RAMS and LCC for railway infrastructure
Part 3 - RAMS - Basics, Methods and examples
### Part 3 – RAMS

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Part 3 – RAMS
Topic 1

- Basics of RAMS
- RAMS-Analysis
- Estimation of RAMS-parameter for existing and new products
- Examples for RAMS--Analyses
- Summary and question?
Definition of RAMS
Technical specifications based on RAMS

Specifications regarding operation and maintenance quality

Description of quality specifications through RAMS values

R
Reliability

A
Availability

M
Maintainability

S
Safety

Technical specifications
The technical performance and safety is described by RAMS

**RAMS** - defined in the CENELEC-standard EN 50126 - is the abbreviation of the terms

- **Reliability** → MTBF - mean time between failure
- **Availability** → availability depends on MTBF and MTTR
- **Maintainability** → MTTR - mean time to restore / repair
- **Safety** → normative requirement

**RAMS** is according to the definition in EN 50126 a **process** or **method**, which assists the avoidance of failures already in the **planning phase of projects**.

**RAMS analyses identify the technical performance and safety on system, module or component level**
Definition of RAMS
When to use RAMS?

Technical performance and safety is described by RAMS

- **RAMS** gains in importance in all sectors of industries with high investments and risks

- **RAMS analysis** should be used during the development and implementation of new products or the planning and realisation of new assets

- **RAMS management** ensures the definition of systems, the performance of risk analysis, the identification of hazard rates, detailed tests and safety certification

- **RAMSS** includes in addition the **Security**, which means the protection of the system against attacks from extern
Depiction of system life cycle with V-model according to EN 50126 as basis for the definition of RAMS-tasks

- Concept
- System Definition
- Risk Analysis
- System Requirements
- Apportionment of System Requirements
- Design & Implementation
- Manufacturing
- System Validation
- Installation
- System Integration & Acceptance
- Project Test and Integration
- Operation & Maintenance
- Modification & Retrofit
- Decommissioning & Disposal
- Performance Monitoring

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Decision are often triggered by today investments
LCC takes into account the life cycle

Target

Cost effective systems

Decision, focused on investment, do not take into account follow-up costs.

Life cycle costing covers the costs for investment, costs for operation, maintenance and the costs for disposal and delivers the best basis for today decisions.
RAMS analyses are necessary for valid LCC

System improvements assessed by RAMS analysis

To identify the **follow-up cost** technical assessment like RAMS analyses are necessary.

A better technical performance, often connected to higher investment costs, reduces the operational costs.

The trade-off can be estimated by RAMS and LCC analyses.
Technical performance of components or sub-systems are starting points for improvements or redesign

How to optimize the infrastructure? – System approach

The spread of life time of the components is very huge.

System optimization is necessary!
The first appearance of failure is responsible for maintenance or renewal of components.

In case of broad PDF, a new design or optimization is necessary.

Over designed components should be optimized too.
The reliability and repair rate are responsible for availability

Reduction of LCC needs system approach

The required repair rate and thus the maintenance activities and costs depend on the
- Required availability
- Failure rate of the components or sub-system

The balance between technical performance and economical aspects are done by LCC

Availability depending on failure and repair rate

Availability including repair rate

Time [a]

Case 1
Case 2
Case 3
Are technical and economical optimum identical?

Reduction of LCC needs system approach

The technical optimum is not equivalent with the economical optimum in any case.

RAMS and LCC analyses, which take into account lifetime and maintenance strategies, point out the economical optimum.
Reliability is the ability of a system to perform and maintain its functions in routine circumstances, as well as hostile or unexpected circumstances.

### Typical parameters

- $\lambda(t)$ - Failure Rate
- MTTF - Mean Time To Failure
- MTBF - Mean Time Between Failures
- MTTFF - Mean Time To First Failure
- MDBF - Mean Distance Between Failures
- MCBF - Mean Cycles Between Failures
- MFDT - Mean Failure Detection Time
- RBD - Reliability Block Diagram

Reliability strongly depends on boundary conditions.
Reliability specialists often describe the lifetime of a population of products using a graphical representation called the “bathtub curve”. The bathtub curve consists of three periods: an infant mortality period with a decreasing failure rate followed by a normal life period (also known as "useful life") with a low, relatively constant failure rate and concluding with a wear-out period that exhibits an increasing failure rate.
Monte-Carlo simulation

Powerful approach to manage uncertainties on the values of some input parameters:

- RAM parameter like failure rate, MTBF, MTTR
- Unit cost value

Steps for implementation

1. **Identify** the variables with uncertainties using expert estimations
2. **Sensitivity analysis** to analyse the impact on RAM or LCC
Steps for implementation cont.

3. **Built probability distributions/probability density functions** which represent the possible values and their probability of occurrence. For the functions different approaches are possible: triangular distribution, normal distribution, lognormal distribution, uniform distribution or Weibull distributions.

The definition of the distributions functions should be done on the basis of
- a RAMS analysis,
- data bases or
- by expert estimations.
4. Run Monte-Carlo simulations
5. Interpretation of Results

Conceptual prob. distribution

Cumulative prob. distribution

Sensitivity analysis
Probabilistic approach with Monte-Carlo simulation

Alternative A
Alternative B

@80% probability alternative A has a NPV less than Alternative B

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Availability – \( A \)

- Theoretical or interior availability considers corrective maintenance
- Technical or engrained availability considers corrective and preventive maintenance

\[
A = \frac{MTTF}{MTTF + MTTR}
\]

Mean Time To Failure

Mean Time To Repair
Maintainability ensures fast repair and improvements

**Maintainability – $M$**

Maintainability is the ease with which a product can be maintained in order to:

- correct defects or their cause
- isolate defects or their cause
- meet new requirements

**Typical parameters**

- MTTR - Mean Time to Restore (Repair)
- MMH - Mean Maintenance Hours
- MDT - Mean Down Time
- MCDT - Mean Corrective Downtime
- MPDT - Mean Preventive Downtime
Safety is often a fixed requirement

**Safety – S**
Safety is the state of being "safe"

**Typical parameters**
- **HR** - Hazard Rate
- **THR** - Tolerable Hazard Rate

**Analyses**
- **FME(C)A** - Failure Mode, Effects (and Criticality) Analysis
- **FTA** - Fault Tree Analysis
- **HA** - Hazard Analysis
- **ETA** - Event Tree Analysis
# RAMS

**Technical performance and safety described by RAMS**

## Typical key parameters and analyses

### Reliability - \( R \)
- \( \lambda (t) \) - Failure Rate
- MTTF - Mean Time To Failure
- MTBF - Mean Time Between Failures
- MTTFF - Mean Time To First Failure
- MDBF - Mean Distance Between Failures
- MCBF - Mean Cycles Between Failures
- MFDT - Mean Failure Detection Time
- RBD - Reliability Block Diagram

### Availability - \( A \)
- Theoretical or interior availability considers corrective maintenance
- Technical or engrained availability considers corrective and preventive maintenance

\[
A = \frac{MTTF}{MTTF + MTTR}
\]

### Maintainability - \( M \)
- MMH - Mean Maintenance Hours
- MDT - Mean Down Time
- MCDT - Mean Corrective Downtime
- MPDT - Mean Preventive Downtime
- MTTR - Mean Time to Restore (Repair)

### Safety - \( S \)
- HR - Hazard Rate
- THR - Tolerable Hazard Rate
- FME(C)A - Failure Mode, Effects (and Criticality) Analysis
- FTA - Fault Tree Analysis
- HA - Hazard Analysis
- ETA - Event Tree Analysis

```markdown
RAMS Technical performance and safety described by RAMS

Typical key parameters and analyses

<table>
<thead>
<tr>
<th><strong>Reliability - ( R )</strong></th>
<th><strong>Maintainability - ( M )</strong></th>
<th><strong>Safety - ( S )</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda (t) )</td>
<td>MMH</td>
<td>HR</td>
</tr>
<tr>
<td>MTTF</td>
<td>MDT</td>
<td>THR</td>
</tr>
<tr>
<td>MTBF</td>
<td>MCDT</td>
<td>FME(C)A</td>
</tr>
<tr>
<td>MTTFF</td>
<td>MPDT</td>
<td>FTA</td>
</tr>
<tr>
<td>MDBF</td>
<td>MTTR</td>
<td>HA</td>
</tr>
<tr>
<td>MCBF</td>
<td></td>
<td>ETA</td>
</tr>
<tr>
<td>MFDT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RBD</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
A = \frac{MTTF}{MTTF + MTTR}
\]

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Standards in the railway sector regarding RAMS

ISO 55000 / PAS 55 Asset management

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Interlink between RAMS and LCC
Technical and economical performance are strongly connected

Specifications regarding operation and maintenance quality

Description of quality specifications through RAMS values

- Reliability (R)
- Availability (A)
- Maintainability (M)
- Safety (S)

LCC

Specifications regarding total life cycle costs

Cost / Benefit

Technical specifications

Operation & Maintenance

Economical specifications

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Part 3 – RAMS
Topic 2

Basics of RAMS
RAMS-Analysis
Estimation of RAMS-parameter for existing and new products
Examples for RAMS-Analyses
Summary and question?
RAMS and LCC need a system description
The weakest element defines the system behavior!

Availability or reliability of railway system

Availability of system depends on availability of sub systems

Availability of railway system depends on availability of systems

Availability of sub system depends on availability of components

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Technical evaluation
RAMS analysis

RAMS analysis according EN 50126

**Boundary conditions**
- System description
- Operation and environment
- LCC analysis

**RAMS-Analysis**
- Hazzard and Risk analysis
- Reliability analysis
- Analysis of maintainability
- Analysis of availability

**Methods**
- Failure mode and effect analysis (FMEA)
- Fault tree analysis (FTA)

**Results**
- MTTF
- MTBF
- MTTR
- MTTM
- MUT
Technical evaluation
RAMS analysis

Simplified RAMS analysis

**Boundary conditions**
- System description
- Operation and environment
- LCC analysis

**RAMS-Analysis**
- Reliability analysis
- Analysis of maintainability
- Analysis of availability

**Methods**
- Expert estimation
- ABC-Analysis Pareto-Analysis

**Results estimation**
- MLTF
- MLBF
- MTTR
- MTTM
- MUT
1. System description and system analysis
   • Technical description of system
   • Specialties of use and operation
   • Technical description of sub-systems
   • Technical description of components

2. Definition of operational and environmental boundaries
   • Reference site: high speed line Nurnberg-Ingoldstadt
   • Identification of relevant operational conditions
   • Environmental conditions
3. Hazard and risk analysis
   • Description of risks and hazards
   • Frequency and rate of hazard
   • Assessment of risk in frequency-consequence matrix

4. Reliability
   • Targets for reliability (requirements of owner, system provider)
   • Definition of kinds of system-failures
   • Reliability analysis – FMEA, field experiences

5. Availability
   • Availability targets (demands of operator or system provider)
   • Availability analysis – data evaluation
Procedure

6. Maintenance and repair
   • Preventive maintenance, demands of system provider, operator
   • corrective maintenance (operator)
   • Maintainability analysis (results of FMEA)

7. Safety
   • Safety targets
   • Hazard states
   • Safety relevant functions and breakdowns / malfunction
   • Risk analysis– FMECA
# Safety

## Risk assessment – definitions and principles acc. EN 50126

**Differences between risk analysis, risk assessment and risk management**

<table>
<thead>
<tr>
<th>Step</th>
<th>Identification and description of hazard</th>
<th>Estimation of risk</th>
<th>Evaluation of risk</th>
<th>Control of risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notation in IEC 61508</td>
<td>Hazard identification</td>
<td>Risk estimation</td>
<td>Risk evaluation</td>
<td>Safety requirements</td>
</tr>
<tr>
<td></td>
<td>Risk analysis</td>
<td></td>
<td></td>
<td>Monitoring of safety performance in operation</td>
</tr>
<tr>
<td></td>
<td>Risk assessment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Risk management</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Safety requirements are part of an iterative risk evaluation if the system can't operate in a tolerable state

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How to define risk?

Risk is the product of probability of occurrence and severity of incident

Risk analysis

Risk analyses have to be undertaken and documented at different phasis of the system

- Method used for risk analyses
- Assumption, limits and vindication of the method
- identified hazards
- Results and reliability of risk estimation
- Results of comparative studies
- Data, sources and reliability of data
- References
### Severity of incidents

<table>
<thead>
<tr>
<th>Severity Level</th>
<th>Consequence to Persons or Environment</th>
<th>Consequence to Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catastrophic</td>
<td>Fatalities and/or multiple severe injuries and/or major damage to the environment</td>
<td></td>
</tr>
<tr>
<td>Critical</td>
<td>Single fatality and/or severe injury and/or significant damage to the environment</td>
<td>Loss of a major system</td>
</tr>
<tr>
<td>Marginal</td>
<td>Minor injury and/or significant threat to the environment</td>
<td>Severe system(s) damage</td>
</tr>
<tr>
<td>Insignificant</td>
<td>Possible minor injury</td>
<td>Minor system damage</td>
</tr>
</tbody>
</table>
## Probability of occurrence

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent</td>
<td>Likely to occur frequently. The hazard will be continually experienced.</td>
</tr>
<tr>
<td>Probable</td>
<td>Will occur several times. The hazard can be expected to occur often.</td>
</tr>
<tr>
<td>Occasional</td>
<td>Likely to occur several times. The hazard can be expected to occur several times</td>
</tr>
<tr>
<td>Remote</td>
<td>Likely to occur sometime in the system lifecycle. The hazard can reasonably be expected to occur</td>
</tr>
<tr>
<td>Improbable</td>
<td>Unlikely to occur, but possible. It can be assumed that the hazard will exceptionally occur.</td>
</tr>
<tr>
<td>Incredible</td>
<td>Extremely unlikely to occur. It can be assumed that the hazard may not occur.</td>
</tr>
</tbody>
</table>
**Risk Categories**

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Actions to be applied against each category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intolerable</td>
<td>Shall be eliminated</td>
</tr>
<tr>
<td>Undesirable</td>
<td>Shall only be accepted when risk reduction is impracticable and with the agreement of the Railway Authority or the Safety Regulatory Authority, as appropriate</td>
</tr>
<tr>
<td>Tolerable</td>
<td>Acceptable with adequate control and with the agreement of the Railway Authority</td>
</tr>
<tr>
<td>Negligible</td>
<td>Acceptable with the agreement of the Railway Authority</td>
</tr>
</tbody>
</table>
## Hazard Risk Matrix

<table>
<thead>
<tr>
<th>Frequency of occurrence of a hazardous event</th>
<th>Risk Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent</td>
<td>Undesirable</td>
</tr>
<tr>
<td>Probable</td>
<td>Tolerable</td>
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<td>Marginal</td>
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<tr>
<td>Insignificant</td>
<td>Critical</td>
</tr>
<tr>
<td>Insignificant</td>
<td>Catastrophic</td>
</tr>
</tbody>
</table>

**Severity Level of Hazard Consequence**
Safety
Risk assessment – definitions and principles acc. EN 50126

Structure and outline

1. Target or scope of analysis
2. Procedure, method and structure of analysis
3. System definition
   - Description, interfaces and delimitation of system
   - Conditions of use and boundaries
4. Risk analysis
   (1) Identification of accidents
      - Definition of accident categories (catastrophic, critical, non-critical failure, ...)
      - Probability of accident (frequent, probable, occasional ...)
      - Accident level: consequence-analysis for estimation of possible consequences
      - Hazard-Risk-Matrix: Combination of probability of occurrence of an accident with the severity of consequences
      → Result: Identification hazards (Hazard and Operability Studies HazOp)
Safety
Risk assessment – definitions and principles acc. EN 50126

Structure and outline

(2) Definition of type of examination for each hazard
   a) Accepted rules and standards
   b) Comparison with reference system
   c) Explicit risk estimation

(3) explicit risk estimation in case of c)
   - Risk calculation
     → Result: relative and qualitative/quantitative classification of risk

5. Risk assessment
   - Decision if risk is tolerable

6. Risk management
   - Measure to reduce or avoid identified risks

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Approach and structure of analysis

*System analyses / system definition:* Description of the system, module or process with respect to essential properties and functions that should be assessed.

**Hazard and Operability Analysis - HAZOP:**
Analysis of possible states of the system (normal- or disturbed operation) and consequences on the safety of the railway system
Identification of all hazards and their consequences
Result: documentation of all hazards

Methods for systematic identification of hazard:

**Fault Tree Analysis, FTA**

or

**Event Tree Analysis, ETA**
Technical evaluation
RAMS analysis

RAMS analysis for new product according EN 50126

Boundary conditions
- System description
- Operation and environment

RAMS-Analysis
- Hazzard and Risk analysis
- Reliability analysis
- Analysis of maintainability
- Analysis of availability

Methods
- Failure mode and effect analysis (FMEA)
- Fault tree analysis (FTA)

Results
- MLTF
- MLBF
- MTTR
- MTTM
- MUT

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RAMS are essential for 24 hour operations. You have to know the technical performance.

Requirements regarding reliability, availability and maintainability of infrastructure strongly depends on train free period.

**Case 1:** All maintenance is possible in train free periods

**Case 2:** Maintenance partly possible in train free period

**Case 3:** Maintenance during train operation reduces availability

⇒ RAMS and LCC ensure economical decisions for future demands.
### Why to use RAMS and LCC in optimization process?

<table>
<thead>
<tr>
<th>Status Quo</th>
<th>Innovation/Optimisation</th>
<th>Economical effects</th>
</tr>
</thead>
</table>
| **Technical performance**  
  - Reliability  
  - Availability  
  - Maintainability  
  - …  
| **Technical performance**  
  - Reliability  
  - Availability  
  - Maintainability  
  - Tolerance against conditions  
  - …  
| **Change in initial investment** (t=0)  
**Migration costs**  
**Costs for new regulations**  
**Decreasing costs for environmental sustainability**  
**Decrease maintenance cost**  
**Decrease costs for non availability**  
**…**  
| **Environmental perform.**  
  - Noise  
  - Ground born vibration  
  - …  
| **Environmental perform.**  
  - Noise  
  - Ground born vibration  
  - …  
| **Additional income?**  
| **Costs (drivers)**  
  - Investment  
  - Operation  
  - Maintenance  
  - Non availability  
| **Change in Costs**  
  - …  
| **Traffic prognosis**  
| **Social economical effects**  
|
### Part 3 – RAMS

**Topic 3**

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<td>Summary and question?</td>
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How to get RAM(S) – parameter for existing or new products?

1. Description of system

- Identification of relevant sub-systems and components e.g. on basis of availability of sub-system and components

  \[ A_{Sub,i} = A_{C,1} \cdot A_{C,2} \cdot \ldots \cdot A_{C,n} \]

  \[ A_{System} = A_{Sub,1} \cdot A_{Sub,2} \cdot \ldots \cdot A_{Sub,n} \]

- Adapted breakdown of system or sub-system

- Pareto-analysis for further reductions of complexity
How to get RAM – parameter for existing and new products?

2. Analysis of existing products

- Analyses of maintenance activities and collection of related boundary conditions
- Analyses of measurements
- Estimation of experts
- Calculation of RAM parameters for sub-system from components
How to get RAM – parameter for existing and new products?

3. Estimation of behaviour of new products

- Technical analysis like
  - Failure mode and effect analysis (FMEA) or
  - Fault tree analysis (FTA)
- Calculation with simulation models
- Field tests
- Laboratory tests
- Expert estimations from operators
- Sensitivity analysis of system behaviour
- Estimation from suppliers

Advantage: sharing risks between suppliers and operators regarding new products or processes
Calculation of reliability from maintenance history
Part 3 – RAMS

Topic 4

Basics of RAMS

RAMS-Analysis

Estimation of RAMS-parameter for existing and new products

Examples for RAMS-Analyses

Summary and question?
RAMS and LCC Analysis for slab track

RAMS- and LCC Analysis for German slab track supplier

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Approach

1. Analysis status quo
   - Hattstedt
   - Rott-Malsch
   - NBS N-In

2. RAMS-Analysis
   - Supplier information
   - DB - experiences
   - P300

3. LCC-Analysis
   - Slab track
   - Ballasted track
   - P300 (NBS N-In)

Restrictions
- Data (Experiences)
- Transfer of experiences
- Distribution functions

Restrictions:
- RAMS-values
- Mean values
- Mean state of system
Technical evaluation
RAMS analysis

RAMS analysis for new slab track according EN 50126

Boundary conditions
- System description
- Operation and environment

RAMS-Analysis
- Hazard and Risk analysis
- Reliability analysis
- Analysis of maintainability
- Analysis of availability

Methods
- Failure mode and effect analysis (FMEA)
- Fault tree analysis (FTA)

Results
- MLTF
- MLBF
- MTTR
- MTTM
- MUT
Technical evaluation
RAMS analysis

Procedure

Technical evaluation of possible solutions

- **Specification** of general **requirements** and boundary conditions
  - Availability – MTTR, MTTM, MUT
  - Reliability – MLBF, MLTF
  - Environmental requirements, noise, ground borne vibration
  - Safety requirements
  - case study derailment of freight or high speed passenger train
  - Risk of settlement of sub-structure
  - Installation costs
  - Longitudinal displacement of bridge due to temperature
  - Temperature ranges
  - Worst load case
  - Switches
Technical evaluation
RAMS analysis

Technical evaluation of possible solutions

- Specification of technical requirements like
  - Design relevant parameters like strains, stresses, deflection, loading, etc.
  - Installation, adjustable track geometry
  - Correction of track geometry during operation
  - Noise protection
  - Expansion joints

- Translation of requirements in criteria’s for evaluation
  - Fixed requirements – knock-out criteria
  - Requirements
  - Nice to have

- Definition of criteria's taken into account the risks of non proofed or novel systems as in FMEA
Technical evaluation
RAMS analysis

Procedure cont.

Technical evaluation of possible solutions

- Definition of weight and evaluation factors for non fixed criteria’s  
  e.g. 1 to 10 like used in FMEA
- Compilation of possible slab track solutions
- Estimation of technical risks, RAM(S) “analysis” - expert estimation
- Evaluation of ballasted track as the reference solution
- Evaluation of slab track solutions

Results of technical evaluation

- Documentation of evaluation process
- Traceable ranking of solution
- Basis for LCC analysis
Technical evaluation
RAMS-Analysis

Procedure

Construction- and System-FMEA

⇒ Basis for RAMS-analysis
  ⇒ Reliability analysis
  ⇒ Availability analysis
  ⇒ Maintainability
  ⇒ Safety

Structure  Functions  Failures  Measure, Assessment  Faulttree (FTA)
System description / focus of analysis

Focus on analysis of supplier specific sub systems and components
Sub system – track plate

Sub systems and components of track plate

Description of function and failure analysis

- Net of functions
- Net of failures
Technical evaluation
FMEA

Sub system – track plate

Example for net of sub functions – electrical connection within track plate

- Gleistragplatte
  - Technische Nutzungsdauer >= 60 Jahre
- Feste Fahrbahn System Bögl
  - Einhalten der Umweltschutzbestimmungen und Mitweltverträglichkeit
- Gleistragplatte
  - Technische Nutzungsdauer >= 60 Jahre
- Gleistragplatte
  - Erdung und Rückstromführung
- Erdung GTP
  - Vermeiden thermischer Belastung in Bewehrung
- Erdung GTP
  - Gewährleistung von elektromagnetischer Verträglichkeit
- Erdung GTP
  - Vermeiden von Kriechströmen
- Erdung GTP
  - Begrenzen der Berührungsspannung auf zulässigen Wert

Längsbewehrung Erdung elektrische Verbindung innerhalb der Tragplatte

- Merkmale Längsbewehrung
  - Durchmesser Längstab für Erdung >= 16 mm
- Merkmale Längsbewehrung
  - Anzahl Längsstäbe für Erdung >= 3
- Merkmale Längsbewehrung
  - Schweißnahtlänge >= 200 mm
- Merkmale Längsbewehrung
  - Obere Bewehrungslage
- Merkmale Längsbewehrung
  - Mindestbetondeckung: 5cm
Sub system – track plate

Example for net of sub failure – coupling of plates – bulging of plates

- Längskoppelstab
  - Keine ausreichende Verspannung der GTP
- Mutter
  - Zugspannung in Längskoppelstab zu gering
- Längskoppelstab
  - Versagen des Längskoppelstabs
- Mutter
  - Ermüdung der Schraubverbindung
- Spannschloss
  - Bruch bei Verspannung
- Spannschloss
  - Ermüdung des Spannschlosses
- Verguss
  - Zerstörung des Vergusses

- Koppelfuge
  - Aufwölbung der Platten bei hohen Temperaturgradienten

- Gleistragplatte
  - Überbelastung der GTP, Unterguss oder HGT

- Schrumpfschlauch
  - Schrumpfschlauch nicht wasserdicht

DB Netz AG and UIC - RAMS and LCC for infrastructure, Istanbul 2014
Technical evaluation
FMEA

Assessment and prioritization

Measure-analysis, Assessment

Target

Assessment of the status quo, identification of measures for avoidance and detection; denomination of responsible persons and dates

Prioritizing acc. \( S \times P \times D = \text{RPN} \)

\( S \) ... like Severity (e.g. 10 very critical, 1 non-critical)
→ Assessment index defines the **consequence of failure**

\( P \) ... like Probability
(e.g. 1 long-term experience, 8 use of new technology)
→ Assess the probability of the **appearance of the failure**, taken into account all measures for avoidance

\( D \) ... like Detection
(e.g. 3 apparent defect, 10 no detection possible)
→ Assess the probability of the detection of the cause, type or consequence of a failure with the defined detection measures

\( \text{RPN} \) ... Risk priority number
Product from \( S \times P \times D \), points out the ranking of the risk in system (e.g. \( 10 \times 8 \times 10 = 800 \))
## Example for calculation of RPN from S, P, D

### FMEA (Failure Mode and Effect Analysis)

<table>
<thead>
<tr>
<th>System Element</th>
<th>System Element: Stützpunkt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>Montage der Schraubenbefestigung auf der GTP ermöglichen</td>
</tr>
<tr>
<td>Einbau im vorgegebenen Geometriepunkt</td>
<td>9 Montage der Schraubenbefestigung auf der GTP ermöglichen</td>
</tr>
<tr>
<td>Fehlerfolge</td>
<td>B Fehler, K Vermeidungsmöglichkeit</td>
</tr>
</tbody>
</table>

**Assessment of severity of failure with „9“, fatal**

**Estimation of probability of failure with „4“, moderate, i.e. Known system with changed boundary conditions**

\[ S \times P \times D = RPN \]

**Estimation of the probability of detection; „6“, moderate, i.e.. Known system with changed boundary conditions**

---

DB Netz AG and UIC - RAMS and LCC for infrastructure, Istanbul 2014
Results of FMEA

Results

The evaluation of the FMEA results in low risk priority numbers. (Pareto analysis) and point out some potential for improvements for some part of the construction.

The results are basing on calculations and experiences and are reliable.

The installation quality is ensured by a quality management system.
Results of RAMS-analysis

Manufacturer specific requirements

Targets for reliability: no
Requirements for preventive maintenance: no
Requirements for corrective maintenance: no, disaster concept

Operator and IM specific requirements

Targets for reliability: yes, Delays less than 5 minutes
Targets for availability: yes, 20 h/a between 5:00 and 1:00 o'clock

Requirements for preventive maintenance: no
Requirements for corrective maintenance: yes, defined in standards

Result: the technical requirements of operator and IM are completely fulfilled!
Results of RAMS-analysis

Incidents regarding reliability concentrate mainly on
- rail
- grounding
- coupling of plates
- steel for lateral pre-stressing of plate
- track plate and
- grouting.
RAMS basics
To perform an effective RAM(S) study

1. Definition of the scope
   • objectives and scope
   • responsibilities and time schedule
   • RAMS management and related boundaries

2. System description and operational and environmental boundaries
   • definition of RAMS parameters and targets
   • definition of the boundary conditions, system description incl. the interfaces between systems/sub-systems/components
   • operational (modes of operation, life expectancy) and environmental conditions
   • definition of the reliability, availability, maintainability and safety targets
   • definition of variant study
   • definition of system requirement specifications

3. Data assessment
   • collection and processing of data
   • analysis and assessment of data
RAMS basics
To perform an effective RAM(S) study

4. RAMS analysis
   • calculation tool for RAM analysis
   • RAM modelling, review of RAM models
   • RAM analysis incl. hazard and risk analysis methods (FMEA, ETA etc.)
   • interpretation of results
   • taking reference to the defined specifications, compare the achieved results with expectations and demands
   • validation of RAM calculation

5. RAM results as input for combined RAMS & LCC analysis

6. Social cost-and-benefit analysis

7. Proof of RAMS performance

8. Documentation of input and output parameters and follow-up of the gathered data
Abu Dhabi Metro Study – Scope of work regarding the System Assurance Plan (ADMS Stages 1 to 5)

Design / Construction Phase of a Project

**Project Stages**
- Planning
- Preliminary Design
- Contracting
- Detailed Design
- Manufacturing
- Installation
- Testing & Comm.
- Trial Operations
- Revenue Operation
- End of Project

**ADAPT Stage**
- Stage 1: Feasibility Study
- Stage 2: Preliminary Design
- Stage 3: Tender Process
- Stage 4: Design Review & Contract Administration
- Stage 5: Defects Liability & Project Close-Out

**EN 50126 Phase**
- Phase 1
- Phases 2 - 5
- Phase 6 - 9
- Phase 10
- Phase 11
- Phase 12-14

**Phase Related RAM Tasks**
- Phase 1: Set RAM Policy
- Phase 2 - 5: Implement RAM Programme
- Phase 6 - 9: FRACAS (Commence Failure Reporting & Corrective Action System) and DRACAS
- Phase 10: Assess RAM Demonstration
- Phase 11: On going Procurement of spare Parts & tools
- Phase 12-14: Performance Monitoring

**RAM Management**
- Set RAM Policy
- O & M Conditions and Impact
- Establish RAM Programme and
- RAM Improvement Testing
- FRACAS (Commence Failure Reporting & Corrective Action System) and DRACAS

**System Definition & Application**
- System Requirements & Apportionment of System Req.
- System definition & Application Conditions

**Previously achieved RAM Performance**
- RAM/LCC implications

**Performance Monitoring**
- Modification and Retrofit
- Decommissioning & Disposal

**Maintenance, Logistic Support**
- Performance Monitoring
- Modification and Retrofit
- Decommissioning & Disposal

**69**
The System Assurance Plan of the Abu Dhabi Metro study requires the overall consideration and assessment of the infrastructure, rail systems, rolling stock, other systems and their interfaces.

**Integrated RAM case**
- Dealing with RAM analysis in a professional way in terms of taking the entire Railway System into consideration
- Customer – Infrastructure – Rolling Stock – Operation – Maintenance – Monitoring
- Operating Efficiency transport system that meets the needs of residents, visitors, and businesses in the most efficient, safe, attractive, reliable, and environmentally sustainable way

**Infrastructure**
- Track, Tunnel, Stations etc.
- Depot and workshop facilities

**Rolling Stock**
- Principles, Technical Characteristics
- Train/Car Formulation, Metro Train

**Operation & Maintenance**
- Policies and Procedures
- Competency and Training

**Rail System**
- Signaling, Train Control (ATC)

**Other System Interfaces**
- PSD, Power Supply System, System Integration, Engineering Safety etc.
Interaction between RAMS and LCC (combined RAMS and LCC analyses)

Specifications regarding operation and maintenance quality

Description of quality specifications through RAMS values

R
Reliability
A
Availability
M
Maintainability
S
Safety

Procurement  Operation  Maintenance  Non-Availability

LCC

Specifications regarding total life cycle costs

Cost / Benefit

Technical specifications
Operation & Maintenance
Economical specifications

DB Netz AG and UIC - RAMS and LCC for infrastructure, Istanbul 2014
Abu Dhabi Metro Study – Procedure to define the RAM targets/requirements within Stage 1

(1) System description and definition of Boundary conditions incl. **Operation, Maintenance and environmental conditions** which affect the Availability, Reliability & Maintainability of the system.

(2) Estimation of the **RAM requirements** to meet the requirements of the specific application: result is proposal and recommendation of Reliability/Availability/Maintainability targets at high level.

(3) Consider **RAM and LCC implications** of the variants
   - define and document the **potential failures** requiring prompt action and affecting the Reliability and Availability
   - define **MTBF** and **MTTR** which affect Operation, Maintenance and the overall performance
   - perform a preliminary system compatibility analysis (**FTA, FMEA and Risk analysis**)
   - perform LCC estimation

(4) To evaluate **Reliability targets** for the respective systems

(5) To evaluate the **system interactions**. For transformation of RAM requirements in technical criteria’s of the concerned design/construction. These interactions are such as:
   - between RAM and LCC,
   - between single RAM parameters and
   - between the single systems, e. g. interaction between track and rolling stock

DB Netz AG, Systemschnittstelle Infrastruktur, I.NVT 8, Wali Nawabi, 21.02.2013
Slab track:
- Cracks in concrete
- Loosening of fastening elements
- Settlement of foundation

Switches:
- Renewal of switch
- Renewal of crossing
- Failure with operating of switch

Rail:
- Renewal of rail
- Rail breakage

Question:
Is this activity possible within the time for Maintenance?
If yes, the Availability target is achievable.
If not, there is an impact on Availability.

Measures/Provisions:
- change of Maintenance regime (shortened interval; monitoring; )
- demand for better technique solution (better material, better technology)
Initial Concept and Technical Parameters according to “O & M Strategy Report”

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBD — Airport (via Airport Express)</td>
<td>16 minutes</td>
</tr>
<tr>
<td>CBD — Airport (via “Metro”)</td>
<td>45 minutes</td>
</tr>
<tr>
<td>CBD — Capital District</td>
<td>29 minutes</td>
</tr>
<tr>
<td>Capital-District — Airport</td>
<td>16 minutes</td>
</tr>
<tr>
<td>Dwell Times</td>
<td>30 — 45 seconds</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Periods</th>
<th>Minimum Headways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak-period</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Off-peak period</td>
<td>10 minutes</td>
</tr>
</tbody>
</table>

Metro services: 06:00 am and 01:00 am
Maintenance: 01:00 am and 06:00 am

DB Netz AG, Systemschnittstelle Infrastruktur, I.NVT 8, Wali Nawabi, 21.02.2013
Example: As a consequence of the defined set of technical data

- **Operation Time:** **06:00 am and 01:00 am each day**
- **Time for Maintenance:** **01:00 am and 06:00 am each day = 5 hours**
- **MTTR:** $<< 5$ hours otherwise there will be a reduction of Availability

<table>
<thead>
<tr>
<th>Operation Time</th>
<th>19</th>
<th>hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Down time</td>
<td>5</td>
<td>hours per day</td>
</tr>
<tr>
<td>Availability Target</td>
<td>0.995</td>
<td>%</td>
</tr>
<tr>
<td>Up Time</td>
<td>19.00</td>
<td>hours</td>
</tr>
<tr>
<td></td>
<td>0.005</td>
<td>%</td>
</tr>
<tr>
<td>Down Time p. a.</td>
<td>35</td>
<td>hours p. a.</td>
</tr>
<tr>
<td>MTTR</td>
<td>4.0</td>
<td>hours</td>
</tr>
<tr>
<td>Switch Failure</td>
<td>9</td>
<td>Failures p. a.</td>
</tr>
<tr>
<td>MTBF (min)</td>
<td>42</td>
<td>days p. a.</td>
</tr>
</tbody>
</table>

E. g. 20 Switches: MTTR=4 hrs; F=34/4=8 failures; MTBF=8/20=0.43 p. a.; $\lambda (t)=1/MTBF=1/0.43=2.3$
Abu Dhabi Metro Study – Procedure to define the RAM targets/requirements within Stage 1

Interrelation between Availability and MTTR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation Time</td>
<td>19</td>
<td>hours</td>
</tr>
<tr>
<td>Down time</td>
<td>5</td>
<td>hours per day</td>
</tr>
<tr>
<td>Availability</td>
<td>0,990</td>
<td>%</td>
</tr>
<tr>
<td>Up Time</td>
<td>19</td>
<td>hours</td>
</tr>
<tr>
<td></td>
<td>0,01</td>
<td>%</td>
</tr>
<tr>
<td>Down Time p. a.</td>
<td>69</td>
<td>hours p. a.</td>
</tr>
<tr>
<td>MTTR</td>
<td>4</td>
<td>hours</td>
</tr>
<tr>
<td>Switch Failure</td>
<td>17</td>
<td>Failures p. a.</td>
</tr>
<tr>
<td>MTBF (min)</td>
<td>21</td>
<td>days p. a.</td>
</tr>
</tbody>
</table>

Impact on MTBF, RAM

Impact on Cost (LCC)
Abu Dhabi Metro Study – Definition of provisional RAM targets for the overall system at a high level

<table>
<thead>
<tr>
<th>System</th>
<th>RAM Target (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollingstock</td>
<td>99.77%</td>
</tr>
<tr>
<td>Automatic Train Control</td>
<td>99.87%</td>
</tr>
<tr>
<td>Platform Screen Doors</td>
<td>99.97%</td>
</tr>
<tr>
<td>Automatic fare Collection</td>
<td>97.50%</td>
</tr>
<tr>
<td>Escalators</td>
<td>98.00%</td>
</tr>
<tr>
<td>Elevators</td>
<td>98.00%</td>
</tr>
<tr>
<td>Communications systems</td>
<td>99.75%</td>
</tr>
<tr>
<td>Power supply systems</td>
<td>99.95%</td>
</tr>
<tr>
<td>Tunnel, station and track</td>
<td>99.95%</td>
</tr>
<tr>
<td>Depot and workshop facilities</td>
<td>97.50%</td>
</tr>
<tr>
<td>Total ADM: reliability as a system</td>
<td>99.02%</td>
</tr>
</tbody>
</table>
The RAM targets chosen for the Abu Dhabi metro are based on international best practice during the normal life period of a system ("bathtub curve"). Lower Availability will be expected during the infant mortality and end of life periods.
Abu Dhabi Metro Study – Definition of provisional RAM targets for the overall system at a high level

Boundary threats:

- The RAM Targets do **not factor in boundary threats** (i.e. external factors that have an impact on the ability of the system to deliver the performance targets).

- **Boundary threats** to the system are identified as but not limited to the availability of:
  - Electrical supply for traction and station services power;
  - Mains water supply;
  - External communications links, including telephone and data transfer capabilities;

- It is assumed that external **Service Level Agreements** will be made between these **service providers** and the **Abu Dhabi government** under a yet to be determined structure. Accordingly these agreements should set performance targets commensurate with the previously defined RAM targets.
Part 3 – RAMS
Could you follow?

Basics of RAMS
RAMS-Analysis
Estimation of RAMS-parameter for existing and new products
Examples for RAMS-Analyses
Summary and question?
PART 3 addresses ...

- RAMS and LCC are strongly connected and need a system description.
- Technical performance of components or sub-systems are starting points for improvements or redesign.
- Estimation of RAMS parameters are possible.
- RAMS analysis are necessary to fulfil customer requirements
- RAMS analyses need a **frame work** (methods, documentation, resources, ....)
- FMEA is a structured method to identify the weak points of a design, production or process
- FMEA delivers the input needed for reliability, maintainability and safety
RAMS and LCC for Infrastructure
Do you have questions?

Questions and answers

- Q:
- A:
- Q:
- A:
End of part 3 …

Let’s have a short break!