RAMS Technology for Railway Engineering in the Gotthard and Ceneri Base Tunnels

Project Description

Introduction

The base tunnels on the new rail links passing through the Alps (NRLA) are planned to last for more than one hundred years. High requirements were posed regarding permissible risks and fault frequency so that the railway engineering equipment functions as safely and reliably as possible. The fulfilment of these requirements must be documented by the contractor by means of secured predictions. RAMS technology forms the basis for this in keeping with CENELEC standard 50126, which has been applied in its entirety for the first time for infrastructure projects of this magnitude.

The NRLA Gotthard axis in addition to the new Gotthard-South rail route primarily constitutes the Gotthard Base Tunnel (GBT) and the Ceneri Base Tunnel (CBT) (Fig. 1). The 57 km long GBT was ceremoniously opened on June 1, 2016. Scheduled rail traffic through the 15 km long CBT has started operation as was originally planned at the end of 2020.

The Alp Transit Gotthard AG (ATG), a fully-owned subsidy of the Swiss Federal Railways (SBB) as the principal for the Gotthard axis was responsible for driving the tunnels, constructing and furnishing the shell as well as for the railway engineering.

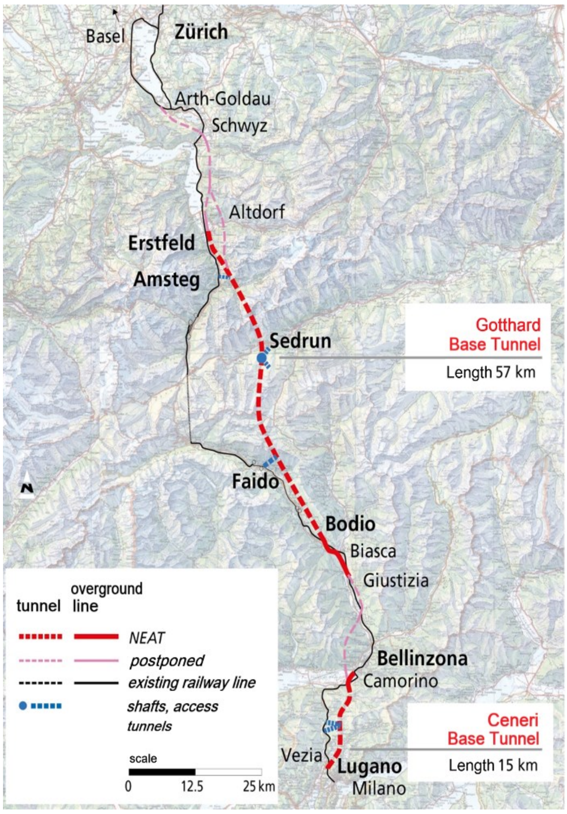

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Figure 1: The Gotthard axis – part of the new rail routes passing the Alps (NRLA)

Railway Engineering

The railway engineering for the two base tunnels comprises tracks, points, a 50 Hz power supply, the traction power supply, data network and radio connections as well as signalling systems (Figs. 2 + 3).

Figure 2: A view into GBT tunnel infrastructure

The Transtec Gotthard was the general contractor for the railway engineering in the Gotthard Base Tunnel and the north and south access routes. This consortium pooled the resources of Alpiq In Teq AG, Alcatel-Lucent Schweiz AG, Thales Rail Signalling Solutions AG, Heitkamp Construction Swiss GmbH and Balfour Beatty Rail GmbH. In the Ceneri Base Tunnel the CPC JV (cablex, Porr and Condotte) was the responsible contractor for the railway engineering contract section (catenary wire, rail power and power supply, cable, telecom and radio systems) as well as for the overall coordination. The Mons Ceneris JV is responsible for installing the track, the Thales Rail Signalling Solutions AG for the signalling and automation systems and the Nokia AG is in charge of the control technology.

In addition to an integrated management system, which ensures that requirements are fulfilled with regard to quality, industrial safety, health and environmental management, a superordinated RAMS management system makes certain that specifications and verifications are provided for characterising the long-term behaviour of the cited systems.

The acronym RAMS for its part stands for Reliability, Availability, Maintainability, Safety. Towards this end, the corresponding methodology is provided by the CENELEC Standard EN 50126 and will assist in eliminating possible faults already during the planning phase.

The direct link to the quality management becomes evident here: The longer a fault remains undiscovered in the later phases of the product life cycle, the higher are the costs for eliminating this fault in general. In this connection, one also refers to the rule of ten of fault costs: The costs for avoiding or eliminating faults increase by roughly the factor 10 with each life cycle phase.

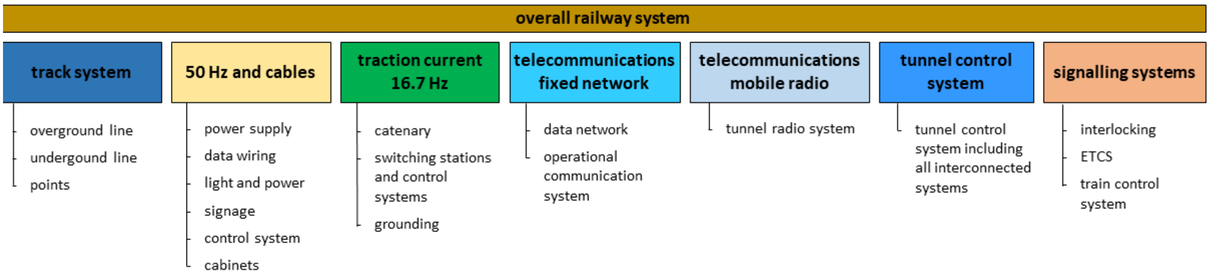

Figure 3: Structure of rail engineering in the CBT and GBT

The CENELEC Standard EN 50126

The approach in keeping with EN 50126 embraces the entire product life cycle, starting with the concept by way of the development, design, production, assembly, testing, operation and maintenance right up to decommissioning the system in question (Fig.4). In every life cycle phase defined RAMS tasks as well as verification and validation processes must be executed. Already at the tendering stage for the railway engineering for the two major Swiss tunnel projects the ATG put forward very explicit provisional RAMS analyses according to EN 50126, which provided bidders with an initial basis for assessing the satisfiability of the RAMS requirements. At the same time, the bidders were called upon to provide detailed RAMS calculations for the railway engineering systems within the scope of their offers. The reason behind this was to refine them from the beginning of the project work for execution in relation to the concrete planning and to continue updating this until the first commissioning.

This close orientation to the EN 50126 represents a first for infrastructure projects of this magnitude on the railway sector both nationally as well as internationally. In this context, the general validity of the standard is revealed, which essentially is only intended for electric and electronic components from the rail applications sector. In the GBT and CBT projects it has also been adopted for examining the track system, which largely comprises mechanical components.

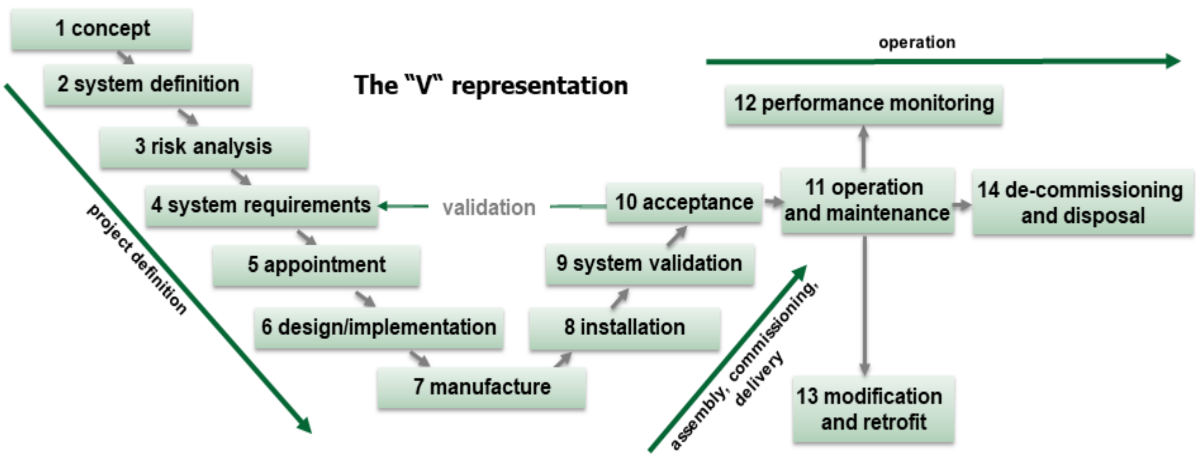

Figure 4: System life cycle according to CENELEC EN 50126

RAMS Methodology

The elements of RAMS are defined as follows:

Reliability: Probability that a unit can fulfil its designated function for a given time period under prevailing conditions.

Availability: Capacity of a product to be in a state, in which it can fulfil a designated function under prevailing conditions at a given point in time or during a given time period - under the premise that the required external resources exist.

Maintainability: Probability that a determined maintenance measure within a given time period can be executed for a component under preexisting operating conditions, providing the maintenance is carried out under predetermined conditions and defined methods and resources are applied.

Safety: Freedom from unacceptable risk of harm.

The topic of RAMS cannot be considered separated from the functional design and development of the given systems and processes. Thus, sufficient safety and reliability of the products must be assured through corresponding system structures, which if necessary are set up on redundant channels or part-systems. For example, a power supply that is as trouble-free as possible can be produced with two practically independent power networks.

Maintainability for its part is also no parameter, which solely describes the organisational measures and methods, far rather it depends to an equal extent on the technical possibilities, provided by the systems being maintained. Modular construction, the application of standardised components and good accessibility represent significant characteristics in this respect.

In contrast to the actual technical planning, which enables the calculation of exact output values based on proven physical interrelationships, which are normally speaking directly measurable after implementing the systems, the analysis of the RAMS characteristics is not trivial.

For instance, specifically for the system traction power it can be calculated exactly how the related switching systems, the control technology, the overhead line, the cables and the earthing system have to be configured and dimensioned in order to ensure that 16.7 Hz voltage is present at every point of the route. These parameters furthermore can be directly monitored by means of corresponding measuring technology. On the other hand, there is no measuring device capable of ascertaining directly the technical service life of components, for example, components for the overhead line.

In order to be able to come up with suitable conclusions on the reliability of technical systems, adequate observations (random checks) are necessary over a sufficiently long period of time. Then corresponding parameters for the totality of the observed components (population) can be derived through mathematical statistics.

However, even the key values determined in this manner only describe the desired parameters within the framework of a certain statistical safety without representing any absolute values. Furthermore, the reliability behaviour does not represent a chronological constant value. Physical and chemical influences result in inevitable wear affecting all components, which sooner or later will culminate in malfunction and in turn, the loss of functionality unless these are previously replaced. And as the factors of influence are so varied, the actual service life of each component is different, even when components of the same type and batch are involved.

The values determined with the aid of statistics merely represent estimates of the desired parameters for the contemplated population. Every statistical result is always linked with uncertainty.

Apart from the actual parameters so-called estimation errors can be calculated, which provide an indication of how exact the statistical estimates reflect the desired values.

This vagueness can be quantified by means of the probability calculation at the end of the random population check.

The cited basic conditions must always be taken into consideration for predicting the RAMS behaviour of a technical system. As a result, it also applies for the RAMS considerations for the railway engineering systems in the GBT and CBT projects that all relevant analytical results and derived statements generally embrace a certain confidence range.

Contemplation of human and systematic influences represents a particular challenge.

Pertinent norms call for the inclusion of these factors in the risk evaluation process, also because the frequencies of such incidents are generally higher by the factor of 100 to 10.000 than random technical causes.

Whereas technical reliability behaviour can still be sufficiently well estimated by means of statistics, human errors in particular are difficult to quantify.

Universal modelling approaches are still incomplete in this respect. In the GBT and CBT projects factors of influence are derived from the findings obtained in operating similar systems, which contribute to the evaluation of probability of occurrence.

RAMS Planning

The CENELEC Standard EN 50126 provides general guidelines for the responsibilities in the RAMS process during the life cycle of a typical rail project: Thus, the requirements are customarily determined by the client or operator or the supervisory authority. Similarly, approval is obtained by the client or permits by the supervisory authority within the scope of directives. Normally the contractor is responsible for working out and implementing solutions, results and verifications. Validation is generally undertaken on a joint basis. Contractual and legal relations between the parties involved can, however, also allocate these tasks in a different manner. In order to ensure that the RAMS requirements for a project can be fulfilled correctly, the EN 50126 among other things calls for a safety plan and a RAM programme to be set up to document the chronologically determined activities, resources and occurrences.

As the safety aspects are partially also interlinked with the reliability and availability criteria and similar tasks are pending in this respect in the individual life cycle phases, both documents can be included in a central RAMS plan.

This RAMS plan describes the process of fulfilling the RAMS requirements placed on the system, serves to introduce an organisational structure for responsibilities and measures, sets the super-ordinated conformity standards at overall system level and defines the documents to be presented to the client and supervisory authority for the provision of proof, which are part of the complete package of verification for obtaining clearance and an operating licence. The responsible supervisory authority for the GBT and CBT is the Swiss Federal Office of Transport (FOT/BAV).

RAMS Requirements

The requirements posed on the systems for railway engineering are derived from the superordinated requirements for operating tunnels. The safety requirements for the overall system are in this case of decisive significance. Requirements relating to reliability, availability and maintainability are subordinated to them.

The qualitative and quantitative safety requirements posed by the ATG (or the SBB as operator) on the railway engineering system were established by means of a quantitative risk analysis (QRA), in which an identification of possible hazards and their effects as well as an estimation of the probability of occurrence took place.

Functional demands for the individual part-systems emerged from this with respect to the system architecture in order to avoid specific hazards.

The concept risk represents the combination of the probability of occurrence of an incident and its effect (extent of damage). The possible number of injured or fatalities during operation of normal services represents the indicator for the extent of incidents in both tunnel projects GBT and CBT.

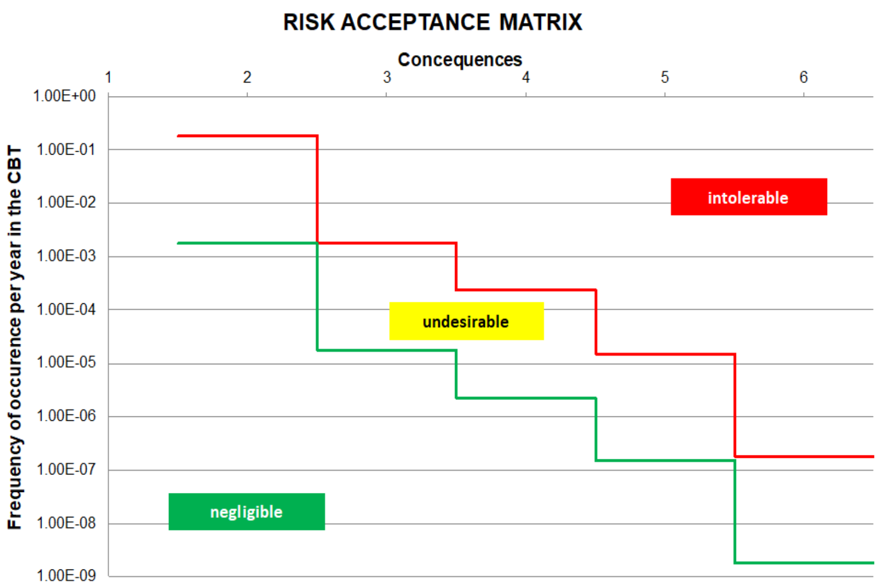

Figure 5: Risk acceptance matrix for the overall system rail engineering within Project CBT

Six hazard levels were defined for the evaluation of the identified risks:

- **Hazard level 1:** no safety-relevant effect or minor injuries
- **Hazard level 2:** injured, no fatalities
- **Hazard level 3:** 1-2 fatalities
- **Hazard level 4:** 3-10 fatalities
- **Hazard level 5:** 11-100 fatalities
- **Hazard level 6:** > 100 fatalities

By including the specific frequencies of occurrence, a so-called risk acceptance matrix results, from which it can be derived whether risks are to be classified as negligible, undesirable or intolerable (Fig. 5).

Scenarios, which are regarded as negligible, are assumed to be acceptable and no further measures are resorted to.

In similar fashion to the hazard levels the ATG established four fault categories for modelling the reliability and assess the availability, which permit uniform evaluation and classification of technical failures:

- **Fault category 1:** stability of timetable affected by no more than one hour
- **Fault category 2:** stability of timetable only slightly affected until troubleshooting
- **Fault category 3:** immediate shutdown of one or several route sections
- **Fault category 4:** total shutdown of both directions of travel

Maximum permissible fault frequencies have been defined per fault category during the course of imposing the requirements for the part-systems and the overall system.

Thus, in the CBT an incident involving a total shutdown of both tunnel tubes is permissible once every ten years at the most (Table 1).

Fault category	1	2	2	4
Permissible number of faults per year	10	5	1.25	0.1

Table 1: Max. permissible fault frequency for the rail engineering equipment of GBT

RAMS-Phases and Milestones

The contractors are obliged to verify continuously the level attained by the railway engineering system with regard to safety as well as reliability, availability and maintainability in the individual RAMS phases in accordance with EN 50126. Accordingly, it is necessary to provide the relevant verification documents to the ATG and the BAV when pre-determined project milestones are reached (Fig. 6).

As completion of these milestones forms the basis for the remuneration for the work carried out, RAMS verification management also plays its part in milestone-related reimbursement.

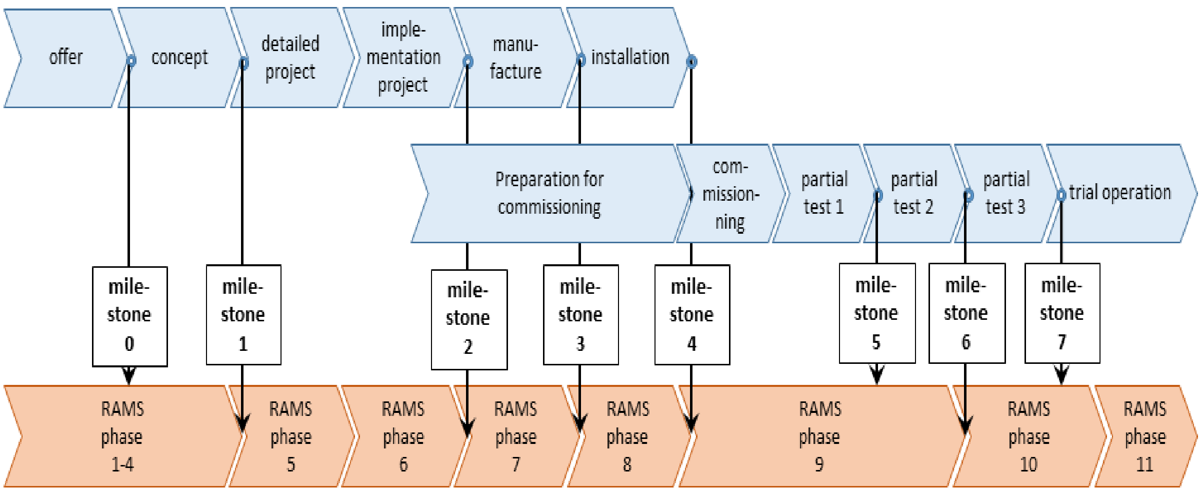

Figure 6: Relationship between RAMS phases, project phases and milestones

Permits

Obtaining the various approvals and permits as well as producing the necessary verifications is of central importance for commissioning.

The ATG is responsible for procuring the necessary clearance documents and operating licences. Towards this end, it must be proved that all facilities and systems correspond with all requirements and that the regulations - especially those governing safety - are adhered to. Commissioning alone requires no less than around 1000 different verifications. Furthermore, there are independent tests by external safety authorities, experts and reviewers. A substantial part of the verification documents relates to reliability, availability, maintainability and in particular, safety.

For this purpose, the ATG consistently applies RAMS methodology in keeping with CENELEC Standards EN 50126 and EN 50129.

Verification Documents

RAMS verification documentation comprises safety cases, RAM demonstrations and RAMS management reports (Fig. 7).

These documents are updated for the individual railway engineering sub-systems as well as super-ordinated at part-system and overall system levels.

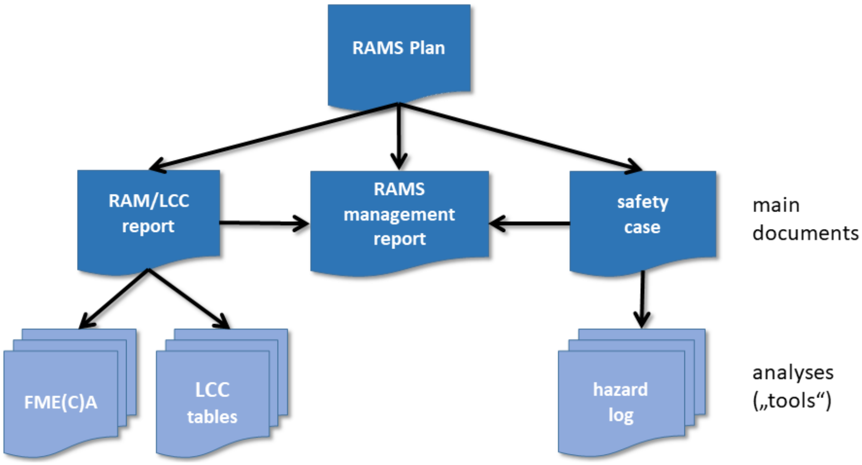

Figure 7: RAMS Verification Documents

The main objective of the RAMS considerations is to plausibly verify through predictions that the maximum permissible frequency of occurrence per hazard level as well as the maximum permissible frequency of occurrence per fault category can be met.

These verifications are updated within the scope of project progress with the objective of minimising the vagueness of the RAMS prognosis continuously as the project advances, by relying on increasingly more detailed planning and better input values.

The safety verification primarily serves to prove the achievability of the necessary safety characteristics of the systems. It indicates under which conditions the quantitative safety targets of the overall railway engineering system are to be fulfilled and evaluates, whether the targets can be accomplished commensurate with the current level of knowledge. The RAM demonstration document serves to prove the achievability of the necessary RAM characteristics of the systems. It indicates whether the quantitative RAM targets of the overall railway engineering system can be fulfilled on the basis of the current available information.

In this connection, the relevant system requirements posed on environmental conditions, supply systems, spare-part availability and maintenance are correspondingly taken into consideration.

The calculations, on which the safety case and the RAM demonstration are based, depend on input values, which if possible are supplied and verified by the manufacturers of the applied components.

If no information is available from the manufacturers, suitable reference values from comparable projects or estimates by experts can be used as an approximate solution. In this case, all input values have to be examined by the appropriate planners and the responsible RAMS experts.

The RAMS management report for its part describes the activities in the sectors safety, reliability, availability and maintainability which are applied during the project planning cycle for the railway engineering right up to the current level of the project, and it provides information on whether the requirements contained in the RAMS plan will be met.

Analytical Methods

In general, the starting point for the RAMS analyses constitutes a comprehensive FMECA (Failure Mode Effect and Criticality Analysis), from which safety-relevant and reliability-relevant incidents for the most essential operating conditions of the systems can be derived.

The FMECA's approach is an inductive one. Inductive approaches are based on the assumption of a triggering incident (e.g. malfunction of a component) and attempt to respond to the question of possible consequences in a methodical, forward-looking manner. Fault Tree Analyses (FTA) can also be applied for the quantitative consideration of complex part-systems and the interaction of redundancies. The incidents classified as safety-relevant are additionally documented with a corresponding risk evaluation on the basis of incident scenarios and the distribution of consequences in hazard logs (Fig. 8).

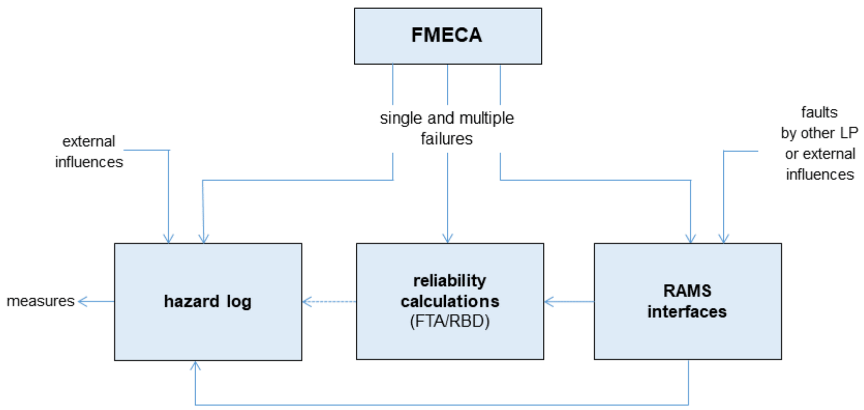

Figure 8: FMECA and other RAMS analysis methods

However, not every technical malfunction leads to a possible consequence involving injured persons or even fatalities. The general influences of incidents, which can have their origin in other relevant subsystems or even external sectors (SBB, national grid, Polycom radio network, etc.), are taken into consideration via a RAMS interface process and documented by RAMS interface lists, which are also based on the FMEA principle. Standard document templates were evolved for the GBT and CBT projects after consultations between the ATG and the contractors.

These are intended to be used stringently in all sub-sections of railway engineering equipment so that a well-structured, lucid, complete and transparent RAMS documentation can be achieved. These guidelines not only apply to the actual verification documents as such but are also aimed at documenting FMEA, hazard logs and RAMS-relevant interfaces. A document management system was applied in order to deal with and interlink the individual entries, as in some cases complex interrelationships ensue resulting from consideration at the various system levels and from the multi-layered cause-effect-relationships between the individual documents and analyses. For example, among other things the FMEA standard software APIS IQ-FMEA was introduced for a model-based risk analysis, which depicts the cause-effect relationships easily comprehensible by means of a graphic interface. IZP-Software RAMS-Office NG export and import interfaces enable these analyses to be transferred to the project-specific document templates (Fig. 9).

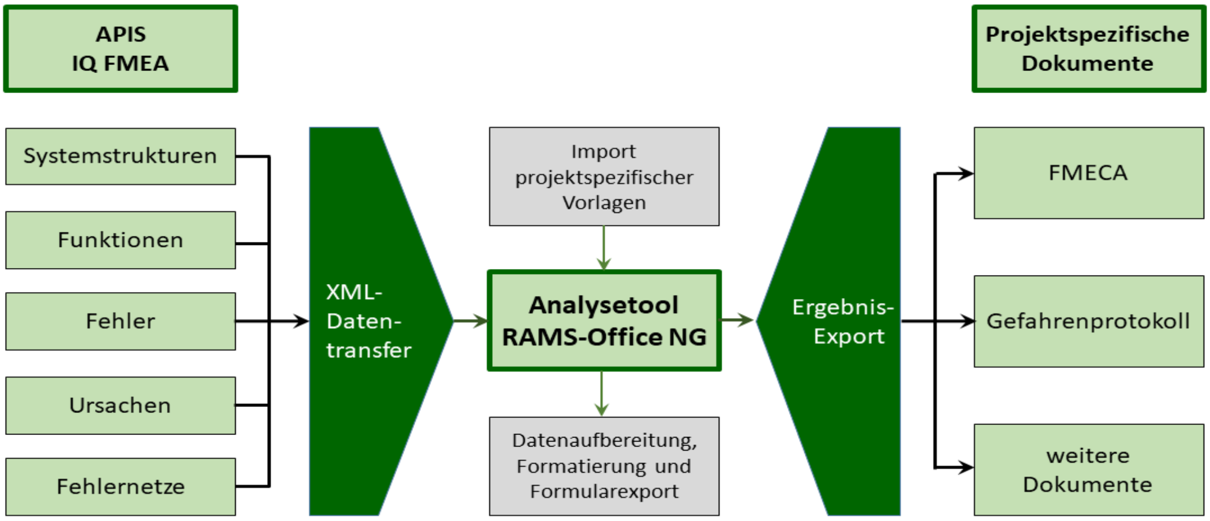

Figure 9: Computer-supported document management with the aid of APIS IQ-FMEA and RAMS-Office NG

RAMS Management

The RAMS-related tasks according to EN 50126 are carried out equally by competent members of staff from the ATG and the contractors. The contractors are responsible for producing approvable safety cases, demonstrations for reliability, availability and maintainability within the scope of the RAMS processes for their respective area of responsibility. The CPC JV's responsibility for the overall coordination in the Ceneri Base Tunnel project also relates to the planning and coordination of the superordinated RAMS process for meeting the RAMS requirements for the overall railway engineering system. The RAMS services concerning coordinating, planning and engineering according to EN 50126 are undertaken within the CPC JV by the “Ingenieurgesellschaft Zuverlässigkeit und Prozessmodellierung Dresden mbH” (IZP Dresden).

IZP Dresden has been active for twenty years as service provider in the fields of RAMS specifications, RAMS/LCC prognoses, software and data analyses as well as further education. The IZP Dresden in fact, actually provided support for compiling the offer of the Transtec Gotthard AG (TTG) for the GBT project and the installation of the solid slab track by the TTG's track working group.

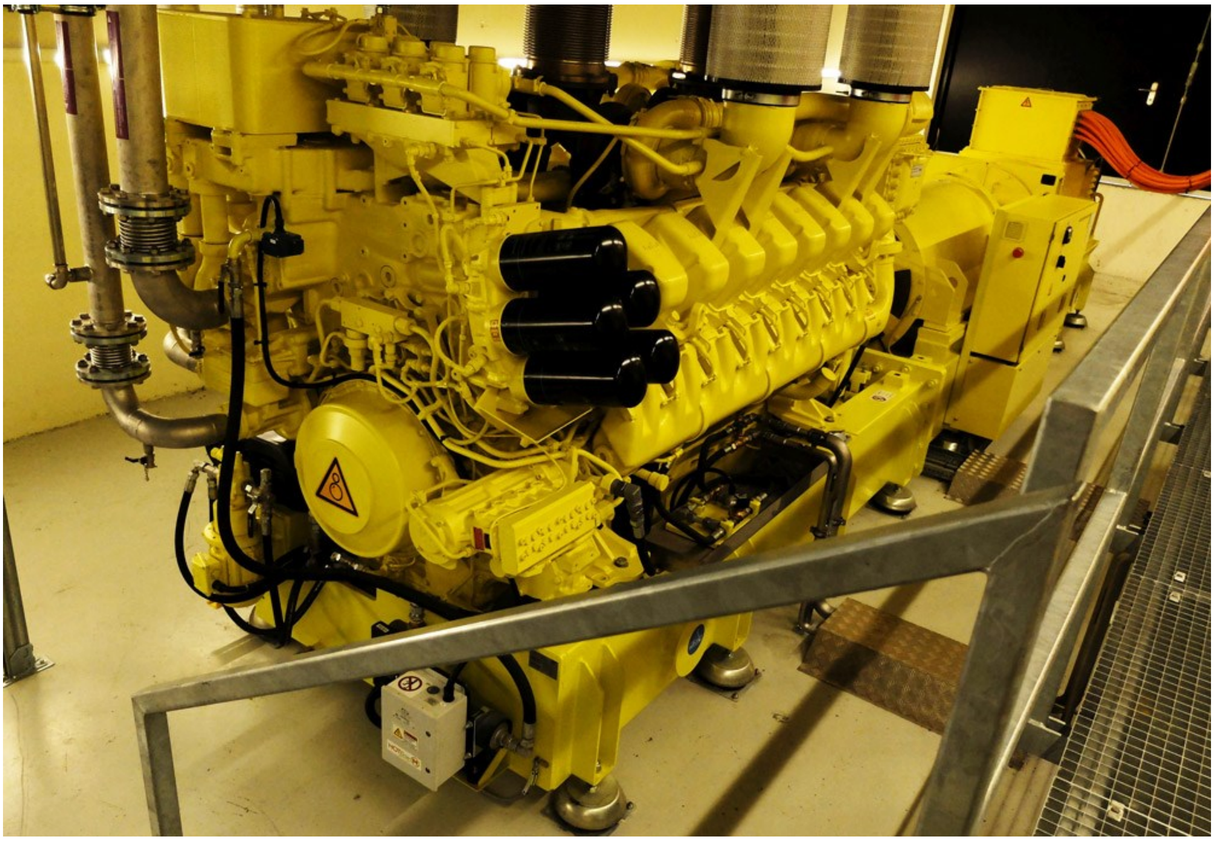

Figure 10: Allowing a stable operation: 1 out of 4 no-break aggregates within CBT engineering rooms

Summary

A close interrelationship prevails between the project-related quality management and compliance with the systematic RAMS methodology according to CENELEC Standard EN 50126 for accomplishing the railway engineering in the GBT and CBT tunnel projects.

The consistent application of the RAMS methodology enhances product quality, which has to be ensured by the project execution, from the very beginning. In this context, transparent and continuous provision of verification facilitates the relations between contractor, client and supervisory authority, improves the understanding of the system, reduces the number of subsequent changes and ensures a system development in line with the specifications.

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