therefore only vehicle kilometres are an important factor for lorries. The statistics concerning lorry vehicle kilometres are limited and have only been available from 2005-2009. There are two types of lorries mentioned in the statistics and these are merged to simplify the final model and enable calculations. The types of lorries are "small lorries" (Norwegian: "små godsbiler") and "large lorries" (Norwegian: "store lastebiler"). In Figure 44 the total lorry vehicle kilometres is presented.

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[14] Cp. [27].

**Lorry transport: B. vehicle kilometres per year w. 3-year average trend line**
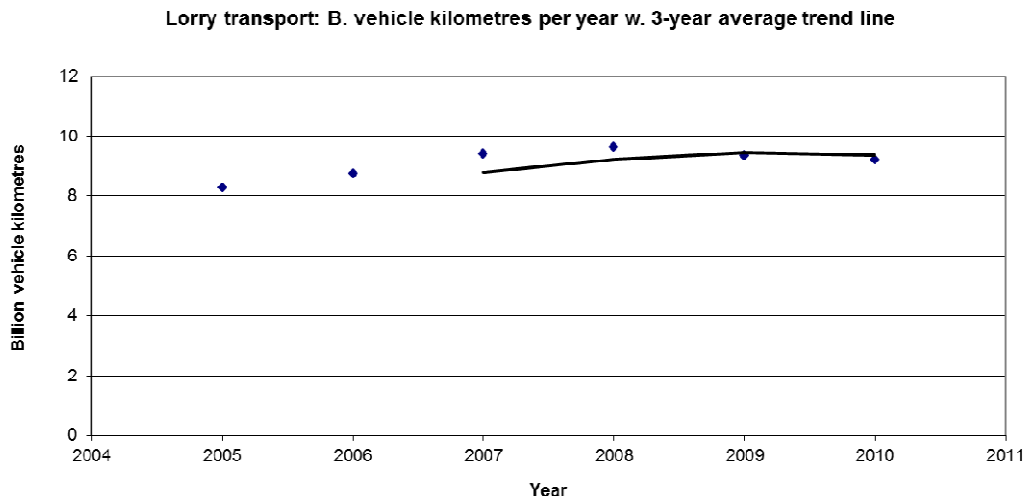


Figure 44: Billion vehicle kilometres in lorries on Norwegian roads.[15]

The current annual lorry vehicle kilometres were calculated to be 9.39, expressed as a three-year mean value. The annual increase in lorry vehicle kilometres for the last five years is according to the Kendall slope analysis 2.3 %.

### 3.2.5  Air transport

Air transport in Norway has increased steadily during the latter part of the 20th century with some exceptions. Also during the first decade of the 21st century an increase can be noted. In Figure 45 the yearly total air plane passenger kilometres in Norway is presented for the years 1970-2010.

**Air transport: B. passenger kilometres per year w. 3-year average trend line**
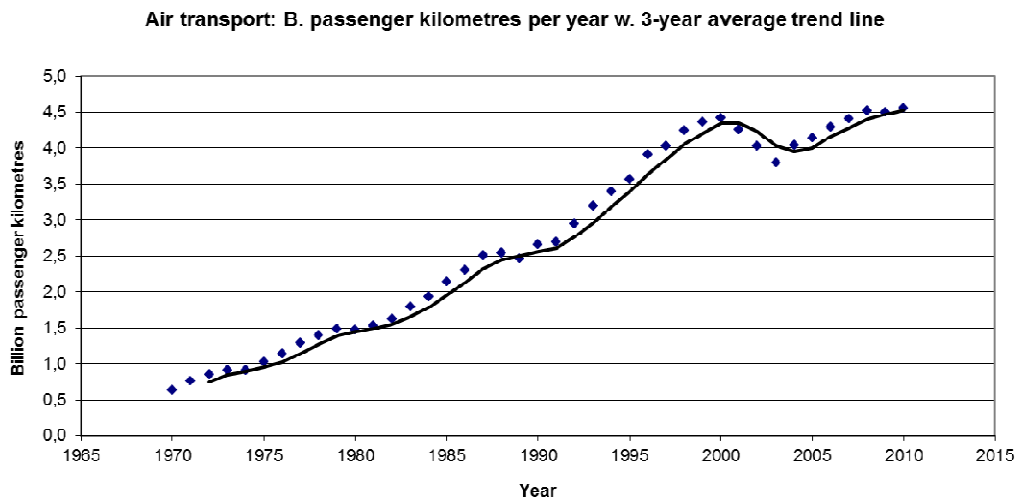


Figure 45: Billion passenger kilometres with airplanes in Norway. 1970-2010.[16]

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[15] Cp. [27].
[16] Cp. [25].

The current annual airplane passenger kilometres were calculated to be 4.53 billion, expressed as a three-year mean value. The annual increase in air plane passenger kilometres is according to the Kendall slope analysis 5.21 %.

### 3.2.6  Ferry transport

The amount of passenger kilometres on ferries is relatively limited as shown in Figure 46. In addition, the analysis made by Atkins predicted a marginal or no significant impact on ferry transport from the implementation of HSR (depending on the corridor).  As a consequence of this, ferry transports have not been included in the safety calculations.

**Ferry transport: B. passenger kilometres per year w. 3-year average trend line**



Figure 46: Billion passenger kilometres with ferry transport in Norway. 2005-2008.[17]

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[17] Cp. [28].

## 3.3  Predicted transport volumes

To calculate the changes in safety due to HSR implementation requires predictions of future changes in transport volumes. Future transport volumes have been predicted by Atkins and Significance for different transport modes and the effects an implementation of HSR will have on these in Norway. Atkins has calculated the volumes for car, air, coach, classic rail (conventional rail), HSR and ferry traffic. Significance has calculated the changes in freight traffic.

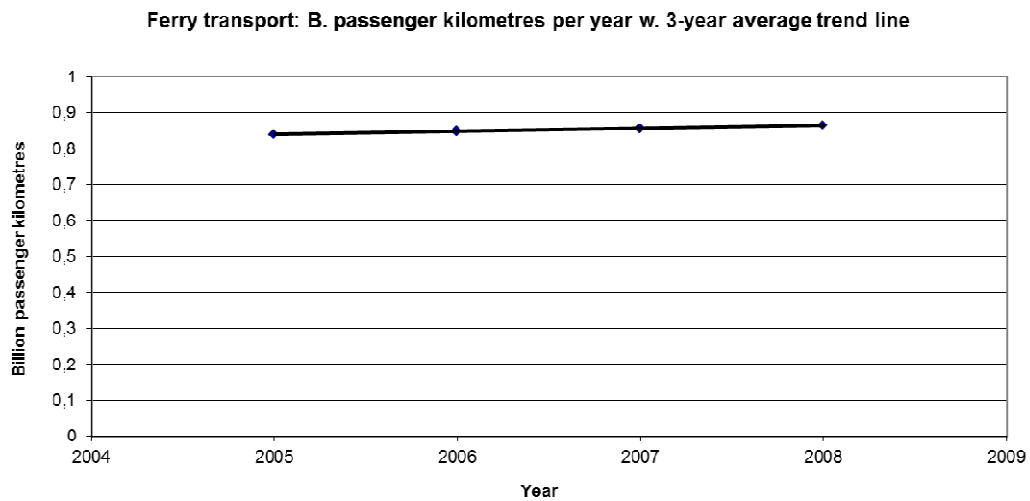### 3.3.1  Main prediction of transport volumes

Most of the predictions of future transport volumes with and without HSR on different corridors have been made by Atkins. Their focus has been to calculate transported passenger kilometres (pax kilometres) and to some extent also the amount of vehicle traffic. Predictions have been made for the years 2024, 2043 and 2060. Atkins has only calculated transport volumes for journeys longer than 100 kilometres. An example of the results is presented in, Table 65: Annual passenger (pax) kilometres and annual vehicle kilometres in millions in the year 2024 for the S2P-corridor. Only journeys longer than 100 kilometres are included. RC is without HSR and DS is with HSR.Table 65, Table 66 and Table 67. These results are for the S2P corridor between Oslo-Stavanger.  For full details of the predicted transport volumes, see the Atkins study.

Table 65: Annual passenger (pax) kilometres and annual vehicle kilometres in millions in the year 2024 for the S2P-corridor. Only journeys longer than 100 kilometres are included. RC is without HSR and DS is with HSR.

| | Annual Pax km (million) | | | Annual Vehicle km (million) | |
|---|---|---|---|---|---|
| Mode | RC | DS | Mode | RC | DS |
| Car | 16 927 | 16 565 | Car | 10 789 | 10 554 |
| Air | 6 894 | 6 449 | Air | 74.2 | 74.2 |
| Coach | 1 985 | 1 936 | Coach | 370.0 | 370.0 |
| Classic Rail | 2 261 | 2 187 | Classic Rail | 68.1 | 68.1 |
| HSR | 0 | 1 559 | HSR | 0 | 9.4 |
| Ferry | 274 | 274 | Ferry | 13.6 | 13.6 |
| Total | 28 341 | 28 970 | Total | 11 315 | 11 089 |

*Classic Rail = Conventional rail

Table 66: Annual passenger (pax) kilometres and annual vehicle kilometres in millions in the year 2043 for the S2P-corridor. Only journeys longer than 100 kilometres are included. RC is without HSR and DS is with HSR.

| | Annual Pax km (million) | | | | Annual Vehicle km (million) | |
|---|---|---|---|---|---|---|
| Mode | RC | DS | | Mode | RC | DS |
| Car | 22 274 | 21 853 | | Car | 14 168 | 13 894 |
| Air | 8 794 | 8 256 | | Air | 74.2 | 74.2 |
| Coach | 2 522 | 2 467 | | Coach | 370.0 | 370.0 |
| Classic Rail | 2 925 | 2 840 | | Classic Rail | 68.1 | 68.1 |
| HSR | 0 | 1 819 | | HSR | 0 | 9.4 |
| Ferry | 344 | 344 | | Ferry | 13.6 | 13.6 |
| Total | 36 858 | 37 579 | | Total | 14 694 | 14 430 |

*Classic Rail = Conventional rail

Table 67: Annual passenger (pax) kilometres and annual vehicle kilometres in millions in the year 2060 for the S2P-corridor. Only journeys longer than100 kilometres are included. RC is without HSR and DS is with HSR.

| | Annual Pax km (million) | | | | Annual Vehicle km (million) | |
|---|---|---|---|---|---|---|
| Mode | RC | DS | | Mode | RC | DS |
| Car | 27 908 | 27 429 | | Car | 17 735 | 17 423 |
| Air | 10 849 | 10 211 | | Air | 74.2 | 74.2 |
| Coach | 3 076 | 3 015 | | Coach | 370.0 | 370.0 |
| Classic Rail | 3 609 | 3 514 | | Classic Rail | 68.1 | 68.1 |
| HSR | 0 | 2 093 | | HSR | 0 | 9.4 |
| Ferry | 415 | 415 | | Ferry | 13.6 | 13.6 |
| Total | 45 857 | 46 678 | | Total | 18 261 | 17 958 |

*Classic Rail = Conventional rail

Given the predictions presented above, the total amount of travel (passenger kilometres) in Norway is estimated to increase with approximately 2 % if S2P is built.

No changes in air, conventional rail and coach vehicle kilometres have been predicted. This is due to an assumption in the Atkins model that there is no competitive response from these transport modes to an HSR implementation.

In the safety model the transport data calculated by Atkins are used as starting values and to calculate the annual increase in passenger kilometres and, when applicable, vehicle kilometres. The safety model requires an estimate of the annual change in transport volumes for each transport mode. The model assumes that the change in transport volume is constant over the time horizon that is studied.

The annual increase in transport was represented by the mean annual increase based on the three prediction years (2024, 2043 and 2060).

### 3.3.2  Prediction of changes in freight traffic

A prediction of changes in freight traffic if HSR traffic is implemented on different corridors has been made. A small transfer of goods from lorries to trains can be expected if HSR is built. The largest change in freight traffic is predicted to occur if HSR between Oslo and Trondheim is built. This could result in a decrease in transported tonne kilometres with lorries with ~0.2 % and an increase of transported train goods tonne kilometres with ~0.4 %; see also Table 68. It is not

specified which year these values are calculated for, so it is assumed that the actual year is 2011.

Table 68: Changes in transported total tonne kilometres for different types of freight transportation in Norway if HSR is implemented on different corridors.

| | Tonne kilometres/year (million) | | | | |
|---|---|---|---|---|---|
| Corridor | Lorry | Sea | Rail | Air | Total |
| Trondheim-Oslo | -57.686 | -26.849 | 73.325 | 0 | -11.210 |
| Stavanger-Oslo | -15.780 | 0 | 19.336 | 0 | 3.556 |
| Bergen-Oslo | -52.173 | 69.966 | -12.546 | 0 | 5.247 |
| Bergen-Stavanger | 0.124 | 0 | -0.490 | 0 | -0.366 |

Since no prediction of the total volumes of freight traffic has been made, lorries cannot be included in the safety calculations. The change in freight train traffic has although been included in the safety calculations.

To calculate the effect the change in freight traffic has on the societal safety in Norway it is necessary to estimate how many vehicle kilometres the tonne kilometres corresponds to. The average lorry in Norway is estimated to carry approximately 13 tonnes of goods [36] and the average freight train is estimated to carry approximately 440 tonnes of goods. [37] This means that in average a freight train can carry approximately 35 times more goods than a lorry.

In Table 69 the vehicle kilometres that have been used in the calculations are presented. Calculations of the actual vehicle kilometres in 2024 are made using the annual change in vehicle kilometres for lorry (see section 3.2.4.3) and conventional rail (see section 3.2.3).

Table 69: Transported tonne kilometres and vehicle kilometres for lorry and train freight transportation in Norway if HSR is implemented on different corridors. The capacity of one freight train assumed to hold cargo equal to 35 lorries.

| | Lorry | | Rail | |
|---|---|---|---|---|
| Corridor | Tonne kilometres (million) | Vehicle kilometres (million) | Tonne kilometres (million) | Vehicle kilometres (million) |
| Trondheim-Oslo | -57.686 | -4.54 | 73.325 | 0.17 |
| Stavanger-Oslo | -15.780 | -1.24 | 19.336 | 0.04 |
| Bergen-Oslo | -52.173 | -4.11 | -12.546 | -0.03 |
| Bergen-Stavanger | 0.124 | 0.01 | -0.490 | -0.001 |

The changes in vehicle kilometres are very small compared to the total transported vehicle kilometres; compare with section 3.2.3 and 3.2.4.3. The changes in fatalities will therefore be very small due to the marginal change and are not calculated.

## 3.4  Safety

### 3.4.1  Types of data and evaluation approach

Estimations concerning safety levels for the selected modes of transport that are needed for the estimations and forecasts of current and future safety levels for the studied scenarios are:

- Fatalities per passenger kilometre.

- Fatalities per vehicle kilometre.

- Annual change of fatalities per passenger and vehicle kilometre.

This information is needed for each of the different modes of transportation included in the model.

Safety levels for conventional rail and HSR (high-speed rail) were calculated with the use of predicted transport volumes (see section 3.3.1) and Interfleet's fatality estimations (see section 2.8.). The safety levels and annual safety changes used in the model is presented in section 3.4.2.2. The statistical data (see section 3.4.2 and 3.4.2.1) for rail traffic are not used as input but is presented below to provide and understanding of railway safety development.

For transport modes not concerning conventional rail and HSR the safety level and annual safety change per passenger and/or vehicle kilometre were calculated from statistical data.

The reported number of annual fatalities of the different modes of transportation was used to calculate the fatalities per passenger kilometres and vehicle kilometres. For passenger fatalities safety levels are expressed per passenger kilometre and for other fatalities per vehicle kilometre. Consequently, both passenger safety and other people's safety are included in the model.

Some assumptions have been necessary in order to make estimations of the safety levels and are stated in the appropriate sections below. In some cases Swedish and International statistics have been used to complement the Norwegian statistics.

Calculations of the annual change of safety levels over available periods of historical data were made using the Kendall slope factor analysis [24]; see section 3.2.1

For all transports modes, except conventional rail and HSR, it was necessary to extrapolate the starting safety level values from 2011 to 2024. This was done using estimated change of safety levels.

### 3.4.2  Railway transport

The statistics on railway safety in Norway was gathered from Jernbaneverket for the years 1996-2009. Changes in reporting on accidents were made in 2003 after which only accidents with moving trains were reported. In Figure 47 the fatalities on Norwegian railways for passengers, employees and other persons are presented.
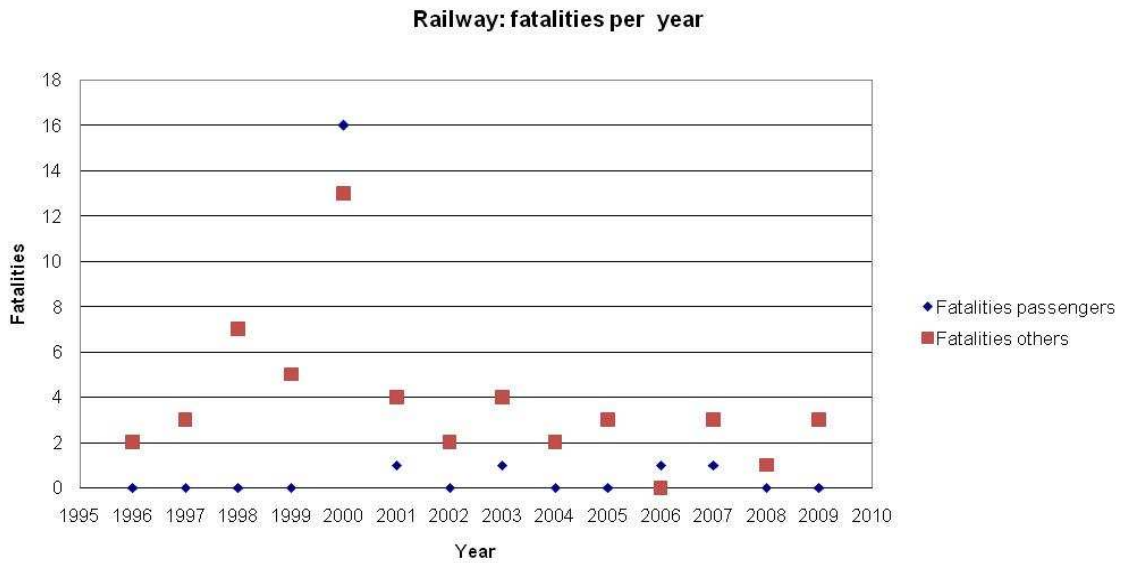
Figure 47: Number of fatalities on Norwegian railways during 1996-2009.[18]

Trains affect the number of fatalities in the transportation system in two ways. The first fatality category concerns passengers. The safety level for this category is dependent on the total number of passenger kilometres. The second category concerns fatalities where trains are causing fatalities among other people. This safety level is dependent on the total number of vehicle kilometres. Travel with train is safe but railways are less safe for people in the vicinity.

### 3.4.2.1  Conventional rail

Norwegian statistics concerning fatality of passengers were available for 1996-2009  [29]. During this period one disastrous accident occurred. In the Åsta-accident which happened in 2000, 16 passengers and 3 employees were killed [29]. This means that the period contains one large scale accident. It should be noted that after 2003 the definition of a railway accident was changed. From 2004 a railway accident must involve a moving train. The annual fatality level per billion kilometres for conventional rail passengers is presented in Figure 48.
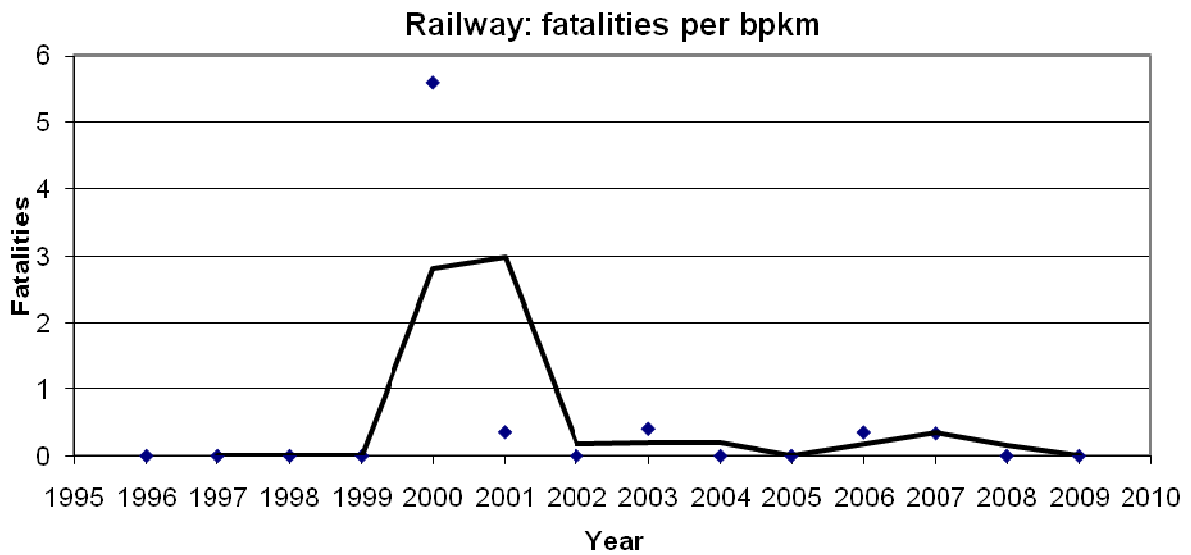
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[18] Cp. [29].

Figure 48: Passenger fatality per billion conventional rail passenger kilometres.

The annual fatality level for other persons per billion vehicle kilometres for conventional rail is presented in Figure 49.
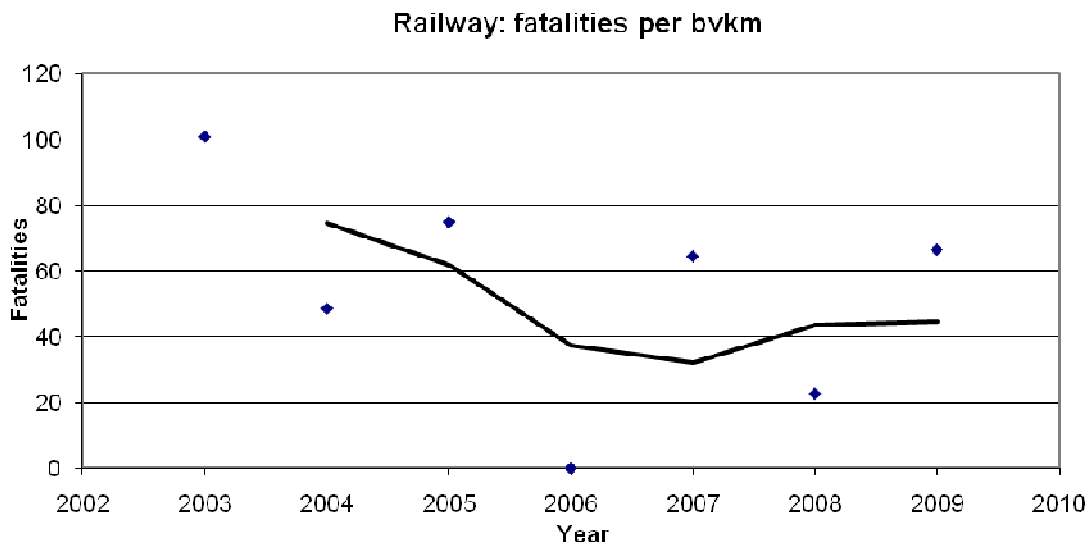
Figure 49: Fatality for others per billion conventional rail vehicle kilometres.

### 3.4.2.2 Railway transport – Safety levels

The starting safety levels concerning conventional rail and HSR are presented below in Table 71 for the different corridors. The data in the table is based on the calculations by Interfleet and Atkins. In the safety model fatality levels are used and not equivalent fatalities (see section 2.5.2.2). The reason that fatalities and not equivalent fatalities are used is that statistical data for other transport modes concerning injuries were not complete. The conversion factor between equivalent fatalities and fatalities are 0.87, calculated from the available statistical data. This means that one fatality corresponds to 0.87 equivalent fatalities.

Table 70: Calculated safety levels 2024 for conventional rail and HSR for journeys longer than 100 kilometres.

| Corridor | Safety level -passengers (fatalities/B.passenger kilometer) | | Safety level - others (fatalities/B.vehicle kilometer) | |
|---|---|---|---|---|
| | Conventional rail | HSR | Conventional rail | HSR |
| Ø2P - Trondheim-Oslo | 0.11 | 0.27 | 51.80 | 204.42 |
| S2P - Stavanger-Oslo | 0.11 | 0.23 | 51.80 | 145.54 |
| H1P - Bergen-Oslo | 0.11 | 0.29 | 51.80 | 133.40 |
| BS1P - Bergen-Stavanger | 0.11 | 0.36 | 51.80 | 39.22 |

The annual safety level changes that were calculated for the different safety levels are presented in Table 71.

Table 71: Calculated average annual safety level change for conventional rail and HSR for journeys longer than 100 kilometres

| Corridor | Safety change - passengers | | Safety level -others | |
|---|---|---|---|---|
| | Conventional rail | HSR | Conventional rail | HSR |
| Ø2P - Trondheim-Oslo | 1.6% | 2.4% | 0.4% | 1.5% |
| S2P  Stavanger Oslo | 1.6% | 2.5% | 0.4% | 1.6% |
| H1P - Bergen-Oslo | 1.6% | 2.5% | 0.4% | 1.6% |
| BS1P - Bergen-Stavanger | 1.6% | 2.4% | 0.4% | 0.02% |

### 3.4.3  Road transport

A dominating part of the total number of persons killed in transports related accident in Norway is killed by road transport, car; coach or lorry. In Figure 50 the total number of people killed in road traffic accidents during 1970-2009 is presented.
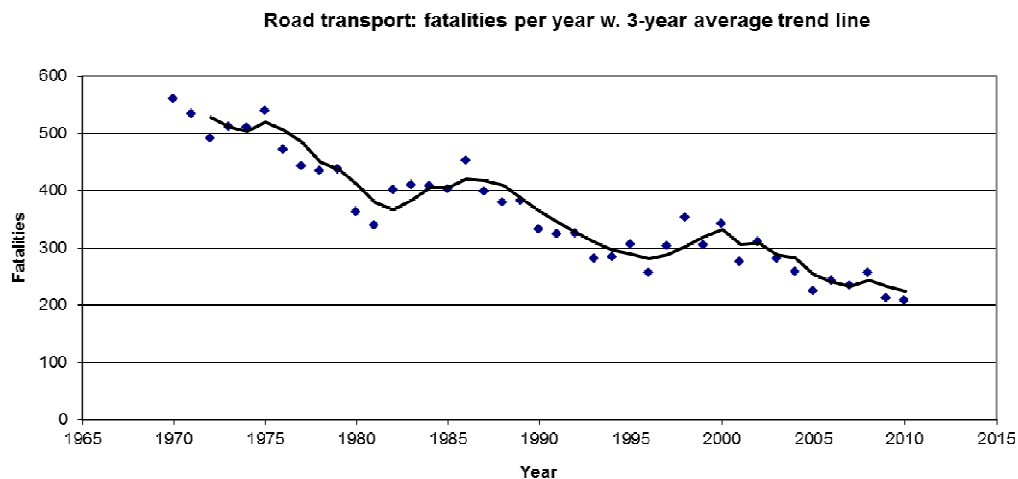


Figure 50: The number of persons killed in road traffic accidents in Norway during 1970-2010.[19]

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[19] Cp. [30].

The available data on road traffic accidents where people are killed vary greatly. To estimate the current and future safety level some adjustments have been necessary. These will be explained in the following sections. In addition Swedish statistics have been used in some instances to predict Norwegian levels.

### 3.4.3.1  Car

Cars affect the number of fatalities in the transportation system in two ways. The first and largest fatality category concerns drivers and passengers. The safety level for this category is dependent on the total number of passenger kilometres (driver and passenger). The second category concerns fatalities were cars are causing fatalities among other people which use roads or are close to roads. This safety level is dependent on the total number of vehicle kilometres.

The safety level for car drivers and passengers was calculated by using Norwegian statistics concerning killed drivers and passengers during 1970-2010. The current safety level was calculated by using the arithmetic mean of the last three years. For passengers and drivers the safety level was calculated to be 2.81 fatalities per billion car passenger kilometres. The annual car passenger safety improvement was calculated to be 3.3 %. The annual fatality level for car passengers is shown in Figure 51.
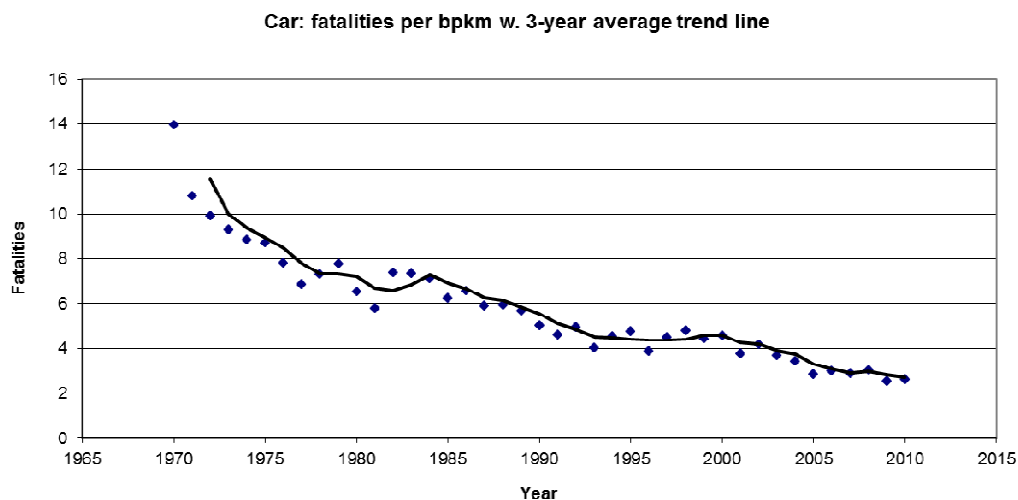


Figure 51: Passenger and driver fatality for car traffic per billion passenger kilometres

Calculation of the safety level for others than car drivers and passengers that are exposed to car vehicles ("cars involved in killing others") was made by using both Norwegian and Swedish [31] statistics. The reason for this is that no Norwegian statistics concerning fatalities involving cars was available. An assumption was made that the relative frequency between fatalities in cars (passengers and drivers) compared to others are approximately the same in Norway and Sweden. To strengthen this argument the proportion of drivers and passengers that was killed in road traffic between 2003 and 2009 in Norway and Sweden were compared. In Sweden 65.1 % of the people killed in traffic accident were drivers or passengers in cars and in Norway the corresponding proportion was 67.5 %.

It was assumed, with the help of Swedish statistics, that most of the fatalities with cars involved excluding the car driver or passenger, are persons walking, biking or otherwise "unprotected". According to Swedish statistics, based on the years 2003-2009, 13.4 % of the total numbers of

fatalities in Swedish road accidents are car accidents where other persons than the car driver or passenger are killed.

Since the total numbers of fatalities on Norwegian roads are known the number of persons killed by cars can be estimated. The estimated fatalities are presented in.
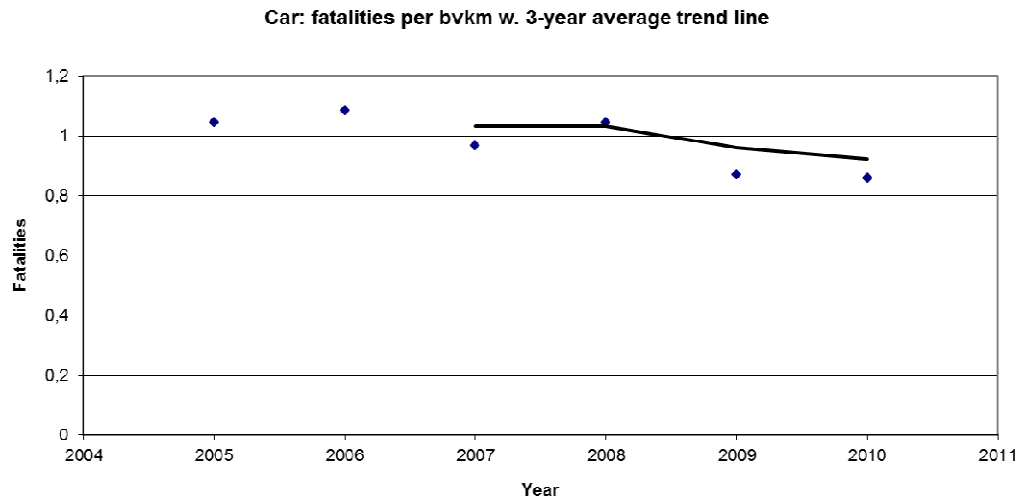
**Car: fatalities per bvkm w. 3-year average trend line**



Figure 52: The estimated number of fatalities for other persons per billion car vehicle kilometres ("cars involved in killing others") excluding passenger and drivers in Norway during 2005-2010.

The reason that the only estimated numbers of "cars killing others" presented are for the years 2005-2010 are that the vehicle kilometres in Norway are only known for this period.

With the estimation of fatalities caused by cars and the known vehicle kilometres the safety level and the annual change of "cars involved in killing others" was calculated. The safety level for "cars involved in killing others" was calculated to be 0.96 fatalities per billion vehicle kilometres in 2011. The annual safety increase was calculated to be 3.8 %. Due to the small amount of data available of car vehicle kilometres the annual safety improvement for others is somewhat unreliable.

### 3.4.3.2  Coach

Coaches affect the number of fatalities in the transportation system in two ways. The first fatality category concerns drivers and passengers. The safety level for this category is dependent on the total number of passenger kilometres. The second category concerns fatalities were coaches are causing fatalities among other people which use roads or are close to roads. This safety level is dependent on the total number of vehicle kilometres. A comparison of fatalities between coaches and cars show that the number of fatalities caused by coaches is very small compared to fatalities caused by cars.

No Norwegian statics concerning the quantity of coach passengers could be identified in this study. The Swedish statics cover a short time span and were therefore not used to calculate the passenger safety. However, in the report *Nasjonal Tiltaksplan for trafikksikkerhet på veg* [32] the number of passenger and driver fatalities per person kilometre in Norway during 1998-2002 is stated to be 0.93 fatalities per billion passenger kilometres. This figure was used to represent the current safety level (year 2011) for coach passengers in this study.

Since no yearly statics were identified concerning coach safety the annual coach passenger safety improvement was estimated to be the same as for car passengers, i.e. 3.3. This safety

level change was only used when calculating the safety level in 2024. In the safety model calculations, starting with the year 2024, the safety change for coaches was assumed to be 0 %.

Determining the safety level for others than coach passengers that are exposed to coach vehicles ("coaches killing others") was made by using both Norwegian [30] and Swedish [31] statistics. The reason for this is that no Norwegian statistics concerning fatalities involving coaches were available. An assumption was made that the relative frequency between fatalities in coaches (passengers and drivers) compared to other fatalities on roads is approximately the same in Norway and Sweden.

It was assumed, with the help of Swedish statistics, that most of the fatalities with coaches involved, coaches and single coach accidents are excluded, are accidents with cars, persons walking, biking or otherwise "unprotected" persons. According to Swedish statistics, based on the years 2003-2009, 1.51 % of the total numbers of fatalities in Swedish road accidents are coach accidents where other persons than the coach driver or passengers are killed.

Since the total numbers of fatalities on Norwegian roads are known the number of persons killed by coaches can be estimated. The estimated fatalities are presented in Figure 53.
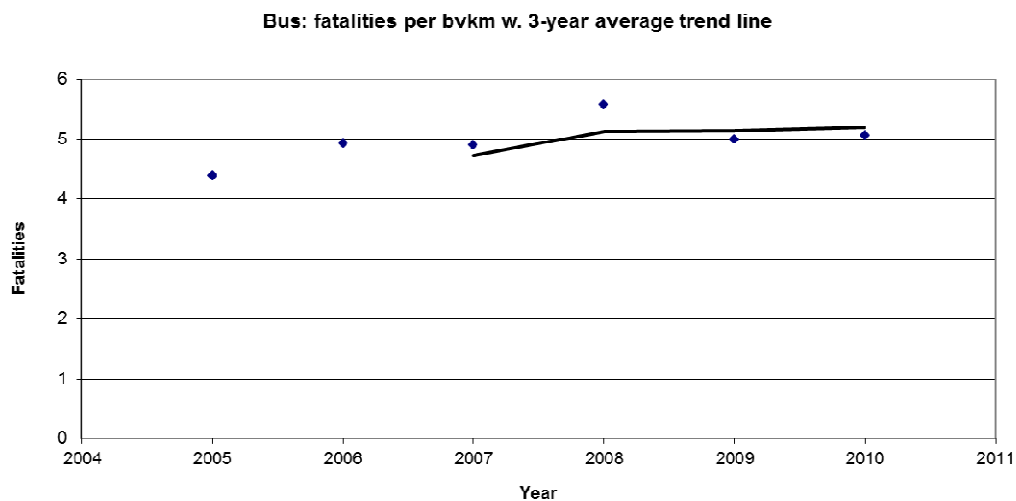


Figure 53: The estimated number of fatalities for other persons per billion coach vehicle kilometres ("coach involved in killing others") after accidents with cars; coaches and single coach accidents are excluded in Norway during 2005-2009.

The reason that the only estimated numbers of "coach involved in killing others" presented are for the years 2005-2010 is that the vehicle kilometres in Norway are only known for this period.

Based on the estimation of fatalities involving coaches and the known vehicle kilometres the safety level and the annual safety change of "coaches involved in killing others" were calculated. For the starting year the safety level for "coaches involved in killing others" was calculated to be 5.15 fatalities per billion vehicle kilometres. The annual safety change was calculated to be -1.6 %, i.e. a decrease in safety. It should be emphasized that this figure is based on a very limited statistical sample hence it was decided to use the safety level change of cars to calculate the starting safety level in 2024. In the safety model calculations, starting with the year 2024, the safety change for coaches was assumed to be 0 %.

### 3.4.3.3  Lorry

Lorries affect the number of fatalities in the transportation system in two ways. The first fatality category concerns lorry drivers. This category is not calculated separately because it was assumed that the number of lorry drivers that are killed constitute a small part of the total fatalities where lorries are involved.

The second category concerns fatalities were lorries are causing fatalities among other people, which use roads or are close to roads. This safety level is dependent on the total number of vehicle kilometres. A comparison of fatalities between lorries and cars show that the number of fatalities caused by lorries is small compared to fatalities caused by cars.

Determining the safety level for others that are exposed to lorry vehicles ("lorries involved in killing others") was made by using both Norwegian [30] and Swedish [31] statistics. The reason for this is that no Norwegian statistics concerning fatalities involving lorries was available. An assumption was made that the relative frequency between fatalities caused by lorries compared to others is approximately the same in Norway and Sweden.

Two important factors should be noted about this safety level concerning cars and lorries. Accidents involving cars are subtracted from the number of fatalities involving lorries because these fatalities are already accounted for in the calculations of the car safety level. Concerning lorries, the safety level for "lorries involved in killing others" also includes lorry drivers killed in lorry-lorry and single lorry accidents.

It was assumed with the help of Swedish statistics, that most of the fatalities with lorries involved, after accidents with cars are excluded, are persons walking, biking or otherwise "unprotected". Also lorry drivers are counted in these fatalities. According to Swedish statistics, based on the years 2003-2009, 7.94 % of the total numbers of fatalities in Swedish road accidents are lorry accidents where other persons than car drivers and passengers are killed.

Assuming that the fraction of lorry fatalities of the total number of road fatalities is approximately the same in Norway and Sweden, the number of persons killed where lorries are involved was estimated, see Figure 54.
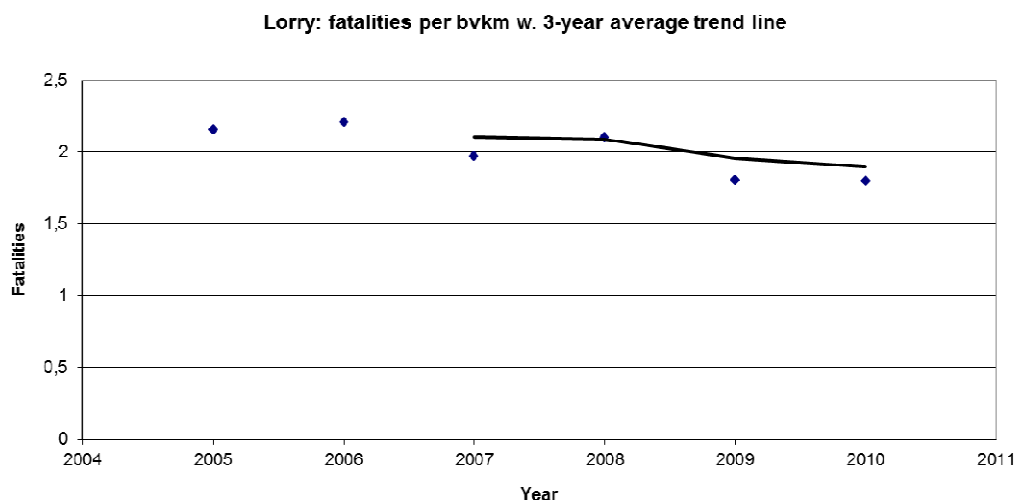


Figure 54: The estimated number of fatalities for other persons per billion lorry vehicle kilometres ("lorries involved in killing others") after accidents with cars are excluded in Norway during 2005-2010.

The reason that the numbers of "lorries involved in killing others" presented is restricted to the years 2005-2010 is that the vehicle kilometres in Norway are only known for this period.

With the estimation of fatalities involving lorries and the known vehicle kilometres the safety level and the annual change of "lorries involved in killing others" was calculated. For the starting year the safety level for "lorries involved in killing others" was calculated to be 1.96 fatalities per billion vehicle kilometres. Note that in the calculated fatality rate persons "killed in cars by lorries" are not included.  The annual safety increase was calculated to be 4.3 %. It should be emphasized that this figure is based on a very limited statistical sample.

### 3.4.3.4  Dependencies

The number of road accidents is affected by several different modes of transportation and also both the quantity of passenger kilometres and vehicle kilometres among other things. In addition there are some dependencies between the different categories of accidents that need to be addressed in the calculations of the present and future safety levels. The following dependencies affecting the quantity of road and total fatalities have been identified:

- Some fatalities in road traffic are probably also counted as level crossing accidents in railway statistics. Since this number is assumed to be small compared to the total number of fatalities in the transport system no special attention is given to this issue. In the Swedish statistics concerning fatalities involving different types of road transport no separate category deals with level crossing accidents.

- In the safety level for both lorries and coaches no correction have been made for accidents were both coach and lorry are involved. This means that a few fatalities can be included in the calculations of both safety levels. In the statistics concerning fatalities involving coaches and lorries no separate category deals with accidents involving coaches and lorries. It is therefore assumed that the effect this will cause on the total number of fatalities is very limited.

- Since coaches and lorries are involved in several accidents with cars per year a decrease in the quantity of coach and lorry traffic will lead to less car fatalities. To correct for this the quantity of car accidents involving lorries and coaches, respectively have been calculated from Swedish statistics.

It is assumed that the relative frequency of traffic elements involved in fatal car accidents are approximately the same in Norway and Sweden. Lorries are involved in 21.76 % of the fatal car accidents and it was assumed that all of the fatalities in these accidents are car drivers or passengers. Coaches are involved in 2.93 % of the fatal car accidents and it is assumed that all of the fatalities in these accidents are car drivers or passengers. It is possible that some of the fatalities in these accidents are lorry drivers, coach drivers or passengers. However these fatalities are estimated to constitute only a small part of the total number of fatalities. With the help of these estimations a correction of the safety levels of cars when lorry and coach traffic change was made.

Based on these assumptions the change in number of fatal car accidents, $F_{o \to s}$, from Scenario 0 to Scenario $s$ can be calculated as:

$$F_{0 \to s} = \left( \frac{D_{T,0} - D_{T,s}}{D_{T,0}} \right) \times 0.218 \times F_{c,0}$$

where $D_{T,0}$ is the number of lorry vehicle kilometres in Scenario 0. $D_{T,s}$ is the number of lorry vehicle kilometres in $s$ and $F_{c,0}$ is the number of car passenger fatalities in Scenario 0.

The car fatalities involving coaches change analogously.

It should be noted that since no changes in coach vehicle kilometres occur, according to the prediction of transport volumes, see section 3.3, no change in car fatalities involving coaches will occur. Since lorries are not included in the calculations no changes will occur concerning the car fatalities affected by lorries either.

### 3.4.4  Air transport

The dominating part of accidents with air planes concerns passengers. This means that fatalities that occur due to air transport are related to the safety level for passengers. The number of fatalities is governed by the quantity of passenger kilometres.

Few fatal air plane accidents occur in Norway. The safety level for air plane passengers was therefore approximated by using international statistics from ICAO [33]. Norwegian statistics concerning transported passenger kilometres were also used. The starting safety level for air plane passengers was calculated with the fatalities per billion air plane passenger kilometres 2008 and 2007 to 0.10 fatalities per billion air plane passenger kilometres. The annual air plane passenger safety improvement was calculated to be 7.6 %. The annual fatality level for international air plane passengers is shown in Figure 55.
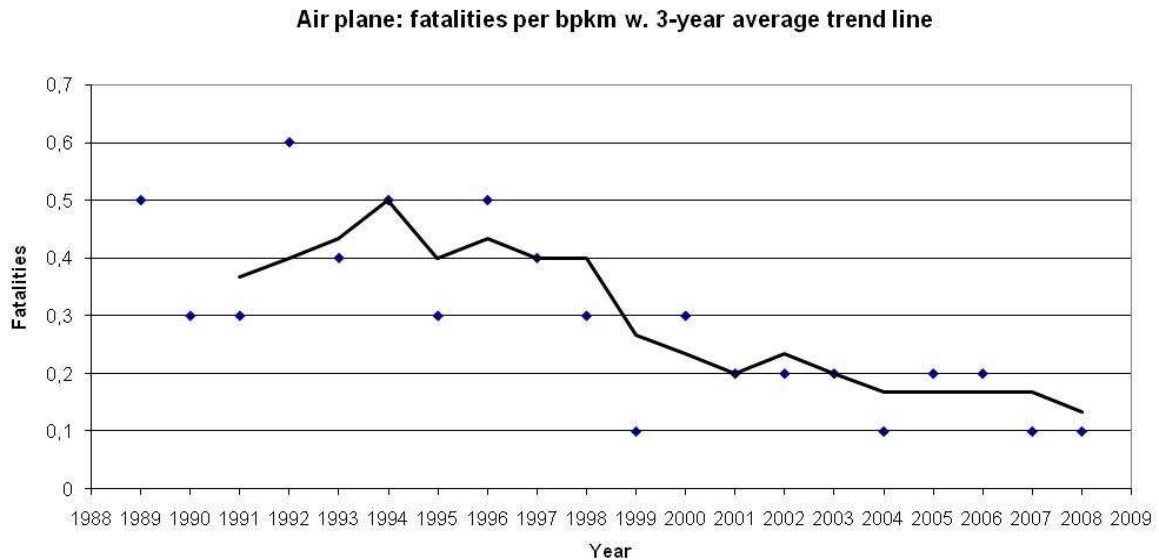


Figure 55: The estimated number of international air plane passenger fatalities per billion air plane passenger kilometres according to the ICAO

### 3.4.5  Ferry transport

Statistics concerning fatalities for all persons on Norwegian ferries are available for the years during 2000-2009. It is probable that these fatalities also include staff persons. The fatalities are presented in Figure 56.
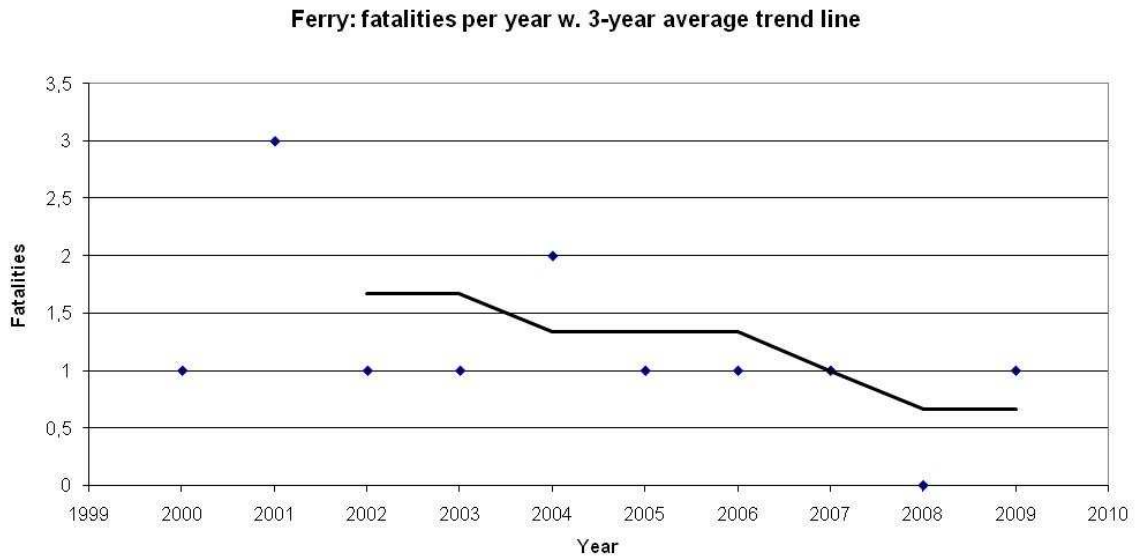


Figure 56: Fatalities on ferries in Norway during 2000-2009.[20]

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[20] Cp. [34].

## 3.5  Model description

### 3.5.1  Model structure

The model for calculations of current safety levels and forecasts of future safety levels was developed in Excel format in the previous phase 2 of the project. It facilitates efficient updating once new information on safety and transport data becomes available. The model was updated from the previous phase in order to take into account the new information made available during the current phase and in order to be able to calculate present and future safety levels for the two following scenarios:

- Future safety level of transport with present relevant modes of transport.
- Future safety level of transport with high speed train operations.

Safety calculations can be made for these scenarios on several different scales. The model was used for safety calculations on a national level, given the input estimates on transport and safety levels and predicted future changes on the four transport corridors.

The current model does not include ferry transport due to no or very small predicted changes in ferry transports due to HSR implementation and the resulting assumption that future HSR operations have a rather limited correlation to safety on ferries.

The model consists of four major parts:

- Input data on safety information
    - Safety per billion person kilometres (bpkm) for road, rail and air travel.
    - Safety per billion vehicle kilometres (bvkm) for road and rail transports.
    - Annual safety change for the different transport modes.
- Input data on transports
    - Person kilometres for road, rail and air travel.
    - Vehicle kilometres for road and rail transports.
- Input on economic factors
    - Value of Statistical Life (VSL)
    - Discount rate
- Output data
    - Total current societal safety level for the different transport modes and in total.
    - The predicted societal safety levels for the two scenarios
    - The changes in safety levels due to HSR operations
    - The economic consequences of the changes in safety levels due to HSR operations
    - Uncertainty estimations of the economic consequences of the changes in safety levels due to HSR operations.

The total societal safety levels and the economic consequences of the changes in levels due to HSR operations were calculated for three different time horizons: 25, 40 and 60 years.

The economic consequences of changed societal safety levels due to operation of HSR were calculated as the net present value (*NPV*) over the specific time horizon *T* for each scenario *s*=[1,2]*:*

$$NPV_s = \sum_{t=0}^{T} \frac{1}{(1+r)^t} F_{o \to s}(t) \cdot VSL$$

where *r* is the discount rate, *t* represents the specific years of the time horizon *T*, $F_{o \to s}$ is the change in safety level between scenario 0 and *s*, and VSL is the value of a statistical life.

The model was developed to facilitate a user-friendly application and the input and output information is compiled on a four-page printable form. The Transport Safety Model is shown in the Annex 1.

The economic consequences of changed safety level were calculated using the Value of Statistical Life (VSL). Two possible values of VSL could be identified, 20 MNOK [10] and  26.2 MNOK [38].  Calculations were made separately for both these values and a sensitivity analysis was performed to investigate the sensitivity of the VSL to the results. A discount rate of 4.5 % with possible changes to 3.5 % and 5.5 % was used for the calculations.

### 3.5.2  Uncertainty analysis

An important feature of the safety forecasts is the ability to account for the inherent uncertainties in the estimations of input data. The principal approach for managing the uncertainties is shown in Figure 57.
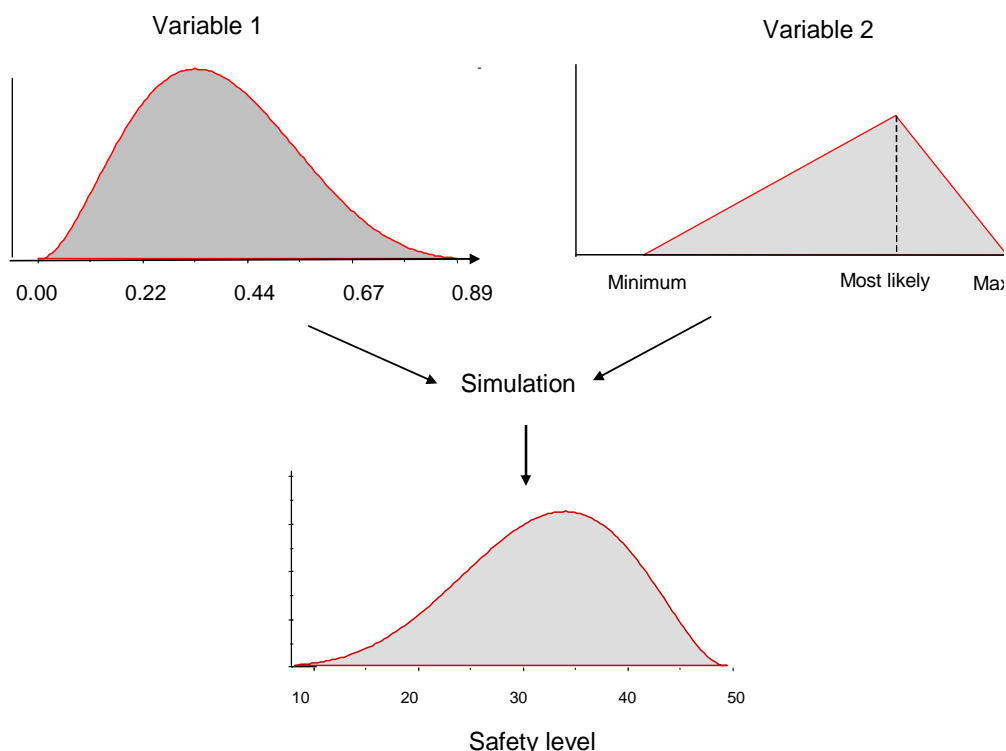


Figure 57: Schematic description of the approach for uncertainty analysis.

The input parameters are regarded as random variables and their uncertainties are represented by statistical distributions. The uncertainties of the input percentages, e.g. the annual safety changes, are represented by beta-distributions [35] and the uncertainties of the transport

kilometres are represented by lognormal distributions. The uncertainties of the passenger safety levels are represented by lognormal distributions. The VSL was assigned a point estimate. However, two separate calculations were made with the two possible VSL values (see previous section) in order to analyse the sensitivity of the VSL-value selection to the outcome. The discount rate was represented by a discrete custom distribution with equal probabilities for all three possible discount rates (see previous section).

It was not possible to perform a detailed uncertainty analysis of each input variable within the scope of this study. Each variable was assigned a generic uncertainty of +/- 10 %.

The resulting uncertainty of the model results is calculated by statistical simulation (Monte Carlo). The method allows for sensitivity analysis of the modelling in order to identify the most uncertain variables in the calculation of the transport safety and its economic consequences. This information can then be used in selecting variables most relevant for further studies and data collection in order to achieve more reliable model results.

The safety modelling tool was developed to facilitate an efficient updating procedure as soon as new and more detailed information becomes available. The tool is an Excel spread sheet model that includes Monte Carlo simulation. To facilitate the Monte Carlo simulation and sensitivity analysis the Crystal Ball © software is needed as an add-in to Excel.

## 3.6   Results

In the following subsections, the calculated results for the four following corridors are presented:

Ø2P                          - HSR between Oslo and Trondheim

S2P                          - HSR between Oslo and Stavanger

H1P                          - HSR between Oslo and Bergen

BS1P                        - HSR between Bergen and Stavanger

The results (number of fatalities, economic consequences, change in passenger traffic, and change in fatalities per passenger kilometre) for the different corridors are compared in section 3.6.5.

The changes due to decreased lorry transport is not calculated since it is marginal, but mainly due to the fact that no predictions on absolute transport volumes are available for this type of transport, only estimates of the changes, see section of limitations 3.0.2.

The changes in freight train traffic have however been included in the calculations, since the increase can be added to the total transported conventional rail vehicle kilometres. This can be seen as a marginal change in fatalities for "Rail others" in Ø2P (the only corridor were the change is large enough to be seen in the figure), e.g. please compare "Rail others" in Figure 58 and Figure 59 were the change of 0.01 fatalities can be seen.

### 3.6.1   Results Ø2P- HSR between Oslo and Trondheim

If HSR is implemented on Ø2P the total amount of transported passenger kilometres during 40 years in Norway for journeys longer than 100 km increases from ~1464 billion kilometres to ~1494 billion kilometres.

The estimated level of societal safety for the Norwegian transport system without HSR implementation, expressed as the number of expected fatalities for the total system and for specific transport modes, is shown in Figure 58. The corresponding figures for a system with HSR implementation on Ø2P are shown in Figure 59.
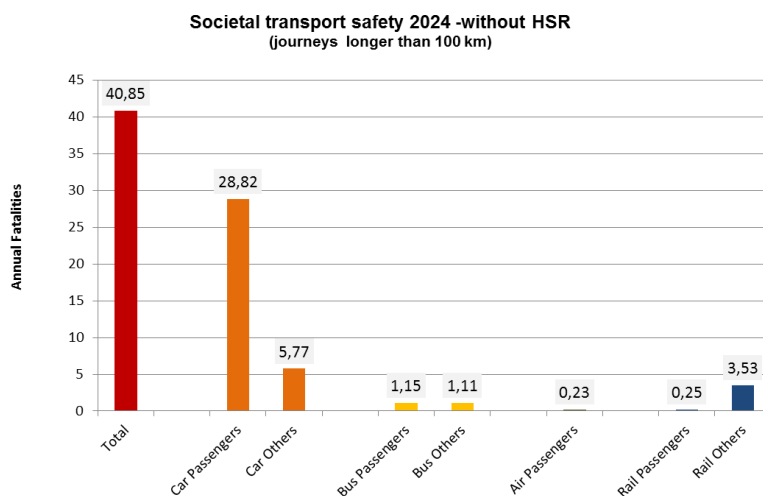
Figure 58: The calculated total current societal safety level of transport means in Norway expressed as the expected number of fatalities for each means of transport for journeys longer than 100 kilometres for the year 2024 without HSR.
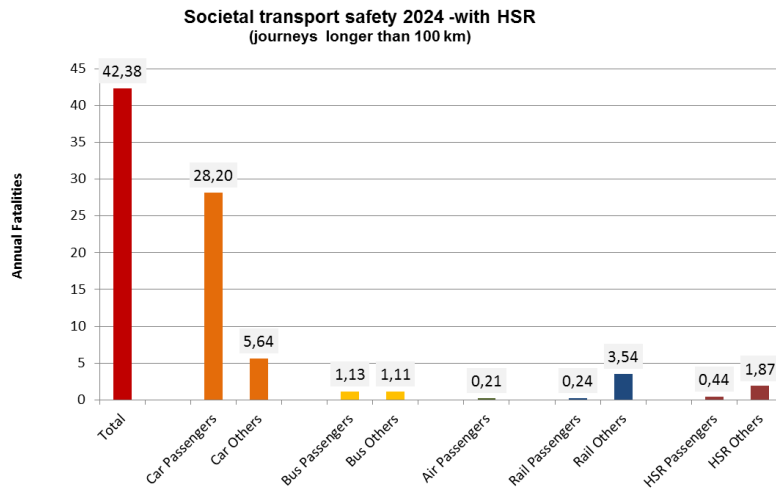


**Societal transport safety 2024 -with HSR**
**(journeys  longer than 100 km)**

Figure 59: The calculated total current societal safety level of transport means in Norway expressed as the expected number of fatalities for each means of transport for journeys longer than 100 kilometres for the year 2024 with HSR on Ø2P.

As seen in the figures, the total number of expected fatalities is subject to a slight increase as a result of HSR implementation. The main reason for this is the predicted large addition of HSR transport volumes compared to the relatively limited reduction in transport volumes for other transport modes.

The change in societal safety for four studied time horizons, expressed as the expected change in the number of fatalities due to HSR implementation on Ø2P, is shown in Figure 60.
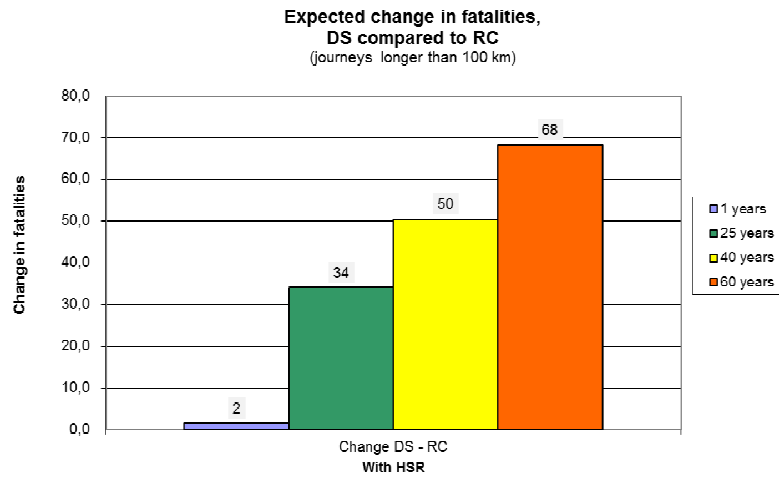
Figure 60: Change in predicted societal transport safety in Norway (additional fatalities) for journeys longer than 100 kilometres if HSR is implemented on Ø2P for four different time horizons.

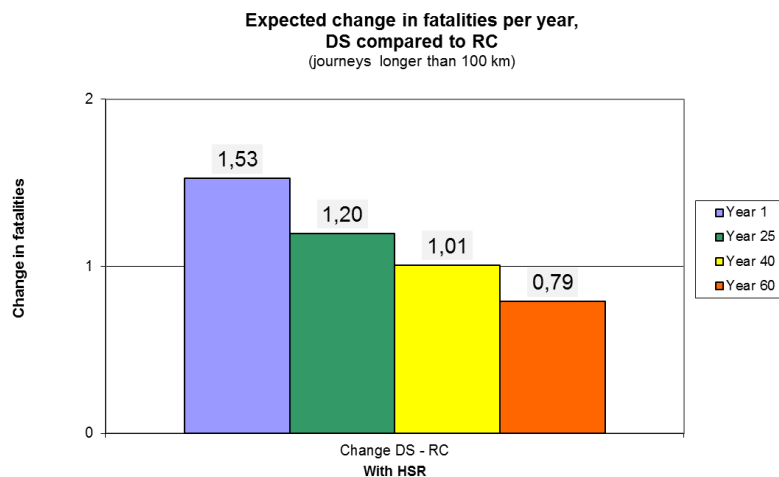The expected annual change in fatalities due to HSR operation on Ø2P is shown in Figure 61.



Figure 61: Additional fatalities per year in Norway for journeys longer than 100 kilometres if HSR is implemented on Ø2P for four different years.

The economic consequences of the changes in societal safety due to HSR implementation on Ø2P is shown in Figure 62 and Figure 63 for the four studied time horizons. The calculations are made with a VSL of 20 MNOK, Figure 62, and 26.2 MNOK, Figure 63.
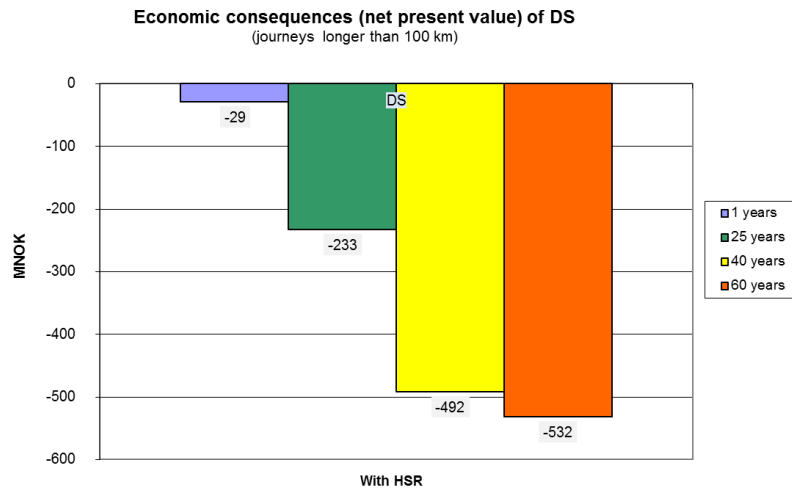
Figure 62: The economic consequences (with VSL=20 MNOK) of transport safety level changes for journeys longer than 100 kilometres if HSR is implemented on Ø2P in Norway for four different time horizons.
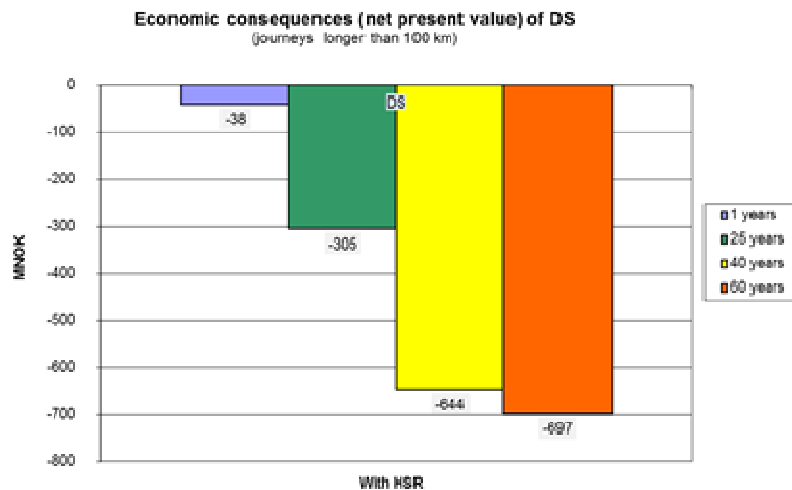


Figure 63: The economic consequences (with VSL=26.2 MNOK) of transport safety level changes for journeys longer than 100 kilometres if HSR is implemented on Ø2P in Norway for four different time horizons.

The change of societal safety over time due to HSR implementation on Ø2P compared to keeping the current transport system is shown in Figure 64. The temporal change in the difference between the two scenarios is expressed as the total number of fatalities per billion passenger transport kilometres in the Norwegian transport system.

**Change in fatalities over time (fatalities/Bpkm) RC-DS**
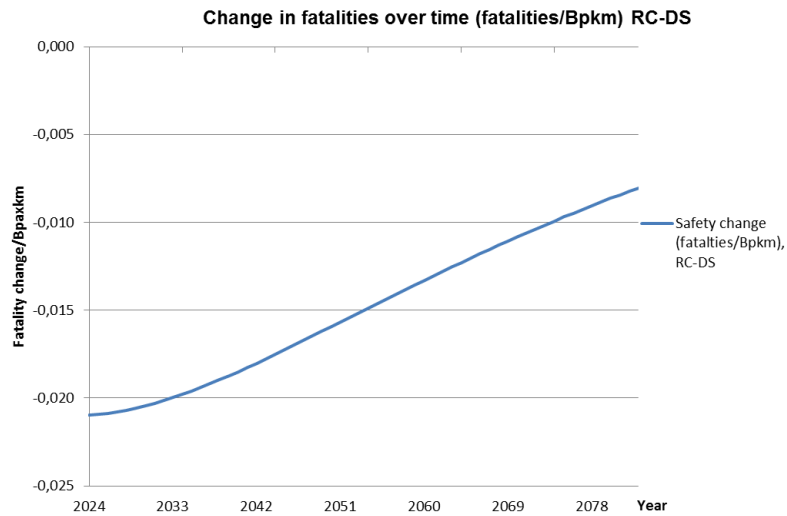


Figure 64: Change in the total safety level (fatalities/Billion passenger kilometres) over time for journeys longer than 100 kilometres in Norway if HSR is implemented on Ø2P compared to the safety level without HSR.

### 3.6.2  Results S2P- HSR between Oslo and Stavanger

If HSR is implemented on S2P the total amount of transported passenger kilometres during 40 years in Norway for journeys longer than 100 km increases from ~1464 billion kilometres to ~1493 billion kilometres.

The estimated level of societal safety for the Norwegian transport system without HSR implementation, expressed as the number of expected fatalities for the total system and for specific transport modes, is shown in Figure 65. The corresponding figures for a system with HSR implementation on S2P are shown in Figure 66.

**Societal transport safety 2024 -without HSR**
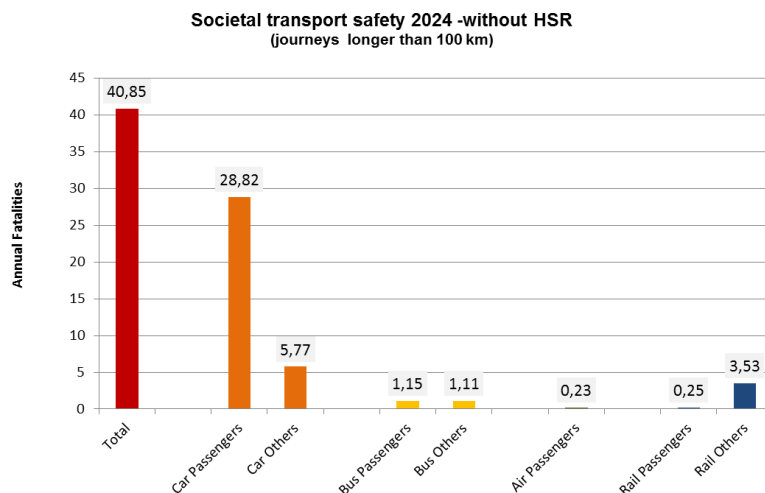**(journeys longer than 100 km)**



Figure 65: The calculated total current societal safety level of transport means in Norway expressed as the expected number of fatalities for each means of transport for journeys longer than 100 kilometres for the year 2024 without HSR.
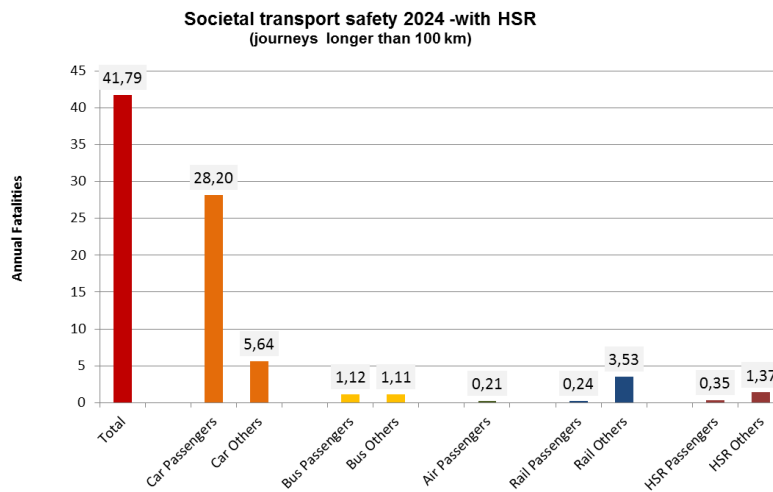
**Societal transport safety 2024 -with HSR**
(journeys longer than 100 km)

Figure 66: The calculated total current societal safety level of transport means in Norway expressed as the expected number of fatalities for each means of transport for journeys longer than 100 kilometres for the year 2024 with HSR on S2P.

As seen in the figures, the total number of expected fatalities is subject to a slight increase as a result of HSR implementation. The main reason for this is the predicted large addition of HSR transport volumes compared to the relatively limited reduction in transport volumes for other transport modes.

The change in societal safety for four studied time horizons, expressed as the expected change in the number of fatalities due to HSR implementation on S2P, is shown in Figure 67.

**Expected change in fatalities,
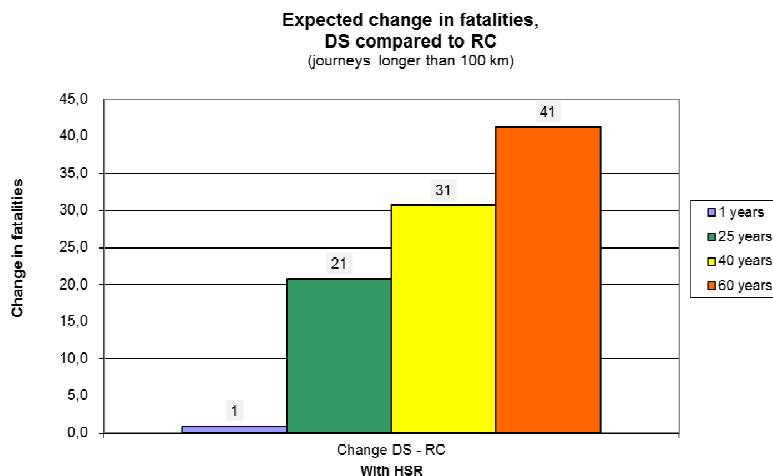DS compared to RC**
(journeys longer than 100 km)

Figure 67: Change in predicted societal transport safety in Norway (additional fatalities) for journeys longer than 100 kilometres if HSR is implemented on S2P for four different time horizons.

The expected annual change in fatalities due to HSR operation on S2P is shown in Figure 68.

**Expected change in fatalities per year,**
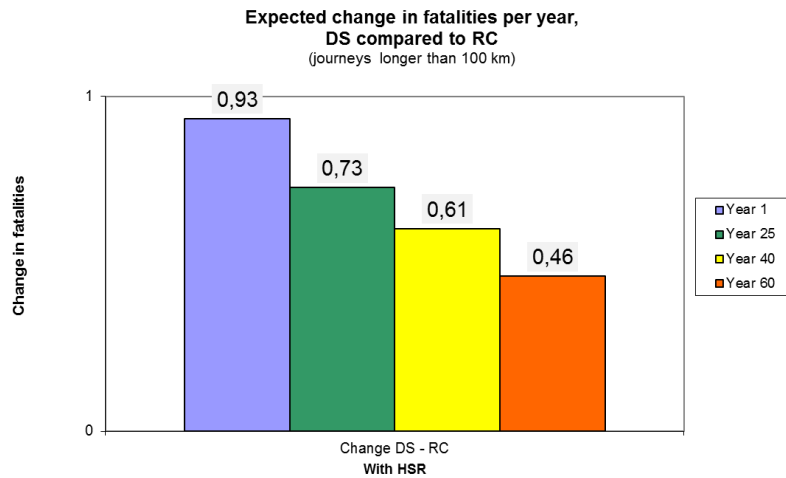**DS compared to RC**
(journeys longer than 100 km)



Figure 68: Additional fatalities per year in Norway for journeys longer than 100 kilometres if HSR is implemented on S2P for four different years.

The economic consequences of the changes in societal safety due to HSR implementation on S2P is shown in Figure 69 and Figure 70 for the four studied time horizons. The calculations are made with a VSL of 20 MNOK, Figure 69, and 26.2 MNOK, Figure 70.

**Economic consequences (net present value) of DS**
(journeys longer than 100 km)
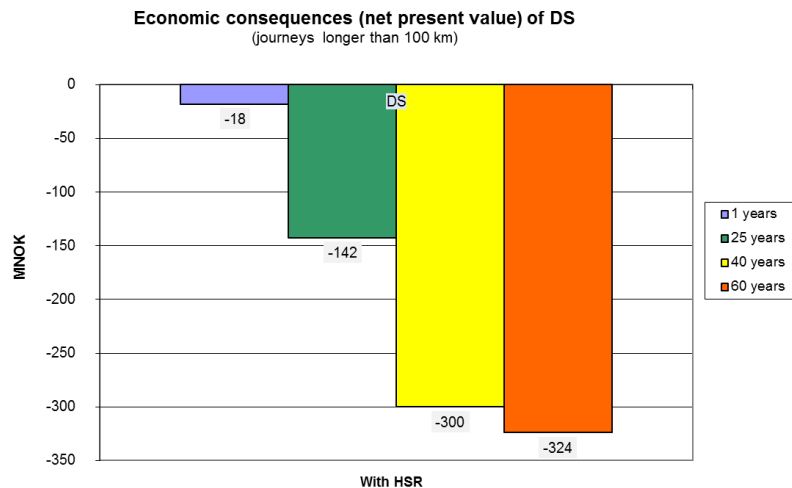


Figure 69: The economic consequences (with VSL=20 MNOK) of transport safety level changes for journeys longer than 100 kilometres with the implementation of HSR on S2P in Norway for four different time horizons.
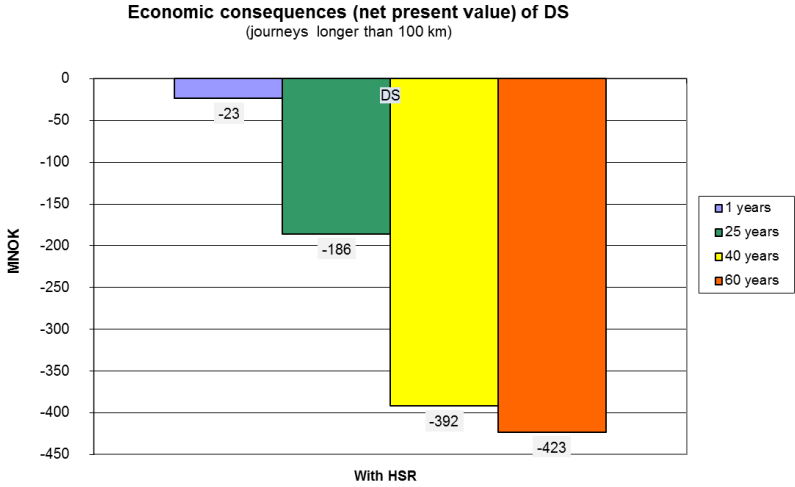
Figure 70: The economic consequences (with VSL=26.2 MNOK) of transport safety level changes for journeys longer than 100 kilometres with the implementation of HSR on S2P in Norway for four different time horizons.

The change of societal safety over time due to HSR implementation on S2P compared to keeping the current transport system is shown in Figure 71. The temporal change in the difference between the two scenarios is expressed as the total number of fatalities per billion passenger transport kilometres in the Norwegian transport system.
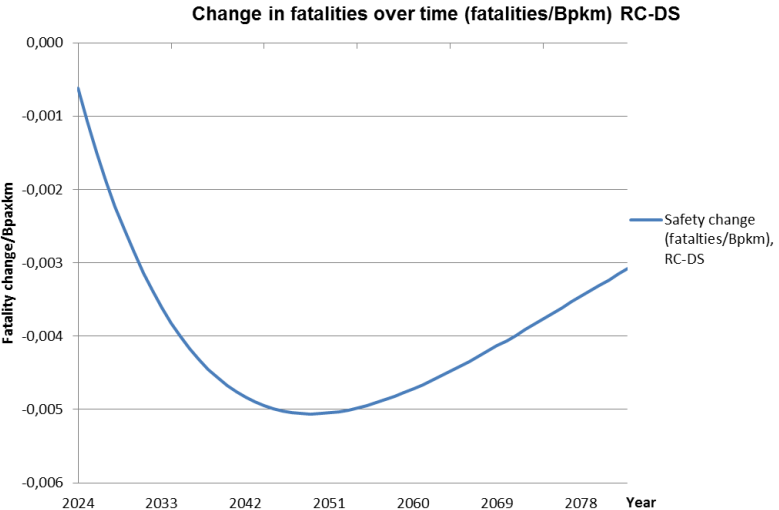


Figure 71: Change in the total safety level (fatalities/Billion passenger kilometres) over time for journeys longer than 100 kilometres in Norway if HSR is implemented on S2P compared to the safety level without HSR.

### 3.6.3  Results H1P- HSR between Oslo and Bergen

If HSR is implemented on H1P the total amount of transported passenger kilometres during 40 years in Norway for journeys longer than 100 km increases from ~1464 billion kilometres to ~1508 billion kilometres.

The estimated level of societal safety for the Norwegian transport system without HSR implementation, expressed as the number of expected fatalities for the total system and for specific transport modes, is shown in Figure 72. The corresponding figures for a system with HSR implementation on H1P are shown in Figure 73.
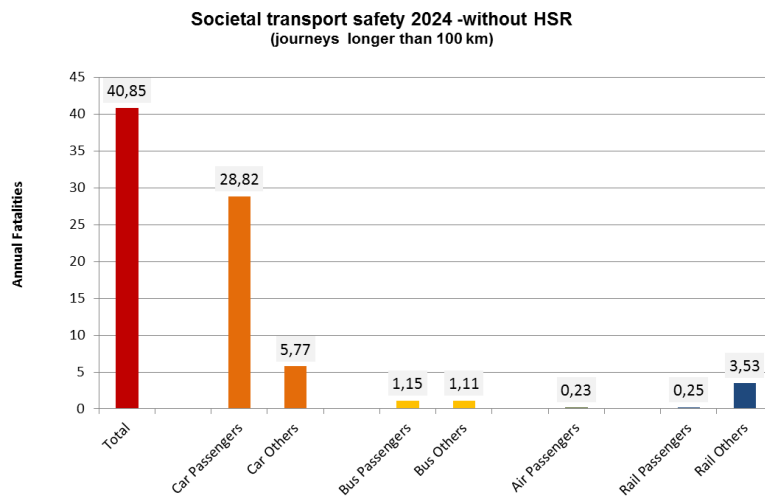


Figure 72: The calculated total current societal safety level of transport means in Norway expressed as the expected number of fatalities for each means of transport for journeys longer than 100 kilometres for the year 2024 without HSR.
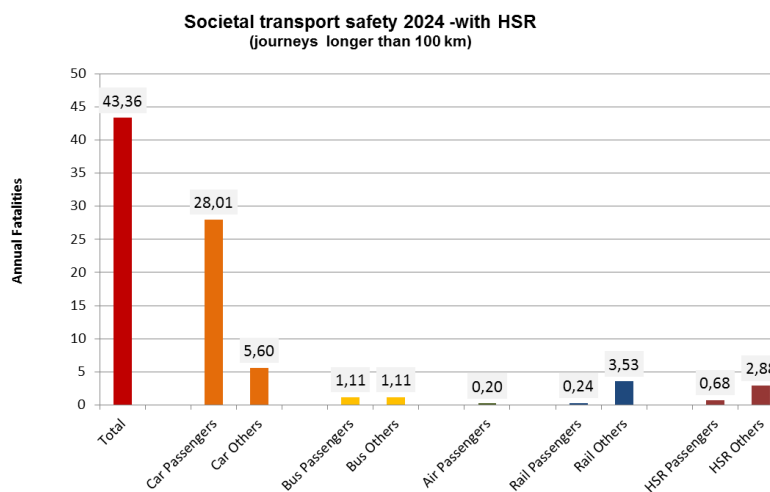


Figure 73: The calculated total current societal safety level of transport means in Norway expressed as the expected number of fatalities for each means of transport for journeys longer than 100 kilometres for the year 2024 with HSR on H1P.

As seen in the figures, the total number of expected fatalities is also for this corridor subject to a slight increase as a result of HSR implementation. The main reason for this is the predicted large addition of HSR transport volumes compared to the relatively limited reduction in transport volumes for other transport modes.

The change in societal safety for four studied time horizons, expressed as the expected change in the number of fatalities due to HSR implementation on H1P, is shown in Figure 74.
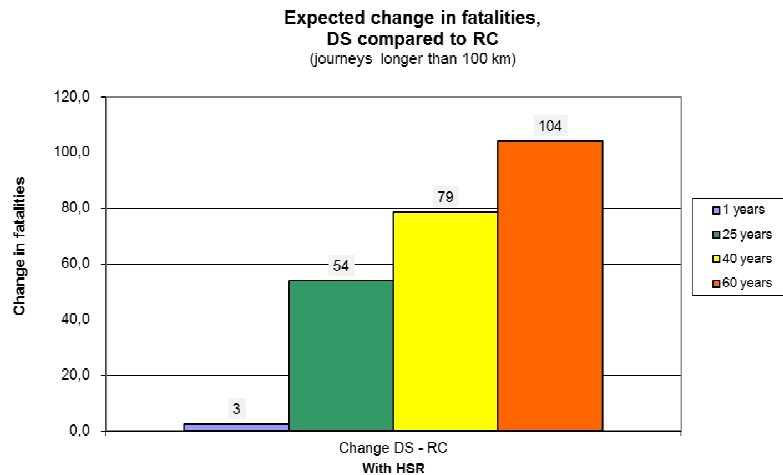


Figure 74: Change in predicted societal transport safety in Norway (additional fatalities) for journeys longer than 100 kilometres if HSR is implemented on H1P for four different time horizons.

The expected annual change in fatalities due to HSR operation on H1P is shown in Figure 75.
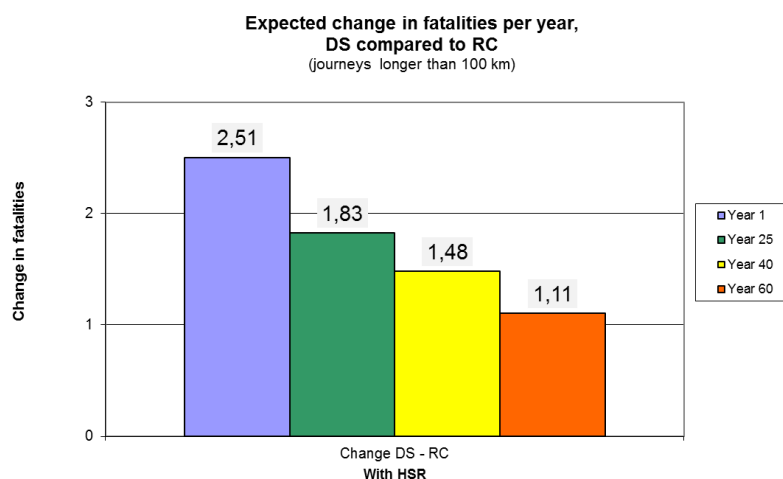


Figure 75: Additional fatalities per year in Norway for journeys longer than 100 kilometres if HSR is implemented on H1P for four different years.

The economic consequences of the changes in societal safety due to HSR implementation on H1P is shown in Figure 76 and Figure 77 for the four studied time horizons. The calculations are made with a VSL of 20 MNOK, Figure 76, and 26.2 MNOK, Figure 77.
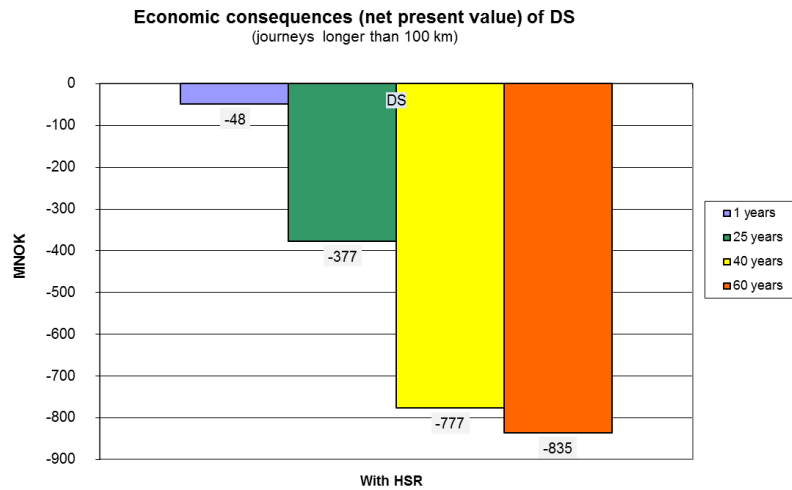
Figure 76: The economic consequences (with VSL=20 MNOK) of transport safety level changes for journeys longer than 100 kilometres if HSR is implemented on H1P in Norway for four different time horizons.
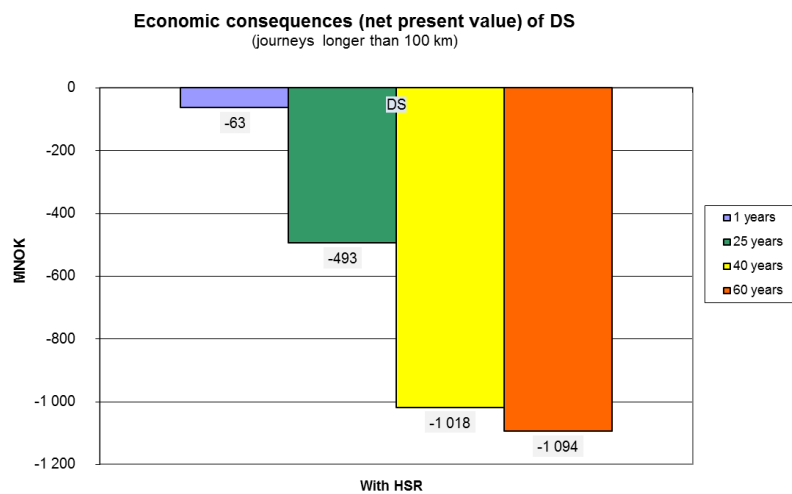
Figure 77: The economic consequences (with VSL=26.2 MNOK) of transport safety level changes for journeys longer than 100 kilometres if HSR is implemented on H1P in Norway for four different time horizons.

The change of societal safety over time due to HSR implementation on H1P compared to keeping the current transport system is shown in Figure 78. The temporal change in the difference between the two scenarios is expressed as the total number of fatalities per billion passenger transport kilometres in the Norwegian transport system.

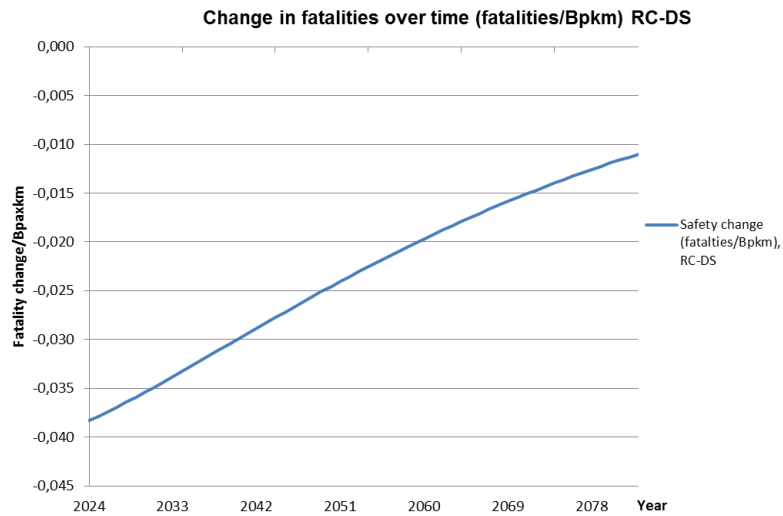**Change in fatalities over time (fatalities/Bpkm) RC-DS**

Figure 78: Change in the total safety level (fatalities/Billion passenger kilometres) over time for journeys longer than 100 kilometres in Norway if HSR is implemented on H1P compared to the safety level without HSR.

### 3.6.4  Results BS1P- HSR between Bergen and Stavanger

If HSR is implemented on BS1P the total amount of transported passenger kilometres during 40 years in Norway for journeys longer than 100 km increases from ~1464 billion kilometres to ~ 1469 billion kilometres.

The estimated level of societal safety for the Norwegian transport system without HSR implementation, expressed as the number of expected fatalities for the total system and for specific transport modes, is shown in Figure 79. The corresponding figures for a system with HSR implementation on BS1P are shown in Figure 80.
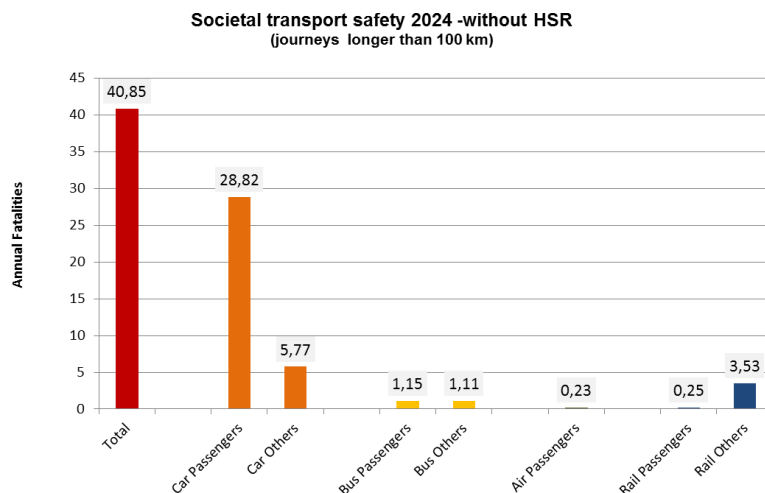
**Societal transport safety 2024 -without HSR**
**(journeys  longer than 100 km)**

Figure 79: The calculated total current societal safety level of transport modes in Norway expressed as the expected number of fatalities for each mode of transport for journeys longer than 100 kilometres for the year 2024 without HSR.
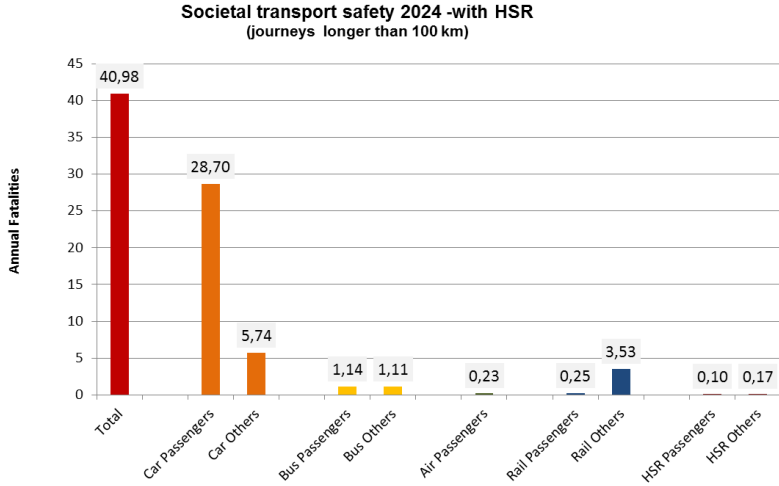
Figure 80: The calculated total current societal safety level of transport means in Norway expressed as the expected number of fatalities for each means of transport for journeys longer than 100 kilometres for the year 2024 with HSR on BS1P.

As seen in the figures, the total number of expected fatalities is subject to a slight increase as a result of HSR implementation. The main reason for this is the predicted large addition of HSR transport volumes compared to the relatively limited reduction in transport volumes for other transport modes.

The change in societal safety for four studied time horizons, expressed as the expected change in the number of fatalities due to HSR implementation on BS1P, is shown in Figure 81.
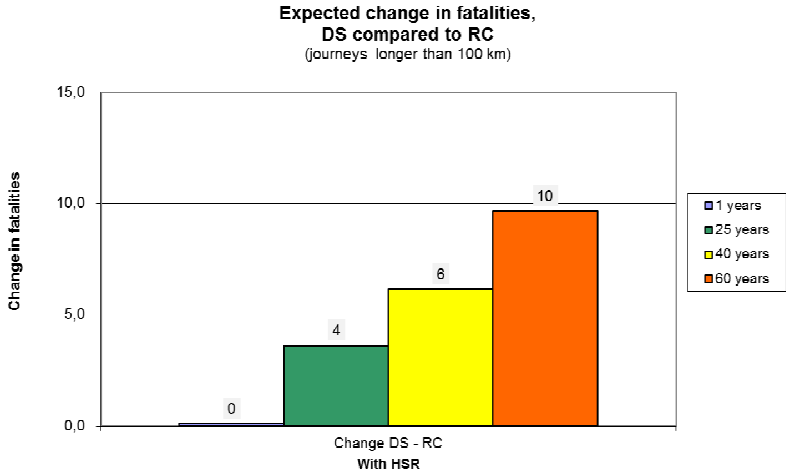


Figure 81: Change in predicted societal transport safety in Norway (additional fatalities) for journeys longer than 100 kilometres if HSR is implemented on BS1P for four different time horizons.

The expected annual change in fatalities due to HSR operation on BS1P is shown in Figure 82.

**Expected change in fatalities per year,
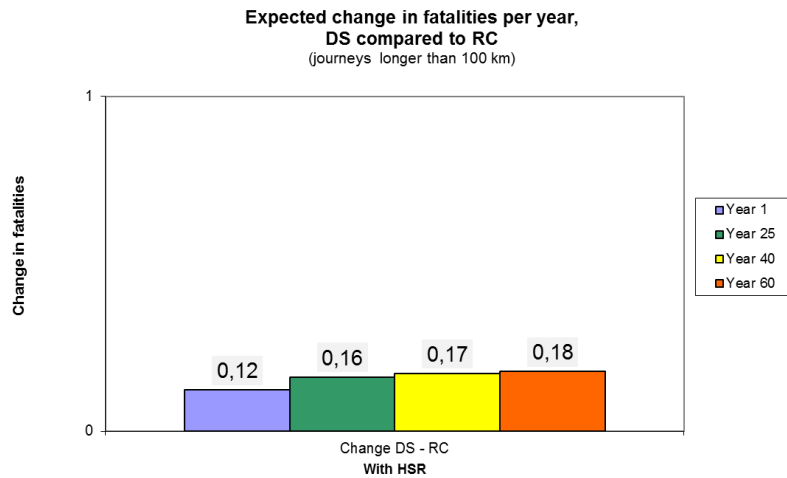DS compared to RC**
(journeys  longer than 100 km)



Figure 82: Additional fatalities per year in Norway for journeys longer than 100 kilometres with implementation of HSR on BS1P for four different years.

The economic consequences of the changes in societal safety due to HSR implementation on BS1P is shown in Figure 83 and Figure 84 for the four studied time horizons. The calculations are made with a VSL of 20 MNOK, Figure 83, and 26.2 MNOK, Figure 84.

**Economic consequences (net present value) of DS**
(journeys  longer than 100 km)



Figure 83: The economic consequences (with VSL=20 MNOK) of transport safety level changes for journeys longer than 100 kilometres if HSR is implemented on BS1P in Norway for four different time horizons.
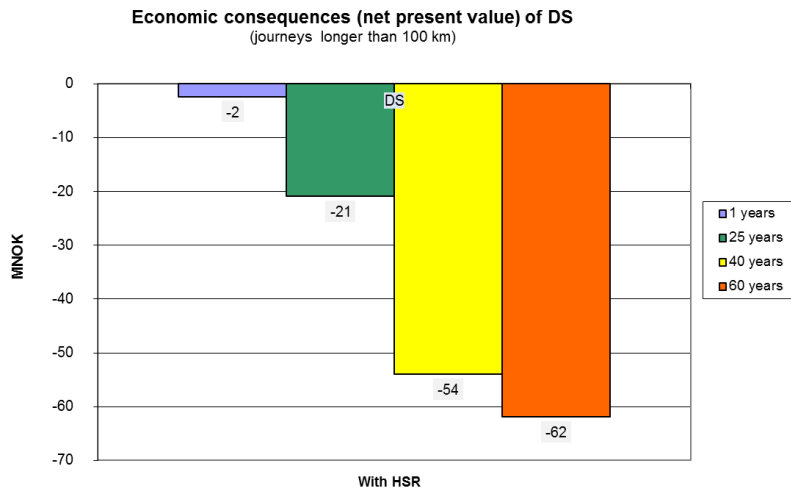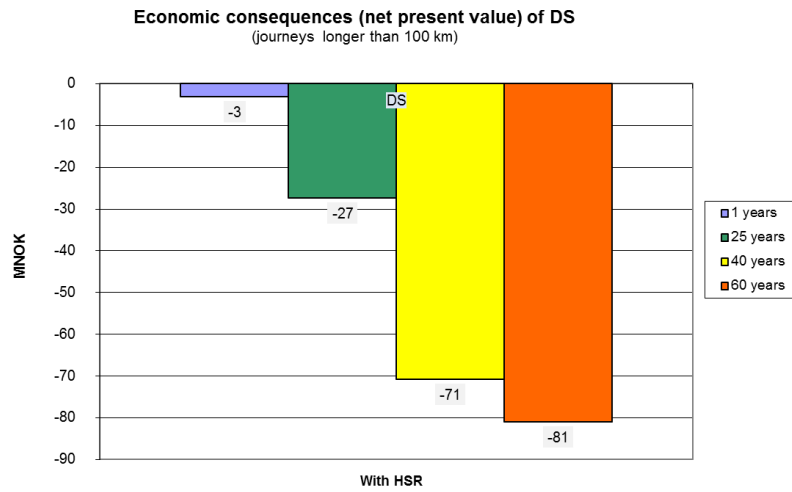
Figure 84: The economic consequences (with VSL=26.2 MNOK) of transport safety level changes for journeys longer than 100 kilometres if HSR is implemented on BS1P in Norway for four different time horizons.

The change of societal safety over time due to HSR implementation on BS1P compared to keeping the current transport system is shown in Figure 85. The temporal change in the difference between the two scenarios is expressed as the total number of fatalities per billion passenger transport kilometres in the Norwegian transport system.
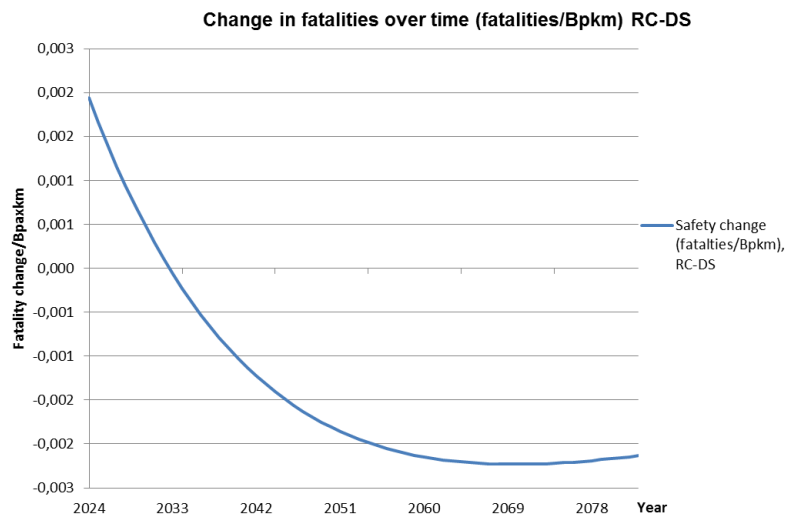


Figure 85: Change in the total safety level (fatalities/Billion passenger kilometres) over time for journeys longer than 100 kilometres in Norway if HSR is implemented on BS1P compared to the safety level without HSR.

### 3.6.5  Comparison of corridors

A comparison between the four HSR transport corridors with respect to the effects on the societal transport safety in Norway for journeys longer than 100 kilometres is displayed in Figure 86 and Figure 87. The expected changes in passenger transport volumes are shown in Figure 88. Note that all diagrams show the effects due to the implementation of HSR on single corridors, not simultaneous implementation on two or more corridors. It can be seen that the changes in safety levels and the economic consequences of these changes are directly proportional to the changes in transport volumes.



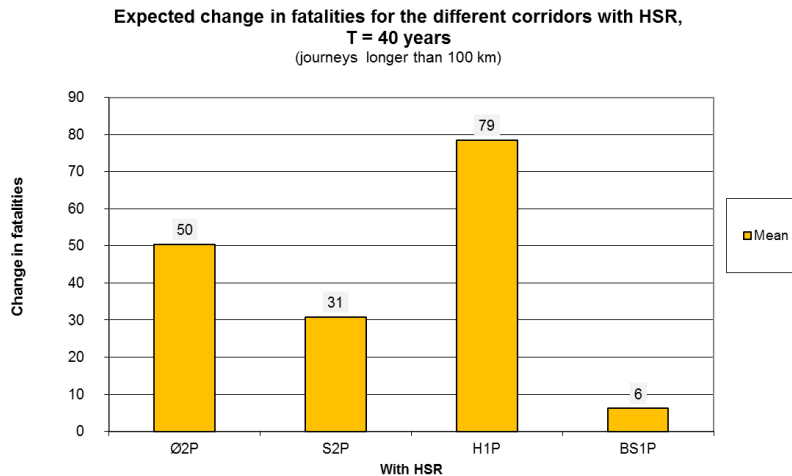Figure 86: Change in predicted societal transport safety in Norway (change in fatalities) accumulated over 40 years for journeys longer than 100 kilometres with the implementation of HSR.
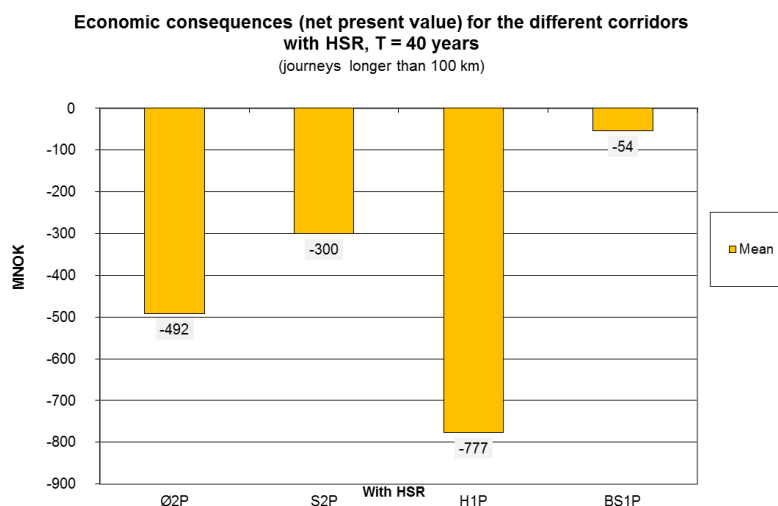


Figure 87: The economic consequences of transport safety level changes accumulated over 40 years for journeys longer than 100 kilometres with the implementation of HSR. Costs are calculated with a VSL = 20 MNOK.
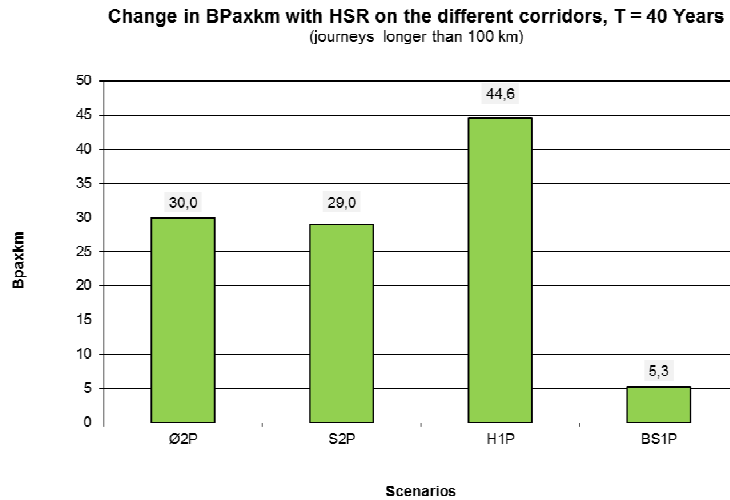
Figure 88: Change in total transported billion passenger kilometres accumulated over 40 years if HSR is implemented.

The expected change in total societal transport safety in relation to the expected change in total transport volume for the Norwegian system (no. of billion passenger kilometres) is shown in Figure 89.
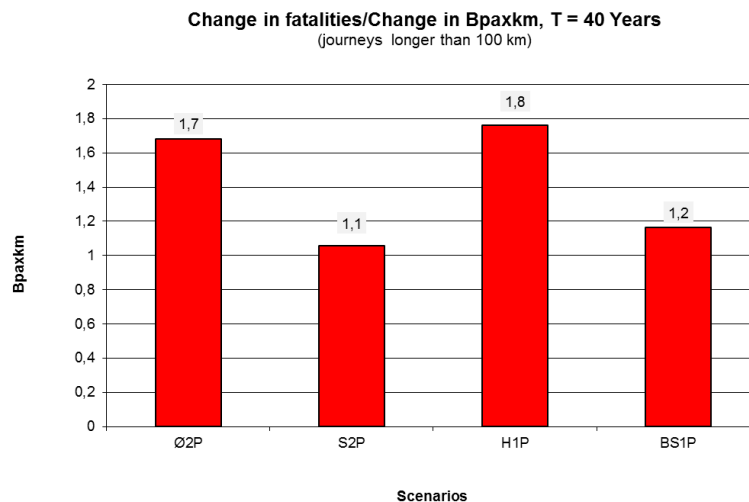


Figure 89: Change in the total safety level (fatalities/Billion passenger kilometres) over time for journeys longer than 100 kilometres in Norway if HSR is implemented compared to the safety level without HSR.

As can be seen from this figure, two of the corridors (BS1P and S2P) are associated with a higher safety level for each additional billion passenger kilometre added to the Norwegian transport system. These corridors thus exhibit a lower marginal increase in fatality numbers.

### 3.6.6  Uncertainty analysis

Uncertainty analysis was made for safety calculations for the two scenarios and for the calculations of economic consequences of safety changes. Due to the limitations of the input data, a detailed uncertainty analysis of each input parameter was not possible. Instead, all input parameters were assigned an uncertainty of ±10 % of the input value. It should therefore be noted that the uncertainty analysis cannot display the true uncertainty of the safety calculations. It should, however, provide a reasonable picture of the relative contribution of the uncertainty from the various input variable to the total uncertainty.

The uncertainty analysis presented here should be considered as generic. A more detailed uncertainty assessment of each input parameter should be performed when more detailed information on the future HSR operations becomes available. The model can be easily updated to incorporate more detailed uncertainty assessments.

The results of the generic uncertainty analysis are shown in Figure 90 and Figure 91 for the 40-year time horizon. The uncertainty analysis was performed on 10'000 Monte Carlo runs of the model. The model is structured so that uncertainty analysis can easily be made also for other time horizons but was not considered to add any substantial information to the present assessment.

Figure 90 displays the 5-percentile, mean and 95-percentile values for the safety forecasts for a time horizon of 40 years. Figure 91 displays the corresponding results for the calculations of economic consequences of safety changes.

Sensitivity analyses based on rank correlation were made for both safety and economic calculations. The sensitivity analysis identifies the variables that contribute most to the total uncertainty of the calculations. These are the most important variables to consider and collect more information about in order to perform model calculations with a higher degree of certainty.

Based on the assigned uncertainty of ±10 % of each input value of the model and the selected statistical distributions described above the variables contributing most to the uncertainty of the calculations can be shown in the sensitivity charts. Figure 92 and Figure 93 show sensitivity charts for the total safety and the economic consequences, respectively, for the H1P corridor. The other corridors exhibit similar sensitivity results, see Annex 3.  As can be seen from the sensitivity charts, the input data for the car transport volumes and safety have the largest impact on the total uncertainty of the calculations. The reason for this is that car traffic is the major mode of transport in the Norwegian transport system and thus contributes most to the expected number of fatalities in the transport system. For the economic calculations, also the selection of the discount rate provides a substantial contribution to the total uncertainty. Other variables seem to motivate less effort in order to decrease the total uncertainty of the safety model calculations.
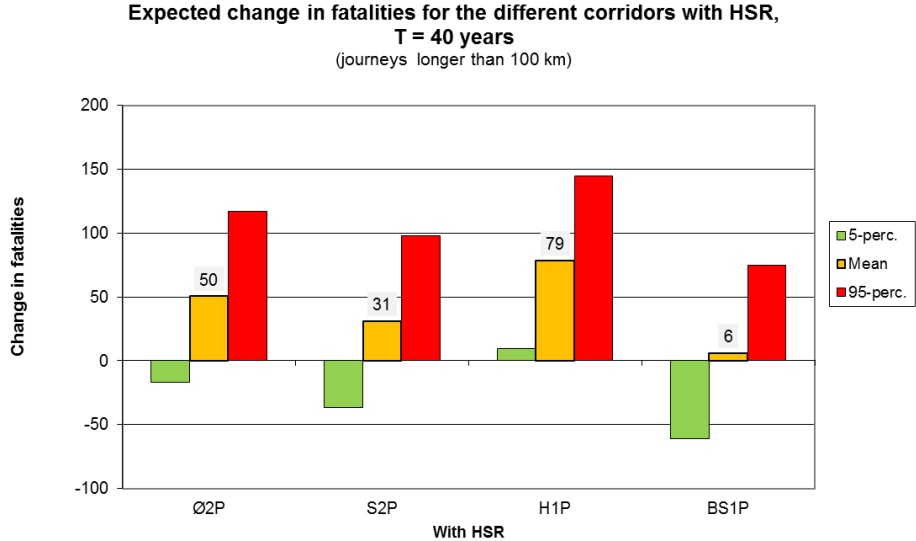
Figure 90: Uncertainty analysis of change in predicted societal transport safety in Norway (change in fatalities) accumulated over 40 years for journeys longer than 100 kilometres with the implementation of HSR on the four corridors.
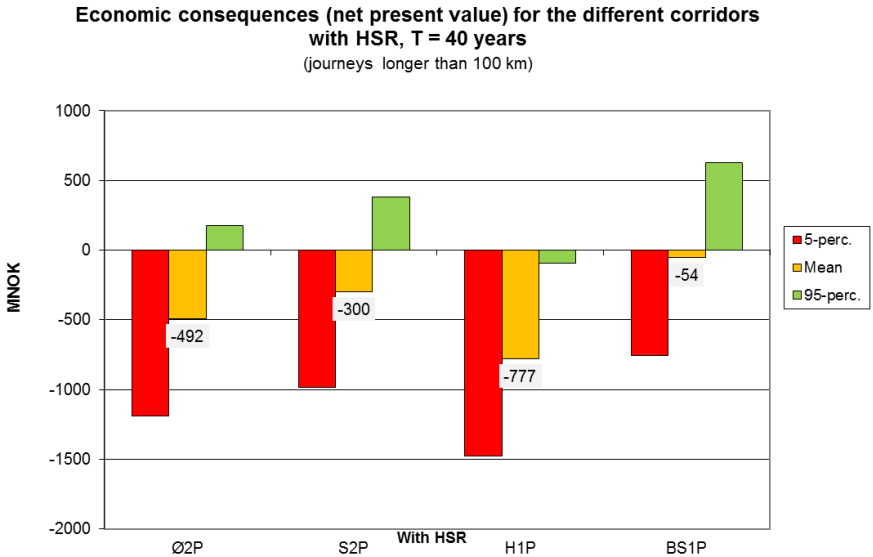


Figure 91: Uncertainty analysis of economic consequences of transport safety level changes accumulated over 40 years for journeys longer than 100 kilometres with the implementation of HSR on the four corridors. Costs are calculated with a VSL = 20 MNOK

Figure 92: Sensitivity analysis of total safety for DS – H1P during 40 years.

Figure 93: Sensitivity analysis of economic consequences for DS – H1P during 40 years.

## 3.7 Conclusion

The following major conclusions were drawn based on the study of the effects on societal safety resulting from the implementation of high speed rail in Norway:

- The change in societal safety levels due to HSR implementation is relatively limited for journeys longer than 100 km in the Norwegian transport system.
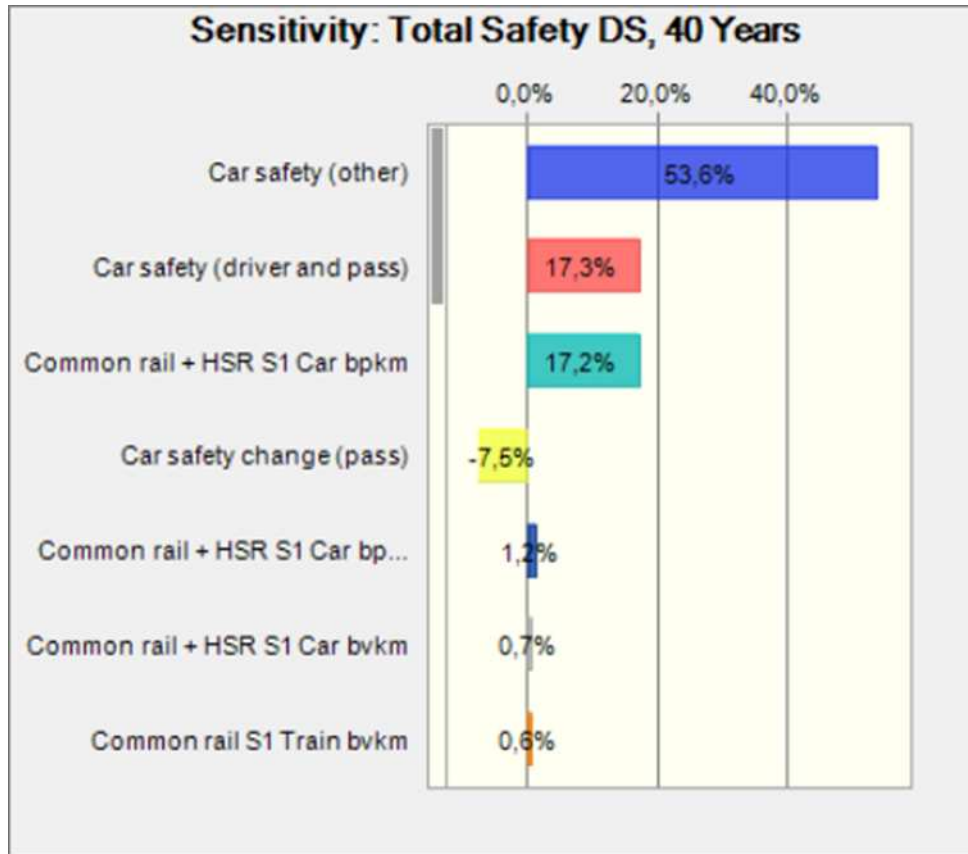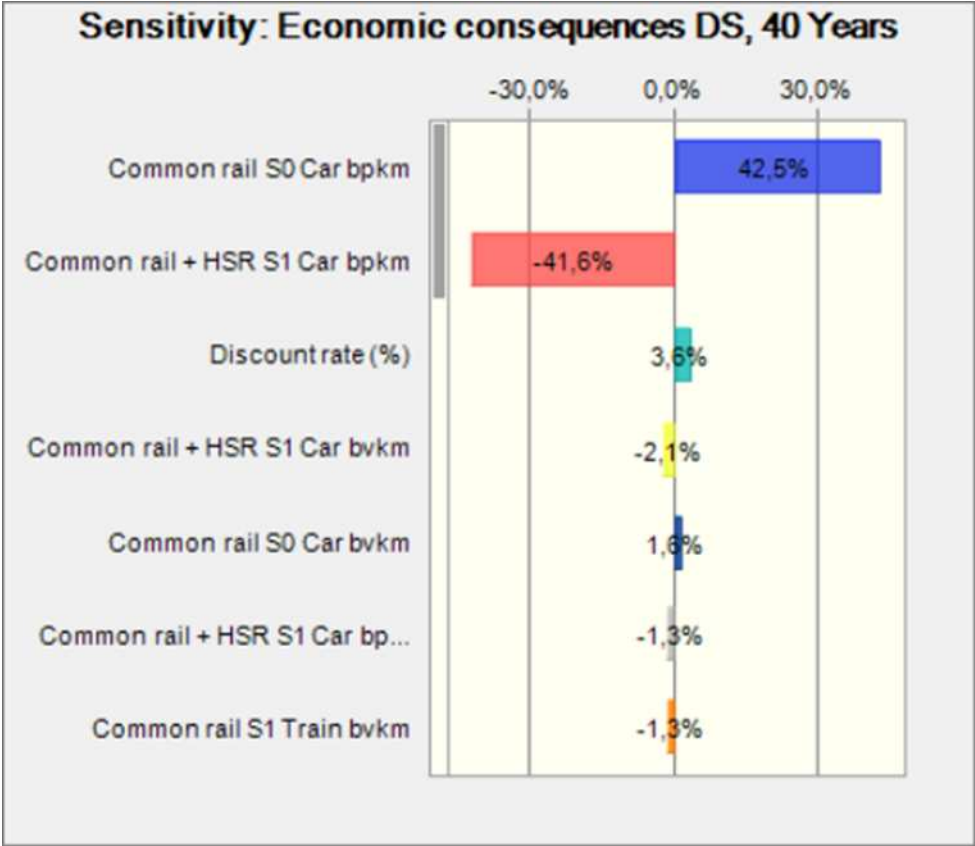
- The change in safety is closely related to the change in total transport volumes for journeys longer than 100 km. This is explained by the fact that the addition of HSR transport volumes is not much compensated by reduction in transport volumes for other transport modes with other specific safety levels (fatalities/passenger kilometre).

- The car transport decrease is predicted to be limited after implementation of HSR, whereas the air transport is predicted to be subject to a larger decrease. The car has a lower specific safety level (fatalities/passenger kilometre) than air transport and train, and air has a higher safety than train transport. Thus, the substantial transfer of passengers from air to train in combination with a substantial addition of HSR traffic results in a decrease in total safety (i.e. an increase of yearly fatalities) that cannot be compensated by the slight reduction in transport volumes for other transport modes.

- The transfer of freight traffic from lorry to rail is predicted to be very limited, resulting in only a minor impact on the total safety.

- In a comparison between the corridors, it can be shown that H1P results in the most substantial safety and economic consequences. These consequences must, however, be put in relation to other consequences of the high speed rail program and may in this perspective be rather limited.

- The implementation of HSR is predicted to lead to an increase in fatalities in the Norwegian transport system. The increase of the total number of fatalities must be put in relation to the increase in transport volumes. The implementation of HSR is expected to contribute with 1.1 to 1.8 fatalities per additional billion passenger kilometre, depending on which of the four studied corridors that is implemented. The increased number of fatalities must be put in relation to other possibilities to increase the transport volumes in Norway.

- The safety difference between a Norwegian transport system with and without HSR is small and with additional mitigation measures, that are discussed in the risk assessment report, the differences could be even smaller or even lead to a decrease in the total number of fatalities in the transport system.

- In the fatality rate calculations in the risk assessment platform accidents have been left out. Since more platform accidents occur on older trains than on newer trains the outcome would probably be favourable to HSR compared to conventional rail if platform accidents were included.

- The current model does not include ferry transport due to lack of information on the quantity of vehicle kilometres, the relatively small amounts of passenger transport and the assumption that future HSR operations will have a rather limited correlation with safety on ferries. The last statement is supported by the prediction of future transports, see section.

- The sensitivity analysis shows that the input data for the car transport volumes and safety have the largest impact on the total uncertainty of the calculations. The reason for this is that car traffic is the major mode of transport in the Norwegian transport system and thus contributes most to the expected number of fatalities in the transport system. For the economic calculations, also the selection of the discount rate provides a substantial contribution to the total uncertainty. The value used for value of statistical life (VSL) also has a significant impact on the outcomes of the economic calculations.

## 3.8 Security of HSR Systems regarding sabotage and terrorism

Sabotage and terrorism are elements which have not been included in the current assessment model due to the difficulty quantifying their probabilities and extents.

Rail transport systems are more vulnerable to sabotage and terrorist attacks than air transport systems, due to their size and extent as well as their accessibility along the entire travel paths. An overall and permanent surveillance and protection is very difficult to render, if it is not impossible.

It is conceivable that if a significant amount of travellers transfer from road and air towards high-speed rail one would have more 'easy targets' with potentially high media impact compared to the current situation, due to the possible higher occupancies and operational speeds and therefore possibly larger numbers of fatalities and attack consequences.

The protection of railway infrastructure systems is compared to aviation more extensive as railway infrastructure is spacious and includes a number of hard controllable system components:

- Railway line,
- Station areas,
- Rail operation areas (depots, shunting yards, holding siding etc.),
- Operation buildings (control centre, energy distribution stations etc.),
- Passenger trains.

Already this overview list makes it clear that a entire and complete protection of all rail system components can hardly be reached.

There have been some sabotage and terrorist attacks on HSR systems so far. Some of the notable ones were a bomb in France in a TGV luggage area and a concrete object lain on the tracks and also a bomb found on the high speed line Madrid – Sevilla [40][39]. Catastrophic consequences had the bombing in Russia on the Moscow – St. Petersburg line [41] with a lot of dead and injured persons. Only the latter of these examples has caused a significant death toll, even though the line was under surveillance by the army. However, it has to be noted that most of the "successful" terrorist attacks so far have been against commuter rail or metro systems, mostly in station areas, where significant numbers of passengers are present [41] [42] [43] [44] or against conventional railway lines like in India.

The only major differences between a HSR system and a conventional rail system are, otherwise as often assumed not the speed, but the separate tracks and corridors. Thus it is reasonable to assume that attack patterns on a high speed rail system are similar to those on a conventional rail system.

However, depending on the risk exposure preventive measures have to be taken to protect passengers and safeguard rail operation. The preventive measures are planned under consideration of their operational costs and the assessment of risk potential. Measures from different countries practise could be:

- Introducing an overall security concept including a security centre responsible for all security aspects over the entire system and lines.

This security centre should not be directly involved in traffic operations but be in permanent contact with operations personnel, and must have a global coordination and surveillance role over the entire system. It should also coordinate any emergency response.

- Ensuring permanent communication between the security centre, operation centre and the trains (redundant radio system, emergency frequency)

- Redundancy of all telecommunication and signaling systems and cables, as well as ensuring that these systems and cables are resistant to attack, sabotage and vandalism.

- Ensuring quick emergency access to all areas and tracks, in case of an accident or attack, and that an appropriate emergency response is possible, especially in remote areas.

- Applying of existing security concepts whose aim it is to prevent assaults on the station architecture as described in [45] and [46] in all stations and buildings.

- Security areas or enclosures in stations.

- Security check of baggage resp. security check equivalent to air transport.

- Access control to platforms e.g. closed ticketing system.

- Complete fencing in all high speed track sections to prevent easy access, if possible including intrusion detection.

- Fencing on bridges to prevent throw of objects on the train and to avoid suicides.

- Prevention of collisions with vehicles went astray by constructing of crash barriers / walls.

- Countries with high risk exposure are planning or operating following measures::

  o Permanent operation of patrol services (incl tracking dogs in Russia)

  o Drones to detect bombs along the line (Russia)

  o Permanent CCTV control of the line (planned in Russia)

- Preventing tampering with rolling stock when not in use.

- Coordination of measures with other countries.


With the implementation of the Task Force on Rail Security, Jernbaneverket took first step to define where rail security has to be improved based on risk exposures. Right now station areas are in the focus of discussions but with entering into the design phase of HSL the handbook for "Security on Rail" should include HSR related aspects. Support is given by the discussion and working group at UIC[47] on the subject of HSR safety and security. In addition to this the risk assessment within subject 2 provides a sound basis to develop the security handbook further. Especially by filling and developing the risk assessment with transportation data out of the corridor analysis.

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# Annexes

Annex 1      Hazard list

Annex 2      Model transport safety

Annex 3      Crystal Ball reports

**Annex 1 Hazard list**

**Annex 2 Model transport safety**

**Annex 3   Crystal ball reports**