ABSTRACT: System RAMS, as seen in the context of the European standard EN50126, is a combination of reliability, availability, maintainability and safety. Railway RAMS is thus a characteristic of the railway systems’ long term operation and is achieved by application of different engineering concepts, methods and tools. The RAMS process goes on from the early planning phases of, and all the way into the operation phases of the system. In railway-infrastructure engineering, the aim is to incorporate RAMS requirements in all decisions concerning the system design, starting with the concept selection, through the detail- and development of concepts, through the design and final layout, and finally the construction of planned solutions. This paper presents some experiences from an ongoing engineering project, and suggests some thoughts about effective work processes and continuous RAMS implementation. The project covered engineering of railway substructures consisting of railway constructions and surrounding terrain. The suggestions are connected to effective RAMS processes, and the most favorable is an approach to RAMS meetings that take part among different disciplines and stakeholders in engineering projects.

1 INTRODUCTION

System RAMS, as seen in the context of the European standard EN50126 (CENELEC, 1999), is a combination of reliability, availability, maintainability and safety. Railway RAMS is thus a characteristic of the railway systems’ long term operation and is achieved by application of different engineering concepts, methods, tools and techniques from the early planning phases of, and all the way into the operation phases of the system.

Even though the EN50126 describes the formal processes of RAMS management in a system life cycle perspective, experience from railway projects revealed challenges with respect to the fulfillment of all the good intentions (Halvorsrud, 2009).

In Norway, the National Rail Administration is usually the main customer in major railway-infrastructure projects. These projects may cover modifications of existing railway systems and infrastructure components, or building of totally new infrastructures. Usually, there are several companies involved in each of the engineering projects. A typical role is being responsible for part-sections of new tracks, or being member of project teams responsible for a single area or discipline. Of that reason, there may be a mutual interest of developing common approaches to high-quality and effective RAMS processes.

1.1 Background

Current experiences from railway RAMS implementations in Norway are that RAMS to a certain degree is an activity for the “experts”, a bit on site of the main business value-chain (Schuman, 2009). RAMS processes are characterized as non-uniform and non-coordinated approaches, and are mainly adapted to each project. Typically, one starts out by defining a major quality plan including a RAMS- and HSE plan. Despite the common regulation (Norwegian-Railway-Inspectorate, 2006) and CENELEC standards (European Committee for Electro-technical Standardization), it turns out somewhat different in practical applications. The future owner of new infrastructure may starts to worry whether or not the current RAMS-process activities are the most adequate and cost-effective. Say it in another way; is it possible to improve through better coordination between actors and focusing on more thorough RAMS approaches?

This paper is based on experiences and learning from participating in an engineering project as responsible for the RAMS-discipline. Gained knowledge is utilized and based upon, in order to suggest ways of improvements of the todays, more or less, common practice. The project referring to covered engineering of railway substructure, which has to be
prepared prior to installation of rail tracks and belonging rail-track equipment. The system life-cycle phases that were covered are the early concept phase, the detail- and development plan phase, and thirdly, the phase of establishing the construction plans. The latter includes detailed design of constructions and the surrounding terrain. This last phase of engineering also makes out the basis for scheduling the construction work and makes out the basis for preparation of tender documents.

Current experiences are from a single engineering project only. Thus, involvement in other similar projects could possibly have led to different approaches or suggestions. Anyway, the purpose of this study was to share those experiences that the author believes could be useful in similar projects. The National Rail Administration promotes project management and follow-up in their projects. The involved consultants thus need effective work processes and near follow-up in order to achieve their schedule and expected quality of deliveries. In this respect, the National Rail Administration promotes the need for, and capabilities of learning by experience from one project to another.

Important success criteria all the way are hand-on feeling of the RAMS issues during the project phases. This requires a close dialog between the responsible discipline leaders of the engineering company. RAMS requirements in decisions are thereof adapted to every project phase.

This paper gives an overview of suggested work processes and routines that were adapted to the RAMS process. As part of project management the RAMS discussions revealed possibilities and practices of the different disciplines. The main intention was to obtain a more efficient and recurrent RAMS process throughout.

1.2 Objective

The main objective of this paper is to suggest improvements of the RAMS process as it is conducted in railway engineering projects. Sub objectives are:

- To give an overview of current practice based on available literature and open sources to industrial practices.
- To suggest improvements of the RAMS process, including the RAMS analyses and implementation of risk reducing measures.

2 PREVIOUS WORK

The railway companies and related consultants have for a long time conducted RAMS-implementation tasks, as e.g. risk analysis and other management-and decision-support approaches. However there are few publications or open available sources dealing with the RAMS implementation part and experiences from applying the EN 51266 standard.

2.1 Literature

As mentioned there is limited work published describing experiences and learning from RAMS implementations. One recognized source presents the most relevant methods and tools (Rausand M., Høyland A., 2004). This text book, as well as other publications within RAMS field, is typically dealing with analytical models and modeling of safety- reliability, availability and maintainability performance. Examples here are the papers of (Marseguerra M., et al., 2006) and (Stamenkovic B.B., et al., 2010).

Others again could focus on the maintenance part more explicitly; e.g. by addressing maintenance optimization models were safety issues are incorporated factors (Vatn J., Aven T., 2010). Another example is (Okstad E., et al., 2009), which adapt analytical approaches to an operational setting.

Some experience from non-straightforward applications of the EN50126 standard is discussed in (de Boer J., et al., 2003). In this paper a new method for hazard identification is described. The dynamic behavior of a system for rail traffic management and safety is analyzed. The paper also touches upon the organization with respect to safety management and suggest some improvements to the organization as described in the CENELEC standards.

2.2 Industrial practices

In an ESRA seminar back in 2009, representatives from the Norwegian Railway Authorities presented some experiences from the use of the EN 50126 standard, mainly from the Norwegian railway industry (Halvorsrud, 2009). ESRA stands for the European Safety and Reliability Association. The main challenges that came up were:

- Lack of clarity around the application area.
- Too much focus on producing documents, and too little on what actually is in them. The quality of the product is not measured in kg documentation.
- Because the focus is on the production of documents rather than the implementations of activities, documents are often produced too late in order to be an effective tool in the RAMS work.
- Too much focus on the implementation of the RAMS process, and too little on what you get out of it.
- RAMS work is a work process being too much on the side of the core project.
- The purpose of RAMS work is only to satisfy the requirements of the railway authority.
Another point is that the progress in railway-infrastructure development is largely depending on yearly founding form the parliament, normally within limited budgets. Despite the situation of having long-term plans for infrastructure development that include new railway routes, projects are typically divided into part sections and initiated on basis of allocations from annual national budgets. Tenders are invited for main engineering of projects that have been sectionalized. Another challenge is that different consultants with varying experience and abilities are expected to compete for these contracts. In this marked situation, the author believes the railway industry could improve by learning from best practices with respect to RAMS implementation. This is believed to be of main importance in a situation with several players and with the main engineering divided into sub-projects that are completed over some time. The current paper aims to be a contribution in this respect.

The above experiences, among others, are the motivation for going into the problem in order to suggest some revised approaches to a more effective RAMS implementation.

3 PROBLEM DESCRIPTION

The main problem is to make the railway-RAMS processes more cost effective and streamlined in a way that satisfies requirements of main stakeholders. Stakeholders are the authorities, the railway companies, the engineering companies involved in planning and construction, and finally, the customers who are going to use the final railway system.

3.1 RAMS requirements

According to the Norwegian safety regulation (Norwegian-Railway-Inspectorate, 2006) it is noted: “The process standards EN 50126 should be followed at new and substantially modified infrastructure. In Norway, as well as in other European countries, there have been different applications of this standard (Schuman, 2009).

EN 50126 is normative in its nature and leaves much of the responsibility to implement the RAMS requirements on the different actors. In such a setting, cooperation between the project partners and a near dialogue with the main customer is important during the main engineering phase. The RAMS process and the applied practices with respect to RAMS implementation should thus be appropriately documented in order to achieve confidence within the National Rail Administration, and finally the Norwegian Railway Inspectorate.

Experiences also tell about challenges of balancing the use of risk-based and suchlike analytical management approaches, towards more descriptive and rule based approaches (National-Rail-Adm., 2010). The latter is traditionally found in the Norwegian railway industry. The inter-link of railway RAMS elements, reliability availability, maintainability and safety is shown in Figure 1.

As seen, reliability and maintainability as well as operation and maintenance affect on both safety and availability. The RAMS elements are thus interlinked and must be treated thereafter. Usually, the safety part of RAMS is treated separately. The National Rail Administration have set up accept criteria covering the railway safety (National-Rail-Adm., 2010). There are three types of criteria related to risk, of which all must be met:

- Social Risk. The upper limit of what the acceptance of risk for the total railway network in Norway.
- Individual risk. Individuals should not be exposed to unduly high risk.
- ALARP criterion. All measures that are practicable, shall implemented.

The Reliability, Availability and Maintainability (RAM) on the other hand, are more a question of specific requirements defined in each infrastructure project. Examples of such are up-time of railway traffic, a limited number of stops accepted due to maintenance failure, or limited total stop time accepted due to maintenance, etc.

In these days, work is going on in connection with Norwegian railway projects searching for typical TOP-events related to RAM, and appurtenant RAM requirements. The intention is to make such requirements more specific and easier to follow up in practice. Such requirements could be related to:

- Finding the optimal maintenance solutions
- Standard procedures of evaluating technical solutions and equipment
- Work processes adding up to the most appropriate operation and maintenance of major constructions, like tunnels, bridges, etc.

Anyway, implementation of such measures is normally based on cost-benefit evaluations.
4 RAMS PROCESS

4.1 Life cycle approach

The system lifecycle is a sequence of phases, each containing tasks, covering the total life of a system from initial concept through the detailed engineering, construction, operation to the final decommissioning and disposal. The lifecycle provides a structure for planning, managing, controlling and monitoring all aspects of a system, including RAMS. The lifecycle concept is fundamental to a successful implementation of the EN 50126 standard. It has thus, formed important input to the Norwegian regulations (authorities), and to the National Rail Administration with its requirements (main customer), but also to the procedures followed by the different actors and consultants being involved.

4.2 Suggested RAMS tasks

As mentioned, the Norwegian safety regulation requires the industry to follow EN 50126. This section gives an overview of a possible implementation during the main project planning phases. The relevant life-cycle phases found in railway applications is illustrated in Figure 2.

![Figure 2. System Lifecycle (CENELEC, 1999)](image)

This figure is taken from EN 50126 and includes fourteen project phases. The engineering or planning phases covers the phases between two and ten. After the system definition there is enough information to start with risk analysis. The engineering ends with the system validation. Phase number eleven to fourteen covers the operation and maintenance phase, performance monitoring, modification, and finally the de-composition and disposal phase. RAMS activities connected to these project phases are not covered in this study.

The Norwegian National Rail Administration has also developed a guideline for implementation of the requirements in EN 50126 (National-Rail-Adm., 2010). For the detail planning phase it emphasis some important requirements to system description and risk analysis.

Phase 2 System Description
- Clear definition of the boundary between the system under study and its environment
- Clear definition of safety requirements to the system
- Identification of hazards and risks by use of appropriate techniques
- Establishment of a safety plan, incl. RAMS

Phase 3 Risk analysis
- The National Rail Administration should make a systematic and thorough identification of potential risks related to changes if new systems are introduced or there are changes to existing systems
- At this stage one should identify hazards and events, calculate risks, and establish a process for continuous risk management.

According to EN 50126, a RAMS plan should be established in the early phases of the project. It should be an overall RAMS plan from the National Rail Administration which is supported by sub-plans from each of the involved consultants. The latter plans should clearly describe the RAMS process of each consultant, the RAMS requirements and organization of the work, and the specific RAMS activities to be carried out.

The main intentions of proper preparation and organization of the RAMS work are:
- RAMS should be an integral part of the engineering work.
- There should be short lines between the results and suggestions presented on basis of RAMS analyses, and implementation of such in the continuous planning process.
- RAMS should not be something that occurs on the side of the main project.

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1 Note 2: Risk analysis may have to be repeated.
2 Note 1: Dependent upon the system being modified.
• RAMS analyses should to the highest degree depend on the input from disciplines, consultants and main stakeholders.

Figure 3 illustrate the suggested main RAMS activities in relation to the value chain. The core engineering process shown in the middle is marked A). At the bottom, the RAMS analyses are marked B), and at the top, marked C), the other RAMS activities and meetings that take place in the engineering phases are shown. The first RAMS analysis is conducted after the early concept evaluations, which also include a concept risk analysis. A HAZID study (Hazard Identification Analysis) is performed prior to the first analysis.

As mentioned, major projects are usually shared between several engineering companies. Thus, one should coordinate RAMS activities with other actors in case of projects running in parallel. Other actors could be responsible for adjacent sections of the same railway. The intention is then to coordinate the RAMS work in order to improve quality of the whole new railway system including its end-documentation. As indicated in Figure 3 RAMS coordination is conducted once a month during the construction-planning phase.

The second RAMS analysis, or RAMS-analysis update, is conducted in prior to finalizing the construction-plan documentation. The latter makes up the basis for the tender documents.

The relevant accident scenarios are:
1. Derailment
2. Collision train against train
3. Collision train against object
4. Fire
5. Passenger injured on platform
6. Person injured near level crossing
7. Person injured when staying in, or near the track

The concept risk analysis also explains how the railway system under preparation should meet the safety acceptance criteria defined by the National Rail Administration (National-Rail-Adm., 2010). Based on information behind the concept selection and the concept risk analysis, meetings are held to discuss the prior system requirements and system boundaries of relevance to system RAMS. At the end of the detail- and development plan phase a formal RAMS analysis is conducted covering the early planning phase. Discipline leaders responsible for elements of relevance to the total system RAMS participate in this meeting. In addition, representatives from the National Rail Administration and other stakeholders are invited. The coarse RAMS-analysis coming from this project phase is regarded a static analysis document. Anyway, it follows the documented deliveries from the early detail and development plan phase.

Most important results of the first RAMS analysis is the hazard-identification part that sums up potential hazards connected to the solutions at this stage. Even though, this is based on early concept evaluations, it provides information regarding important aspects of the planned solutions that needs attention in the more detailed planning phases to come. Thus, risk reducing tasks are identified and evaluated.

4.4 Hazard register

A set of recommended actions from the RAMS analysis is placed in a project-hazard register. This hazard register follows the project all through the planning phases, and into the operation phase.

Entering the last planning phase, here called the construction-plan phase, a more “hands-on” and continuous follow up of RAMS is expected by the customer. At this stage the solutions are decided more in detail, and RAMS requirements should be verified at a more regular basis. Thus, the need for effective work processes and tools that supports the discipline leaders in their daily work is needed. The suggestions presented in this paper are a contribution in that manner.

Usually, the responsible engineering contractor set up internal project meetings in order to coordinate project activities among disciplines, make up status, and follow-up activities of common interest. The meeting is held every second week, and is of

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**Figure 3.** RAMS process and activities in engineering

**4.3 RAMS analysis**

Gained value of the RAMS analysis is meant to be improved decision-making in railway engineering. Decisions are taken on a better basis for optimized solutions; achieving safe railway systems which are suited and prepared for operation and maintenance.

As indicated in Figure 3, the RAMS process conducted in the early concept phase is for the most based on rough concept evaluations only, maybe not documented in a formal report. The detail- and development plan phase usually include a concept risk analysis. The concept risk analysis is part of the documentation that is requested by the Norwegian Railway Authority. The seven groups of accident scenarios defined for railway transportation is initially set up in the concept risk analysis.
course also an important arena for the RAMS discipline, as indicated in Figure 3. Especially, there is a continuous need for managing the interfaces between disciplines, as well as handling suggestions from the other actors of relevance for RAMS. The main focus in these meetings is the project’s hazard register. The suggested hazard register is based on a template found in the safety handbook (National-Rail-Adm., 2010) and consists of the information (columns) shown in Table 1.

Table 1. Hazard register headings

<table>
<thead>
<tr>
<th>Column name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard Id.</td>
</tr>
<tr>
<td>Document Id.</td>
</tr>
<tr>
<td>Description of Hazard</td>
</tr>
<tr>
<td>Top Event (Safety)</td>
</tr>
<tr>
<td>RAM element</td>
</tr>
<tr>
<td>Suggested action</td>
</tr>
<tr>
<td>Comments</td>
</tr>
<tr>
<td>Verification document</td>
</tr>
<tr>
<td>Comments to measure</td>
</tr>
<tr>
<td>Responsible company</td>
</tr>
<tr>
<td>Responsible person</td>
</tr>
<tr>
<td>Scheduled date</td>
</tr>
<tr>
<td>Actual date, case closed</td>
</tr>
<tr>
<td>Transferred to operation</td>
</tr>
<tr>
<td>Responsible for approval</td>
</tr>
<tr>
<td>Approval date</td>
</tr>
</tbody>
</table>

A specific procedure was set up for the RAMS follow-up in the construction-plan phase. It describes steps taken in the internal project meetings and immediate afterwards. During the project meeting, RAMS is the first topic on the agenda lasting for about fifteen minutes.

The first five minutes are used for a status update of the local hazard register. To simplify the review and making it more easy-to-follow, a limited set of information is asked for. The modified working sheet is illustrated in Figure 4.

![Figure 4. Simplified Work sheet for Hazard status review](image)

The procedure is like the following:

- One should not discuss/consider action at the meeting, just check whether measures have been taken (yes or no). In need of further discussions, the RAMS discipline leader and the relevant discipline agree a later time for this.
- If a measure with a closed or expired deadline has not been implemented by managers, this is noted by the project leader as a contemporaneously monitoring point for the next meeting.
- Input/updates from the meeting is registered in the working sheet, and transmitted by RAMS leader to the hazard register at the end of the meeting.

The next ten minutes of the internal project meeting are spent as a round-table session between all the discipline leaders identifying later changes in solutions that may affect on RAMS. The following procedure is followed:

- Identify changes in the solutions that may affect RAMS since last time.
- The RAMS leader considers whether the change affects RAMS and requests the appropriate discipline for detailed descriptions.
- The RAMS leader makes an appointment for an "extra RAMS meeting".

The extra one-hour RAMS meeting is held between the actual discipline leader, the RAMS leader and the HSE&Q management leader. The following tasks are carried out:

- Review of a simplified RAMS form that is actually a short RAMS analysis
- The RAMS leader transmits input/results/new measures from the simplified RAMS form to the hazard register, and save the simplified RAMS form in the same place as the report of the main RAMS analysis.

By running these meeting sessions all through the later engineering phases, the author believes on more dynamic RAMS analyses and successful implementation. Another gained value is that actors are obtaining improved ownership and confidence to the RAMS process.
5 DISCUSSION AND CONCLUSION

In Norway, as in other European countries, the railway authority defines the application of requirements found in EN 50126. Anyway, the RAMS assessments thereof must be based on the applicability of the requirements to the railway system being planned. The main part of the CENELEC standard defines the objectives, requirements, deliverables and verification activities to be undertaken through each lifecycle phase of the system. In that respect, this paper did address a RAMS process applied on railway sub-structure engineering. Project experiences tell about challenges in making the RAMS process a natural part of the project work, producing input of relevance for decision making in infrastructure planning. Too often, RAMS activities end up as a process on side of the core-business in engineering, and as an activity mostly conducted by “hired experts”. Of that reason the suggested procedure intends to close the gap between, or merge the ongoing engineering process and the more theoretical-based RAMS activities. The main strategy in this paper was to introduce closer follow-up activities towards the later project phases in engineering. Especially, this is true valuable regarding the final design decisions. At this stage, most of the system details and characteristics are known, and the RAMS analyses and evaluations would be more accurate and applicable.

5.1 Summary of suggested procedures

Gained experience as a RAMS discipline leader told us that two main RAMS analyses are appropriate to identify and control the most important hazards from the early planning of, through the construction-plan phase. The first analysis reveals hazards in the coarse detail- and development plan phase, and the second analysis focuses more on the detailed solutions, and is conducted prior to the construction-plan deliveries. These two analyses form the basis for appropriate risk reducing measures mainly as input to the ongoing engineering, but also the later operation phase. In the latter project phase we also recognized the need for a more frequent RAMS follow-up. Thus, the suggested procedure, e.g. among others the monthly RAMS-coordination meeting with stakeholders, and the fifteen-minutes RAMS review taking place in the internal project meetings, did document their value. The RAMS analyses are finally delivered as technical reports as part of the project deliveries.

5.2 Main contribution

The main contributions from this study are supposed to be improved ownership to the RAMS process among the different disciplines and stakeholders, and next, a more traceable RAMS process. Through the closer follow up, like having RAMS on the agenda more frequently and thought-through, the RAMS process would gain more value to the final project. Traceability of the RAMS activities and the delivered results are most important for the main customer and stakeholders, but also for the safety authorities. The final approval of the new railway infrastructure, as carried out by the railway authorities, is supposed to be more accurate and effective. Less time and resources are spent on extra demands, review of the RAMS documentation, and making the final statements. Another expected value generated from the engineering work is input of higher quality to the later operation- and maintenance phase. Some of the suggested measures coming from the RAMS analyses will be relevant for operation and maintenance. These are all expected consequences of improved RAMS evaluations.

6 REFERENCES


