Deliverable 3.1
Report on Global Safety Management Framework

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1 Executive Summary

The main objective of the GoSAFE RAIL Project is the transformation of asset safety in the rail sector. This report considers a Global Safety Management Framework (GSMF), which integrates risk assessment frameworks for a number of asset categories including: slopes and retaining walls, level crossings and bridges, tracks and tunnels and network flow model outputs. The framework developed within the project is fully compatible with the European Railway Agency’s Safety Management System (SMS WHEEL), and achieves improvements in railway safety management procedures by implementing the Global Safety Key Performance Indicators, KPIs, identified in Deliverable 1.1 and Deliverable 4.1 of the GoSAFE RAIL project. The Global Safety Framework will form the basis for the Network Decision Support Tool developed in WP3 of the GoSAFE RAIL project.
2 Introduction

Safe and efficient transport infrastructure is a fundamental requirement to facilitate and encourage the movement of goods and people throughout the European Union. There is approximately 215,400 km of rail lines in the EU which represent a significant asset. The safety level of much of the EU rail network is significantly lower than modern highway infrastructure. Replacement costs for civil engineering infrastructure items such as rail track, bridges and tunnels are prohibitive. Given current economic constraints and the challenges of climate change and population growth it is vital that we maintain safety levels and develop optimal ways to manage our rail network and maximise the use of all resources.

The establishment of a Single European Railway Area (SERA) was seen in the 2011 Transport White Paper as being critical to ensuring long-term competitiveness, dealing with growth, fuel security and decarbonisation in the EU. Public investment in Rail is significant, amounting in 2012 to a spending of €34bn on infrastructure (EC 2013). However, given the scale of the network and the significant challenges faced, it is difficult for owners to prioritise rail investment and a large proportion of their budgets are used for repair.

Given these challenges Rail is a safe form of transport. The European Rail Agency (2013) reported that the total number of passenger fatalities on the European rail network was 196, making rail the mode of travel with the lowest number of fatalities. Considering the data as fatalities per person kilometre travelled shows that the safety performance of the rail and air were similar and by far the safest sectors, with the road sector having a fatal accident rate twenty times higher with certain vehicles (e.g. motorbikes) having very high fatality rates.

Despite the very encouraging safety record for rail, a number of high profile failures of rail infrastructure have occurred in recent years, with the incidence appearing to increase in response to climate challenges and aging networks amongst other factors. The focus of the GoSAFE rail project is to provide a near-eradiation of sudden infrastructure failures, provide warning systems for obstructions or intruders on the network and using a sophisticated micro-simulation model allow the impact of safety decisions on network capacity to be determined.

In this report we present our concept for the development of a global safety framework to consider risk assessment across a range of infrastructure assets. The framework is fully compatible with the European Railway Agency Safety Management Systems (SMS) wheel methodology. The Global Safety Framework will have at its core an intelligent data management system. Careful design will allow data from a range of sources to be stored readily in a standard and usable format. This data will include:

1. The safety indicators - a starting point will be Directive 2004/49/EC

2. Statistical data on accident occurrence will be collated corresponding to the safety indicators.
3. As a result of the training of the artificial intelligence models the safety indicators will be updated.

The Railway Safety and Interoperability Directives (Directives 2004/49 and 2008/57/EC) divide the railway system into a number of 'structural areas' (infrastructure, energy, control-command and signalling and rolling stock subsystems) and 'functional areas’ (the operation and traffic management, maintenance, and telematics applications subsystems).

The GoSAFE RAIL Global Safety Management Framework is focused on the structural areas of the railway system, specifically on the railway infrastructure, which is under responsibility of infrastructure managers (IM), as shown in Figure 1.

![Diagram of railway infrastructure](image)

**Figure 1: Parts of the railway infrastructure**
3 Global Safety Management Framework

3.1 Introduction

Infrastructure maintenance planning is traditionally developed based on the infrastructure managers' observations, judgments and choices which are derived by available budgets, planned schedules and abrupt failures. Though, maintenance based on these drivers very often leads to undue maintenance and increased cost, and consequently with safety problems. Maintenance decision-making in railways is a difficult task due to a widespread network of diverse infrastructure objects (e.g. tracks, bridges, switches and crossing, tunnels, electrification system, etc.), availability demands, possession time, deterioration rate and budget constraints. Such infrastructure maintenance requirements pose decision-making dilemmas to the infrastructure managers, where maintenance planning is challenged by the number of conflicting issues. For instance, demand to keep the network available conflicts with increasing rate of deterioration, limited budget vs. aging network, the risk of failures vs. traffic intensity over an asset and so on. For this reason, predictive maintenance is considered to be a most effective maintenance policy that suggests to perform maintenance ahead of reaching performance thresholds and reducing risks related to infrastructure and operational safety. Therefore we are suggesting the implementation of Global Safety Management Framework (GSMF) into the railway management procedures and decision making processes. In the next chapters the structure and processes as parts of GSMF are explained.

3.2 GSMF Structure

This document introduces the conceptual GSMF, which should be integrated in the decision making processes, shown in Figure 2. The conceptual framework outlines the information flow and integration of data and models, such as reliability assessment, risk assessment and whole life cycle model. The suggested GSMF aims to assist rail infrastructure managers in following ways:

- To provide the central data repository of asset registers (geometry, location, etc.),
- To integrate KPIs related to the current condition, maintenance records, failure history, processed sensor data as well as storing the dynamic data, generated as a results of different analysis, for later use
- To implement the reliability-based assessment models and life cycle cost models on the object level
- To integrate risk assessment model based on the hazard scenarios and network effects
- To link between traffic flow model outputs, which makes estimations of traffic disruption impacts based on the planned and unplanned maintenance activities
- To assist in maintenance decision making by recommending maintenance treatments and maintenance plans as a result of following the procedural flow of defining the scope, objective(s) and budget, selecting the assets on network, analysing the assets
state by probabilistic models and risk assessment framework, and prioritizing assets based on defined objectives by using the methods of multi-criteria decision analysis.

![Figure 2: Railway maintenance decision making procedure](image)

The proposed GSMF supports the decision-making processes, by implementation of a decision support tool (DST), which should have high interactivity with decision makers. Therefore, The DST should be able to interact at various levels, e.g. to overview assets’ risk level, or to execute various what-ifs scenarios, etc. In Task 3.4 the DST will be developed, as an integrated computerized system, which consists of many building blocks that support investment and maintenance decision making. Each of these blocks will have dedicated functionality, demand specific data inputs, and provide explicit outputs either directly to users or other building blocks in the pipeline. In this report, the GSMF outlines the information and interaction flow among these modules, which will be implemented later into DST.

### 3.3 Information Flow

In this section, the information flow between the different stages of the decision making process is outlined in order to integrate development of these modules in DST. Figure 3 outlines the information flow of all components of the GSMF. In the following, the details of how this information is integrated for each module is provided:

- **An Information Management System (IMS)** will be developed which acts as a central database repository for all the other tasks of project. The IMS provides the input data to all the systems and techniques being developed and stores their final output.

- PIs need to be regularly collected, either through monitoring data or visual inspection and on-site testing, in order to have current condition of all objects on the track. Numerous PIs should be translated into KPIs, which will be used in the further assessment models.

- Reliability-based assessment of each asset needs to be performed. For most of the structures the assessment is currently still based on visual inspection and condition
rating. The aim is to develop reliability (probabilistic) based assessment models, which should deliver more accurate outputs about the capacity and time-dependent assessment of the structural performance. In addition to the link with IMS block, the output of these modules provides inputs to compute whole life cycle cost analyses and risk assessment.

- A risk assessment methodology takes into account the probability of failure multiplied with the consequence of failure quantified into monetary value. The probability of failure is based on the reliability assessment of the assets. To estimate the consequences on network operations in case of failure, the input from the traffic flow model is provided, which gives the estimation of delays caused by different interruptions.

- Whole life cycle cost analysis model is analysing the application of alternative maintenance regimes on railway infrastructure to estimate the cost, risk and operational effect. Like others, this module is interrelated with other steps in the decision making process.

- To integrate all the modules into the decision making process at the agencies, an integrated computerized Decision Support Tool (DST) will be developed that is able to integrate reliability based assets assessment, risk assessment methodology and whole life cycle cost analysis. The final goal of this step is to enable the user interaction with DST, to execute what-if scenarios for the maintenance planning and investment decision-making. The DST will use railway assets data and computed values from models stored in IMS. It is important to mention that, in addition to execute what-if scenario and facilitating in overall maintenance planning, the DST will aim to provide separate outputs to the users generated from all computational models (reliability, risk and LCC models). For instance, GIS map of reliability based assessment, a GIS risk based map and a map of suggested maintenance alternative for each assets will be created as an output from DST.
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Figure 3: Global Safety Management Framework
The IMS refers to a software program that is designed to store, organize and retrieve information. The purpose of the IMS is to provide a central data repository of all the data of network assets to fulfil the data needs in maintenance planning and decision-making procedures. To develop such a domain-specific IMS requires in-depth domain knowledge and this is developed through serious of interviews and interactive workshops.

3.4 Reliability Assessment Framework

The probability based multi criteria performance optimisation technique will form a key input to the risk assessment framework and ultimately, the DST. The methodology is described in Figure 4.

The process starts with the determination of the critical limits states. This should be performed by a competent engineer using advanced analysis techniques (Connolly, et al., 2016). Probabilistic modelling need not be performed at this stage. The next step is to define the required reliability index. Stochastic modelling of the load and resistance variables is then performed, and this can be based on reported probabilistic models in the literature, as a first pass. Next, the reliability index is calculated for the system in question, for each limit state assessed. This should ideally be done with a combination of simulation, FORM and/or SORM analysis.

Should the reliability index and/or risk be found to be within acceptable bounds, a sensitivity analysis should always be performed to identify critical variables and ensure that the analysis is not overly sensitive to any variable, as this can indicate an overly simplistic analysis. Should the reliability and/or risk be found to be unacceptable, the analysis should be performed again, incorporating additional information. This is where the monitoring information feeds into the overall methodology. Consideration of monitoring such as strain measurements, vibration, water content or other site testing allows a much more accurate calculation of the reliability, and will often show the infrastructure to have significantly greater capacity that previously calculated. The information can be considered stochastically in the analysis using maximum likelihood estimation of distribution parameters or Bayesian statistical updating of the previously calculated statistical models.

Should the risk still be found to be unacceptable, repair and remediation strategies can be considered in the reliability and/or risk domain to optimise their design. Finally, probabilistic deterioration models were also developed in order to consider, for example, structural steel pitting corrosion and deterioration in the strength of engineered slopes.

At present, Infrastructure Managers make safety critical investment decisions based on poor data and an overreliance on subjective visual assessment. Therefore, their estimates of risk are highly questionable. The probabilistic methodology developed for hazard assessment allows an accurate calculation of the failure probability which provides a much more reliable calculation of risk.
The probabilistic modelling of the input variables relating to both load and resistance provides a robust platform to apply monitoring and testing information, where the uncertainty can be accurately quantified. This also allows for a much more accurate calculation of the reliability, providing Infrastructure Managers with greater levels of certainty in risk-based decision making.

System-based analysis has been considered, allowing decision making to be based on the risk level of individual elements or the entire object (e.g. a bridge) and across a wider section or network (e.g. a series of slopes along a line). Finally, the advanced engineering analysis techniques used in conjunction with stochastic modelling allows remediation strategies to be designed in a manner that can optimise both cost and safety.

### 3.5 Whole Life Cycle Model

A Whole life cycle model (WLCM) allows the user to evaluate the life cycle costs of a range of possible alternative maintenance strategies. Thus allowing an infrastructure manager to optimise spending of maintenance budgets across a network.
A key driver for maintenance decisions is the deterioration level and rate of an object. For maintenance planning purposes two approaches can be adopted:

1. A corrective strategy where maintenance is planned after a certain amount of damage has occurred, or:
2. A preventive approach aims to plan maintenance so as to prevent unacceptable damage from occurring.

In practice, often a combination of both strategies is followed, aiming for an optimal balance between costs and performance, see Figure 5a. A good understanding of structure condition and future degradation is necessary for this optimisation, as shown in Figure 5b.

![Figure 5: a) Optimization of Maintenance Costs; b) Life cycle performance](image)

An overview of the whole life cycle cost analysis process is shown in Figure 6. The model includes interactive facilities, which enable the user to:

- Select the region to be considered in the what-if scenarios. This could be a line, a sub-network of interest or the entire national rail network. For the selected region the IM can choose one or multiple asset types for analysis e.g. rail track, bridges, earthworks and switches and crossings.
- The parameters of the analysis, e.g. the time period and discount rates can be defined etc. Two types of analysis periods are considered; a whole life cost analysis period, used at the scheme level to calculate the whole life costs associated with any identified maintenance option for an asset category and a network analysis period, used to analyse total annual budgets for the network under consideration. The scheme period is typically 40 years while the network period is shorter at about 5 years.
The WLCM imports data related to infrastructure assets from the IMS and for each of the infrastructure category, this includes:

- Condition state (in our case ideally based on reliability analysis)
- Maintenance options and the condition thresholds at which these should be implemented
- Deterioration rates to allow the change in condition with time and use to be determined;
- Costs of the different treatments and the durations (i.e. the time taken to carry out the treatments)

Having compared the current condition to the threshold value (for a given ‘look ahead’ period e.g. 2 years) maintenance schemes that combine assets in ‘poor condition now’ with assets expected to reach ‘poor condition’ within a short time (thereby avoiding maintenance schemes in close proximity within short timeframes) are determined. Considering budget constraints it is therefore important to identify those maintenance works that will give the best value for money from the available budget. To enable this, two options are generated for each identified scheme:

- ‘Do Something’ option: this represents the engineering solution based on the condition state and intervention rules;
- ‘Do Nothing/Do minimum: ‘Do Nothing’ represents the postponement of the identified Do Something’ treatment by one year; where the postponement is not...
possible because the condition is below permitted functional levels set on the grounds of safety, the ‘Do Minimum’ option represents the minimum activity required to ensure the asset is safe to use until the next time maintenance is considered, e.g. this could be an increase in the frequency of inspections and/or the application of speed restrictions.

The future costs associated with the two options are calculated by simulating the condition response including the deterioration relationships. The condition is assessed on an annual basis and when a maintenance intervention is carried out the condition is ‘reset’ as appropriate. The indirect costs resulting from delays to passenger and freight (e.g. due to increased journey times) and changed emissions (e.g. due to different speeds, journey lengths) are calculated by the traffic flow model. The residual value of the asset (i.e. the value at the end of the analysis period) is calculated and the difference between this value and the original asset value can be used to define the benefits associated with the investment (cost).

The ability of the WLC to examine the whole life costs of alternative maintenance strategies of not just individual asset types but to also take into account the interaction between the different asset types has the potential to support effective decision making and deliver better overall value for money from the investment into the management of the assets.

### 3.6 Risk Assessment Frameworks

The risk for a given asset is calculated as the product of probability of failure and consequences so that the risk related to assets of different types is comparable. The risk values will be calculated on the object level, e.g. for track, switches and crossings, earthworks and bridges for different condition / reliability levels. The product of the probability and consequences will result in the risk in monetary units related to each state of each object. For the successful application of the risk models, close collaboration between experts involved in the assessment process is needed, due to the interrelatedness of all modules in the framework.

For all the classes of assets, i.e. track, switches and crossings, earthworks and bridges, the states for each class should be defined taking into consideration the possible interventions to be executed in each state and the effect the maintenance options considered by WLCM. Where applicable, data concerning the cost of restoration and the network disruption will be used in the estimation of the consequences related to each asset state. Regarding the track, the state definition of a track section will reflect the condition of the different track elements, e.g. rail, ballast and sleepers condition, failure history. The risk model will, therefore, consider track states that comply with the thresholds regarding track maintenance defined by the owner. Regarding the switches and crossings, the risk model may use the data with respect to the classification of switches and crossings in different types, the condition score, the ultrasonic score, the maintainability score, the duty score, the escalation potential scores and the computation of the combined risk score. Regarding the earthworks, the risk model will use the baseline probability, the hazard value probability for each state of each earthwork, the four vulnerability factors and the final vulnerability factor of each earthwork, for the estimation of
the probability and consequences of failure related to each state of the earthworks, as described in (GDG, 2014).

The cost of preventive maintenance interventions, and the risk of asset failure, including the execution of restoration interventions, both in monetary units, will be used in the DST for the selection of preventive maintenance interventions.

3.7 Example of risk model applied on slopes

The main aim of the model is to determine a relative risk value for each cutting and embankment asset. These risk values are used to rank the assets in order to identify the most critical ones. The risk here is defined as a product of hazard and consequence, as defined in Varnes (1984). Hazard is defined as a likelihood of failure (landslide) on each asset. Consequence describes the impact of a potential landslide occurrence to the train operations. More specific, hazard only represents the susceptibility of an asset to failure without taking account of the asset’s setting, line characteristics etc., while consequence introduces other parameters on which the level of potential impact relies, such as proximity of asset to the tracks, train frequency on that line, etc.

In this tool, hazard is calculated as a product of two separate hazard analysis steps, the first one involving objective slope stability calculations and the second one introducing the influence of subjectively described slope observations, dubbed Degradation Factors. Each step results in a single numerical value. Similarly, a consequence value is calculated in the standalone step. Final risk result for each is then calculated as presented in the Equation 1.

\[ R = H \times C = H_1 \times H_2 \times C = \beta^* \times DF_{TOT} \times VF_{TOT} \]  \hspace{1cm} [1]

Where R is risk, H is hazard, C is consequence, H_1 and H_2 are first and second hazard step respectively, \( \beta^* \) is baseline reliability index (final product of hazard’s first step), DF_{TOT} is a product of all Degradation Factor weights (final product of hazard’s second step), and VF_{TOT} is a product of all Vulnerability Factor weights (final product of consequence analysis). The graphical representation of risk process is shown in Figure 7.

- **Hazard Analysis – Step 1**

In the first step of the hazard analysis, probabilistic limit equilibrium (2D) calculations for each asset are performed. The calculations simultaneously calculate three failure modes for each asset: shallow translational slide, deep rotational slide, and rock wedge. Inputs for this calculation are assumed to come from the infrastructure manager’s (IM’s) asset database and include geometry (slope height, slope angle, adjacent angle etc) and geotechnical properties attached to the soil type of each asset stored in the same database. The input data is described probabilistically, i.e. a mean value, coefficient of variation and distribution type are assigned to each variable.
The outputs of this step are the baseline *reliability index* (β) and baseline *probability of failure* (P_f) (two correlated measures, meaning that any one of them can be used for expressing the hazard).

Figure 7: Diagram of risk model’s risk calculation process

- **Hazard Analysis – Step 2**

The hazard calculations carried out in step one are based only on the slope geometry and geotechnical characteristics. In reality however slope stability depends on a much larger number of factors such as the drainage type and condition, vegetation cover, presence of weathering and erosion, etc.; all with varying degrees of influence. For that reason, the second step of the hazard model introduces the contribution of qualitative expert judgment. The twenty-one most important qualitative earthwork features are identified and their influence to slope stability quantified through assigning a numerical weight to each class (input option) of each feature (called Degradation Factor). The product of weights for each DF, which depends on the combination of features unique to each slope, is multiplied with the baseline reliability index (β*) from the Hazard Step 1 to obtain the hazard reliability index (β_H), see Equation 2. Where DF_TOT is a product of weights of each of 21 DFs.

\[
\beta_H = \beta^* \times DF_{tot} = \beta^* \times \prod_{i=1}^{21} DF_i
\]  

**Consequence Analysis**

From the relative risk ranking viewpoint, the consequence assessment considers the impact of potential landslides on the safe operation of railway operations. This depends on two main characteristics: the ability of landslide to reach the tracks and interfere with a train and the importance (or volume) of traffic on the affected section. Following this approach, four main
features (called Vulnerability Factors) that exhibit influence on the vulnerability of line operations with regards to a landslide originating on the nearby earthwork asset were identified: clearance, line speed, train frequency per day and number of tracks. Each class of each VF was assigned a numerical weight using expert judgment. The total vulnerability factor ($V_{\text{tot}}$) is then obtained as a product of appropriate vulnerability indices for each factor.

- **Risk Calculation and Results**

The final risk value for each asset is obtained as a product of its hazard and consequence values, described in Equation [3]:

$$\beta_R = \beta_H \times V_{\text{tot}}$$  \hspace{1cm} [3]

The risk reliability index $\beta_R$ can be used as a risk value $R$ or it can then be transformed into the ‘$P_f$-based’ value.

The list of risk results describes a single point in time. The results are open to constant change in future given the update of an IM’s asset database inputs following the new rounds of visual inspections, the implementation of monitoring or investigation, potential maintenance/remediation scenarios and subsequent re-run of the tool. It should also be reiterated that risk values obtained in the tool present only a relative measure between assets for ranking purposes and do not imply to any absolute level of risk of using the transport network.

### 3.8 Traffic Flow modelling

To run the traffic flow model developed three kind of input data are required: infrastructure, rolling stock and the existing timetable. Infrastructure consists out of track topology containing attributes like speed limits, gradients, signals. Rolling stock is specified by the so called tractive effort diagram and deceleration functions. Furthermore, the length and the weight of each train set is considered in the running time calculation. Timetable specifies arrivals and departures for all scheduled trains. Additionally, restrictions caused by any maintenance work have to be specified by the location between two main signals, the related time slot and the operational consequence (closure or slow speed zone at any certain limit). In comparison to state of the art in microscopic simulation tools Kronecker Algebra is applied to find optimal solution in terms of punctuality and energy consumption. Therefore the results of the traffic flow model guarantee a deadlock free solution while an Infrastructure Manager can still set priority only on punctuality or only on energy consumption or any combination of both parameters.

In today’s practice, decision-making on maintenance work is often done without looking on the operational impact or at least in a simplified manner. Of course, the impact of one single slow speed zone might be limited but the sum of all slow speed zones along a train run might sum up to a level which cannot be compensated by running time reserves. Using the script
mode of OpenTrack would even allow today to send automated requests from the DST to a traffic flow model to run several simulations to evaluate operational impacts of maintenance works in a larger scale. That feature would help to significantly improve the quality of timetabling during maintenance work. For real time application the speed profiles calculated by Kronecker Algebra should be provided to train drivers to save energy even under harsh conditions and to achieve a minimum of delays.

3.9 Decision Support Tool Development

To develop a holistic management tool, a few functional requirements of the DST are defined. The final version of the DST should be able 1) to support basic create, read, update, and delete queries on assets static and dynamic data, 2) should locate all the assets on the network via GIS model, 3) the models of reliability-based assessment, risk assessment, whole life cycle cost assessment should either be implemented as a part of DST, or DST should be able to send service request(s) to these models, if deployed independently, 4) should support budget planning and maintenance planning, 5) enable the what-if scenarios and finally 6) should be able to report in variety of formats. Following the requirements of DST, this section outlines the DST design and development details. The system architecture of the DST provides the conceptual model to define the structure and components of the system that will work together to provide the functionality as a whole. The DST is based on the logic provided by the GSMF. As stated earlier, each of these models have to interact with each other to provide the output. In order to deal with the involved complexity while implementing these models, the DST is structured in three-tier architecture style where the separations of concerns is introduced by data layer, application layer and presentation layer.

Figure 8: DST System Architecture

Figure 8 shows the DST system architecture. The data layer provides the functionality to interact with database. In addition it authenticates and validates all the data that is created to be stored in the database. The application layer is where the main decision logic is
implemented. It is important to notice that not all of these models will be implemented in the DST, but some models developed as stand-alone tools where the DST will send a request call with input and receive output. For instance, the DST will be able to send request to traffic flow model to run simulations in order to evaluate operational impacts of maintenance works on the network performance. Finally, a presentation layer implements the logic to provide the user interface to the user. This also includes the input console to define the decision questions by infrastructure managers as well as the GIS interfaces to locate and select the assets on network by their functional locations.
4 Safety Management System

4.1 SMS wheel

Railway Undertakings (RUs) and Infrastructure Managers (IMs) are responsible for safe operation according to the Railway Safety Directive 2004/49/EC, Article 4(3) which is why they are required to establish, conduct and continuously improve their Safety Management System. The purpose of the SMS is to provide guidance for reaching organisations business objectives safely regardless of challenging environmental impacts. The Safety Management System (SMS) plays a central role in the EU safety regulatory framework and is a cornerstone of the safety of the railway system in the EU.

Recognising that designing and implementing an accurate SMS is a challenging task for the railway companies, the European Railway Agency’s produced the Safety Management Systems (SMS) wheel as a framework in designing and implementing their SMS and to the National Safety Authorities in assessing the SMSs and supervising the safety performance. SMS Wheel provides information to establish SMS in a certain company for managing safety which contributes to the effective design, planning, delivery and control of railway operation, as part of a company’s business. It covers core railway activities outlined by the Railway Safety Directive 2004/49/EC.

The main objective of the GoSAFE RAIL Project is transformation of asset safety in the rail sector. The approach is fully compatible with current risk assessment approaches such as RAMS and the safety management systems (SMS Wheel) developed by the European Railway Agency. By developing a real-time Safety System the project aims for a near eradication of sudden (brittle) failure of infrastructure assets. This deliverable is aimed to provide a Global Safety Framework which is based on the Performance Indicators (PIs) and Key Performance Indicators (KPIs) provided in Deliverable 1.1 Report on Global Safety KPIs. Global Safety Framework is to be fed in a Network Decision Support Tool in WP3.

The SMS Wheel organizational chart in Figure 9 shows the internal structure of the system. Red blocks present parts of SMS Wheel that are directly tackled with the GoSAFE RAIL projects. In the following chapters improvements that are provided with this project for each part of the SMS Wheel structure are described. (ERA, Application guide, 2010)
Figure 9 SMS Wheel organizational chart
4.2 Improvements in SMS Wheel through KPIs implementation

4.2.1 Operational activities

Asset management

The main focus of asset management in the railway sector is on the physical assets e.g. buildings, networks, infrastructure, equipment. Other types of assets mentioned in the SMS Wheel are human, financial, intangible and information assets. The GoSAFE RAIL project is improving management of the physical and information assets through:

- Integration of Open-Linked Data from a range of sources and transformation to allow for direct use in a safety framework incorporating network modelling.
- Real-time methods for object detection: detecting track obstructions including vehicles, humans and animals specifically on safety-critical sectors of infrastructure, such as level crossings, bridges and tunnels and on open-tracks; detect avalanches through the generated seismic waves.
- Analytical models incorporating Artificial Intelligence (AI) algorithms for predicting asset degradation. Machine learning algorithms are based on the near-miss concept (suggested near-miss PIs provided in Deliverable 1.1). Using low-consequence events to train models is providing statistically significant data for model training. The Safety Framework and the traffic model is then used as a basis for analysis on how the element/structure is behaving or how its behaviour is changing in (near) real-time and eventually predict the future network behaviour.
- Planning of maintenance and intervention strategies with the lowest whole life cycle cost.

Asset management will thus take advantage of the vast amount of data (already existing in railway companies, and increasing daily) through introducing AI and machine learning models. Development of object detection methods will improve reliability of data and introduce new information. Through the improved use of data a competent asset management is developed enabling whole life cycle planning of the whole network with minimum impact on the society and environment.

Emergency management

According to the Railway Safety Directive Each railway organisation must set up an emergency plan identifying and specifying the different types and levels (critical, non-critical etc.) of emergencies that might occur. Each plan should be periodically reviewed and detail the actions, alerts and information to be given in case of an emergency.

The introduction of the near miss concept proposed by this project, which is derived from the approach that minor near misses and accidents have the same relative causal patterns, should be incorporated into emergency management. Emergency actions or steps have to be defined for each clearly defined near miss performance indicator as well as threshold level for triggering these actions. This could for example be increased monitoring, investigation works or remediation actions. A key output in WP3 is a Decision Support Tool (DST) that enables decisions to be made in real-time allowing emergency safety measure and maintenance
scheduling to be prioritised for infrastructure elements exhibiting stress (data driven support). The Safety Framework and the traffic model will thus be a live (evolving tool) that can be used in hindcasting and crucially to predict the future network behaviour, including the number of accidents or delays.

**Decision taking**

The GoSAFE RAIL project is developing its Global Safety Framework and DST to be fully compatible with the ERA approach which states that the safety management system’s processes should be fully integrated into a railway company’s business context. It is important that such companies can rely on robust decision making processes, in order to justify and trace operational safety related decision. Management decisions should take into account direct or indirect impact on safety.

The decision support tool developed in this project is in compliance with the RAMS (Reliability, Availability, Maintainability and Safety) targets as defined in CENELEC norm EN 50126 and with IM’s involved in each stage. This ensures that the outcomes will find immediate implementation. These developments will ensure easier planning of maintenance across the modes and aid in the paradigm shift from renovation schemes to routine maintenance throughout an asset life-cycle, ultimately leading to economic savings and optimal decision taking.

**Control of risks associated with the activity of the RUs/IMs**

The ERA recognises two types of risks regarding stakeholders: risks related to activities carried out solely by RUs or IMs and shared risks (related to activities at interface). This requires an identification of risks in a methodical way to ensure that all significant activities within the organisation have been identified and all the risks flowing from these activities defined. By estimating the consequence and probability of each of the identified risks, it should be possible to prioritise the key risks that need to be analysed in more detail. An RU or IM should also recognise the need and have the commitment to co-operate, where appropriate, with other entities (RU, IM, manufacturer, maintenance supplier, entity in charge of maintenance, vehicle keepers, service provider, procurement entity, sidings, etc.) on issues where they have shared interfaces that are likely to affect the putting in place of adequate risk control measures.

In GoSAFE RAIL WP1 focuses on the development of a global Risk Assessment Methodology (RAM), which uses existing monitoring, and operational data and monitoring for detection of objects on tracks. Using a combination of remote monitoring, case histories and expert judgement the key safety performance indicators associated with railway infrastructure are identified (Deliverable 1.1). A probabilistic risk assessment framework incorporating a unified risk ranking hierarchy to provide infrastructure managers with the decision support required to help them optimally allocate limited resources in a manner which optimises safety is being developed. Consequently, rather than just focusing on risk, the framework takes into consideration the availability of resources to reduce risk, the scale and ability to accept or tolerate risks (i.e. the consequences), the effectiveness or availability of
interventions to reduce risk and the residual risks following an intervention. The methodology allows different interventions to be compared, taking into consideration their relative costs (both direct and indirect).

Data collection & analysis

With regard to risk, at present Infrastructure Managers make safety critical investment decisions based on poor data and an over-reliance on visual assessment. The Safety framework developed in the project allows data on network performance (e.g. visual inspection data, historic failure information, traffic data, databases etc.) to be stored in a Building Information Model, BIM environment. This information feeds into a decision support tool (DST) that enables decisions to be made in real-time allowing emergency safety measures and maintenance scheduling to be prioritised for infrastructure elements exhibiting stress. Algorithms at an object level (e.g. a level crossing, bridge/earthwork or tunnel) and at a network level (traffic flow model and DST) incorporates machine learning to train the system to evolve with time using available monitoring data. Historical and forecast climate data are used as input to the system. Thus the precision of monitoring and predictions will improve with time as the model predictions are compared to the object and network performance.

Safety recommendations

The Global Safety Framework developed in this project has at its core an intelligent data management system. Careful design allows data from a range of sources to be stored readily in a standard and usable format. This data includes:

1. New safety indicators based on the near-miss concept - a starting point will be Directive 2004/49/EC
2. Statistical data on accident occurrence collated corresponding to the safety indicators.
4. As a result of the training of the artificial intelligence models the safety indicators will be updated.

ERAs SMS Wheel clearly identifies the importance of reviewing unsafe conditions and process disruption is part of the basic elements to derive planning of reactive or proactive measures. A safety recommendation in terms of Directive 2004/49/EC is a proposal of a national investigation body to improve railway safety, based on the results of the investigation of one or more accidents or incidents. Through better, innovative and optimized data collection and analysis this project will directly influence these safety recommendations.

4.2.2 Processes for implementation

Configuration control of safety information

The probabilistic risk models described herein depend on the quality of available data, the way it is archived, its availability and ability to use in data analysis. Also measures to control vital safety information are important to maintain and improve safety performance within an organisation. The availability of correct information enables awareness and allows for corrective actions to be taken promptly and efficiently.
This project is incorporating machine learning regimes from the computer sciences with the meaningful interpretation of data (including LiDAR, visual assessment, SHM etc.) for a variety of infrastructural elements. In the first instance, the extension of BIM to data relevant for the asset management of infrastructure involves a significant trans-disciplinary component and moreover, the creation of a platform for ease of use by asset managers. Combining these approaches enables predictions to be made regarding the state / condition of an asset using historical data and climate change inputs in lieu of an exhaustive installation scheme to obtain new data. It allows managers to deal with large amounts of non-numerical data (inspection logs / other reports) in a BIM environment tailored specifically for trans-modal infrastructural management on a Europe-wide level.
5 Conclusion

This document outlines the Global Safety Management Framework and its main components, which will be implemented into the Decision support tool (DST). It is a holistic management tool, which provides the automation and computerized support to the system and techniques being developed in the GoSAFE Rail project.

The Global Safety Management Framework (GSMF) integrates risk assessment frameworks for a number of asset categories including; slopes and retaining walls, level crossings and bridges, tracks and tunnels and network flow model outputs. The framework developed within the project is fully compatible with the European Railway Agency’s Safety Management System (SMS WHEEL), and includes improvements to the safety management procedures by implementing the Global Safety KPIs, identified in Deliverable 1.1 and Deliverable 4.1.
6 References

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