



Committee on Technical Cooperation in the Development of the Rail Transport System / 11th July 2016

Reliability, Availability, Maintainability, Safety (RAMS) and Life Cycle Costs (LCC)

- Major characteristics, definitions and basic terms related to the issue RAMS/LCC
- Goals, background and benefits of the reliability, availability and life cycle cost calculations
- European Standards to support the management and control of RAMS
- Reliability and LCC calculation based on real life example

Prediction is very difficult, especially if it's about the future.

Niels Bohr, winner of the Nobel Prize in Physics

- **Reliability**
- **Availability**
- **Maintainability**
- **Safety**

Considering RAMS for railway applications is necessary because of

- Requirements stipulated in tenders.
- Obtaining a certainty in costs for maintaining the rail system.
- The prevention of image loss due to unreliable rail systems.
- The need to verify that safety-relevant incidents occur “seldom enough”.

Goal: The railway system achieves a **defined level of rail traffic** in a **given time** under **safe conditions**.

How can RAMS standards help to achieve the goal?

- RAMS standards provide guidance what to do in order to increase the confidence that the system guarantees the achievement of this goal.
 - RAMS standards describes how to specify targets in terms of reliability, availability, maintainability and safety.
 - RAMS standards define systematic processes to demonstrate that these targets are achieved.
 - RAMS standards define the responsibilities within the RAMS process throughout the life cycle, i.e. who is doing what in which phase of the life cycle of the railway system.
- ➔ Railway RAMS has a clear influence to system functionality, frequency of service, regularity of service, fare structure, etc. and thus help to **increase the quality of transport service** delivered to the customer.

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Reliability

Probability that an item can perform a required function under given conditions for a given time interval.

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Availability

Ability of a product to be in such a state to perform a required function under given conditions at a given time interval.

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Maintainability

Probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval.

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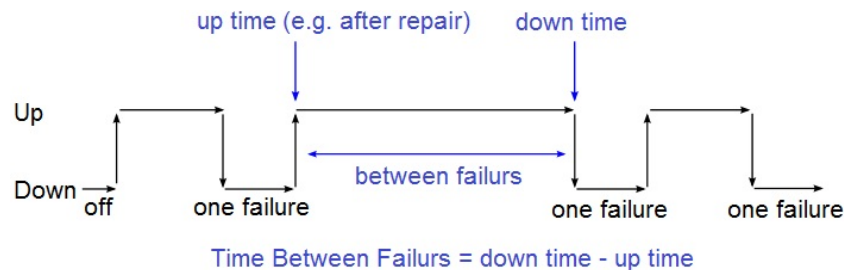
Safety

Freedom from unacceptable risk of harm.



Reliability is quantified as Mean Time Between Failures (MTBF).

The MTBF can be calculated as the arithmetic mean (average) time between failures of a system.



$$MTBF = \frac{\sum (\text{start of downtime} - \text{start of uptime})}{\text{number of failures}}$$

- Mean time between failures (MTBF) describes the expected time between two failures for a repairable system
- Example:
 - Three identical systems starting to function properly at time 0 are working until all of them fail.
 - The first system failed at 100 hours, the second failed at 120 hours and the third failed at 130 hours.
 - The **Reliability** of the system is described by the average of the three failure times, which is MTBF = 116.67 hours



- A different, more manageable unit is used in practice: FIT = Failure in time
- FIT stands for the number of failures during a time interval of 1,000,000,000 hours.

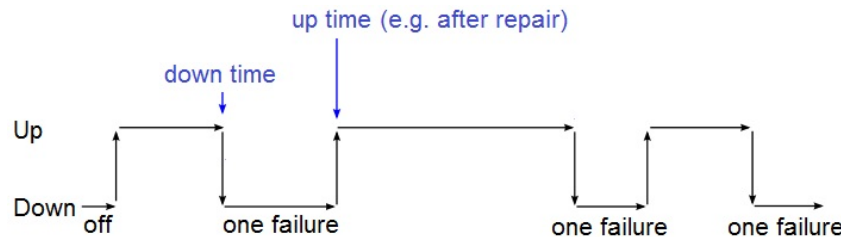
$$\text{Failure rate Lambda } \lambda = \frac{1.000.000.000h}{MTBF} \quad \text{Unit: FIT}$$

- Failure rates of individual components in a system in [FIT] are simply added up:

$$\lambda_1 + \lambda_2 + \lambda_3 + \dots = \lambda_{total}$$



Availability, expressed as A, is the ratio of the total time a system is capable of being used (MTBF) during a given interval which includes both the operational periods (MTBF) and all downtimes (MDT).



$$A = \frac{MTBF}{MTBF + MDT}$$

- Mean down time (MDT) is the average time that a system is non-operational. It includes repair, corrective and preventive maintenance, self-imposed downtime, and any logistics or administrative delays

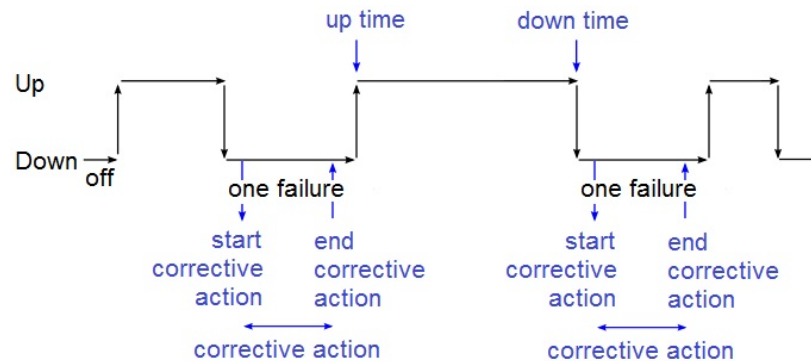
$$MDT = \frac{\sum (\text{start of uptime} - \text{start of downtime})}{\text{number of failures}}$$

- Example: A unit that is capable of being used 100 hours per week (168 hours) would have an Availability of $100/168 = 0.595$



Maintainability is quantified as the Mean Time To Repair (MTTR).

MTTR is the basic measure of the maintainability of repairable items and represents the average time required to repair a failed component or device.



$$MTTR = \frac{\sum (\text{end of corrective action} - \text{start of corrective action})}{\text{number of corrective actions}}$$

- Expressed mathematically, it is the total corrective maintenance time for failures divided by the total number of corrective maintenance actions for failures during a given period of time.
- It generally does not include lead time for parts not readily available or other administrative or logistic downtimes.



Safety can be described by means of the Safety Integrity Level (SIL).

The assignment of SIL is an exercise in risk analysis where the risk associated with a specific hazard to be protected against is calculated .

The Tolerable Hazard Rate (THR) is a figure which guarantees that the resulting risk does not exceed the target risks

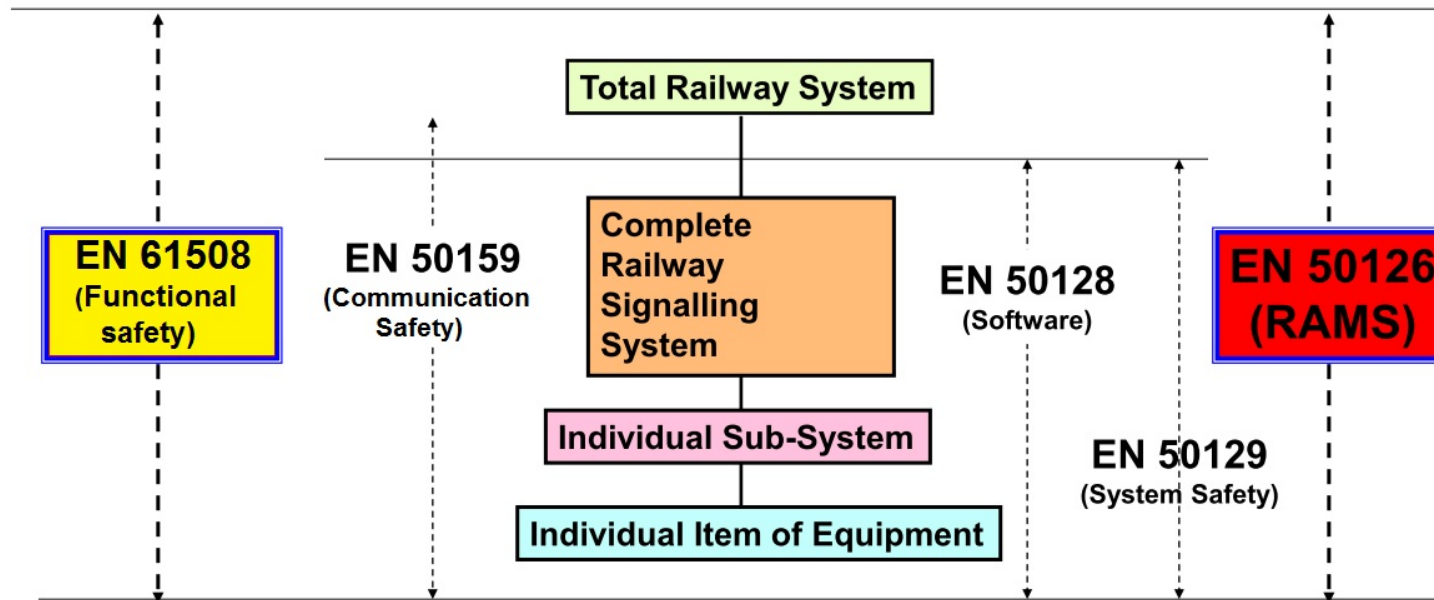
- Based on the international standard IEC 61508 (published by the International Electrotechnical Commission), there are four SILs defined, with SIL 4 the most and SIL 1 the least dependable.

SIL 4 = $10^{-9} < \text{THR} < 10^{-8}$ per hour and per function

SIL 3 = $10^{-8} < \text{THR} < 10^{-7}$

SIL 2 = $10^{-7} < \text{THR} < 10^{-6}$

SIL 1 = $10^{-6} < \text{THR} < 10^{-5}$



EN 50126 Railway Applications: The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS)

EN 50128 Railway Applications: Communication, signaling and processing systems – Software for railway control and protection systems

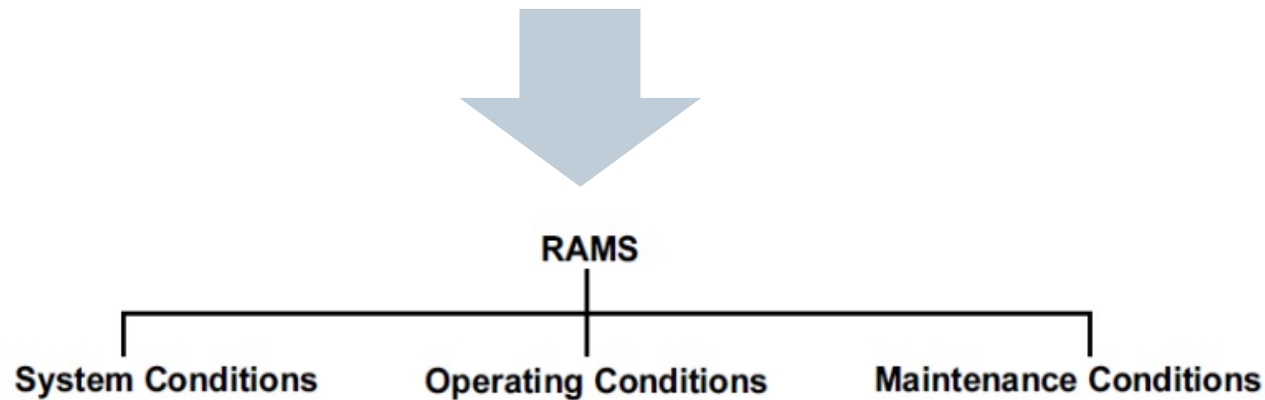
EN 50129 Railway Applications: Communication, signaling and processing systems – Safety-related electronic systems for signaling

EN 50159 Railway Applications: Communication, signaling and processing systems – Safety-related communication in transmission systems

EN 61508 Functional safety of electrical/electronic/programmable electronic safety-related systems

(IEC 61508)

- EN 50126-1:1999 - Part 1: Basic requirements and generic process
- CLC/TR 50126-2:2007 - Part 2: Guide to the application of EN 50126-1 for safety
- CLC/TR 50126-3:2008 - Part 3: Guide to the application of EN 50126-1 for rolling stock RAM



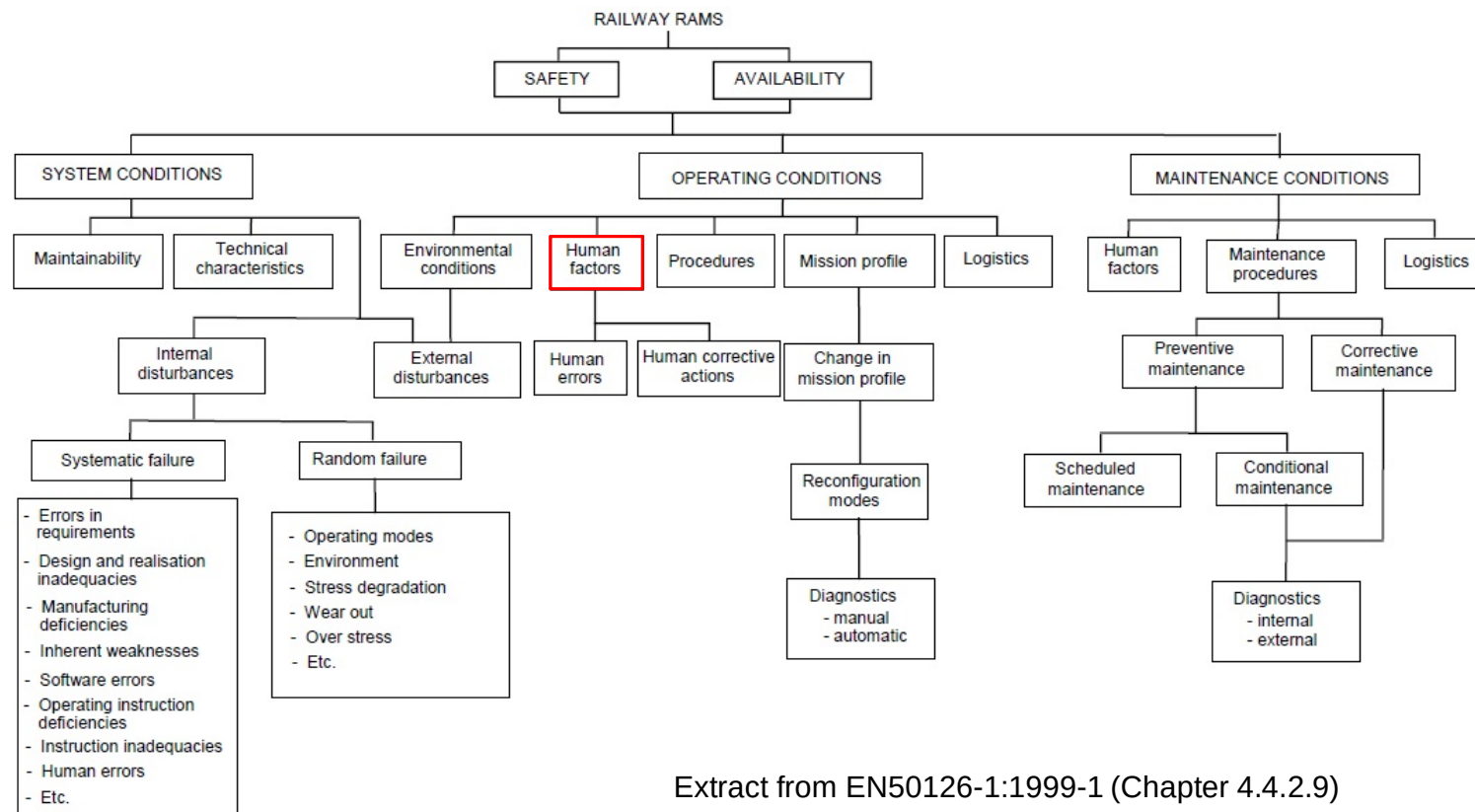
How does EN 50126 helps to increase the quality of transport service ?

EN 50126 helps to

- Identify influence factors to RAMS of a railway system.
- Manage those influence factors, i.e. evaluate the effect of each factor at each phase of the life cycle.
- Perform a risk analysis for various phases of the system life cycle and link tasks to the authority responsible.
- Structure a system life cycle for the purpose of planning, managing, controlling and monitoring all aspects of a system, including RAMS, in order to deliver the right product at the right price within the agreed time scales.
- Support an audit process and to provide a basis for the railway authority and the railway support industry to agree and implement an audit plan for the railway system.
- ... and much more

EN 50126 – Factors Influencing Railway RAMS

In order to derive influencing factors to railway RAMS in detail, EN 50126 provides a structured diagram.



Extract from EN50126-1:1999-1 (Chapter 4.4.2.9)

For example EN 50126 provides a checklist that supports the derivation of human factors which influence system RAMS.

- | | |
|---|---|
| <ul style="list-style-type: none">a) the allocation of system functions between human and machine.b) the effect on human performance within the system of:<ul style="list-style-type: none">– the human/system interface;– the environment, including the physical environment and ergonomic requirements;– human working patterns;– human competence;– the design of human tasks;– human interworking;– human feedback process;– railway organisational structure;– railway culture;– professional railway vocabulary;– problems arising from the introduction of new technology.c) requirements on the system arising from:<ul style="list-style-type: none">– human competence;– human motivation and aspiration support;– mitigating the effects of human behavioural changes;– operational safeguards;– human reaction time and space.d) the requirements on the system arising from human information processing capabilities, including:<ul style="list-style-type: none">– human/machine communications; | <ul style="list-style-type: none">– density of information transfer;– rate of information transfer;– the quality of information;– human reaction to abnormal situations;– human training;– supporting human decision making processes;– other factors contributing to human strain. <ul style="list-style-type: none">e) the effect on the system of human/system interface factors, including:<ul style="list-style-type: none">– the design and operation of the human/system interface;– the effect of human error;– the effect of deliberate human rule violation;– human involvement and intervention in the system;– human system monitoring and override;– human perception of risk;– human involvement in critical areas of the system;– human ability to anticipate system problems.f) human factors in system design and development, including:<ul style="list-style-type: none">– human competency;– human independence during design;– human involvement in verification and validation;– interface between human and automated tools;– systematic failure prevention processes. |
|---|---|

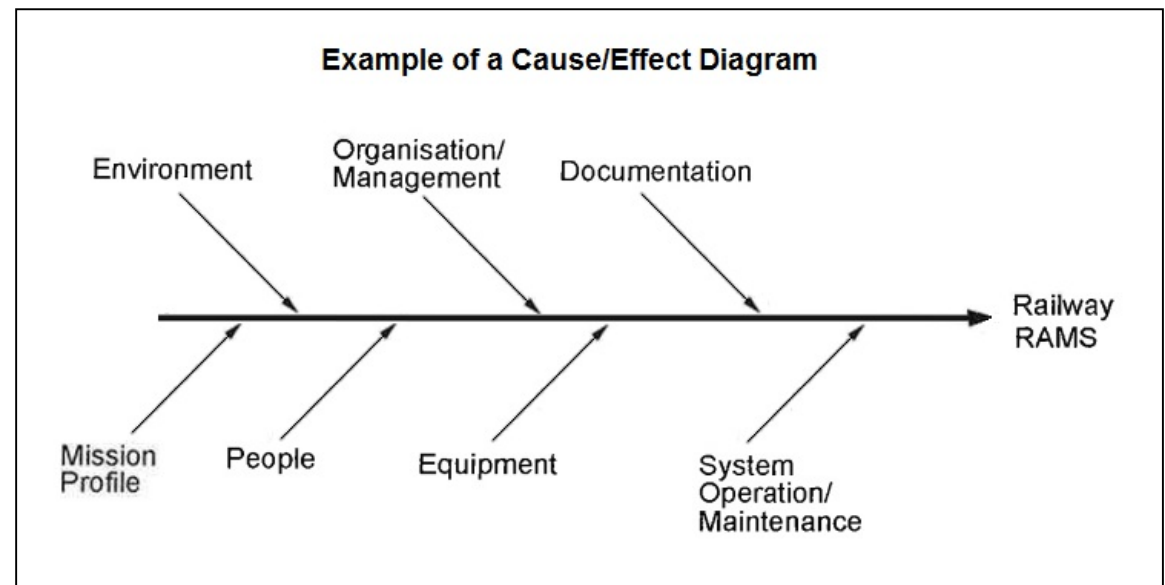
Extract from EN50126-1:1999-1 (Chapter 4.4.2.11)

Similar checklists exist for railway specific factors such as system operation, environment, etc.

EN 50126 recommends to create and to use cause/effect diagrams as part of the process to define those factors which will affect the successful achievement of a system that complies with specified RAMS requirements.

➔ Target is to develop a level of understanding of the system.

The collection of information and data of influencing factors belong to phase 1 of the system life cycle: **Concept Phase**



Extract from EN50126-1:1999-1 (Chapter 4.4.2.12)

The influencing factors need to be managed and controlled!

→ EN 50126 provides guidelines to establish mechanisms and procedures for the effective control of the influencing factors.

Examples:

- Definition of **reliability** targets in order to meet the required performance of system failure modes and mean time between failure (MTBF), e.g.: for rolling stock.
- Description of the **maintenance** policy and the types of Revision encountered, e.g. R0-R3 for rolling-stock.
- Description of **safety** targets and safety policy of the application; identifying and listing the safety related functions (e.g. braking) or units (e.g. coach door).
- Specification of the system **availability**, e.g. in parts attributed to *planned* non-availability (Maintenance) or *unplanned* non-availability (Repair).

Above tasks belong to phase 2 of the system life cycle:

System Definitions and Application Conditions

Tables from EN50126-1:1999-1 (Annex A)

Failure Category	System Failure Mode	Effect on Operation	MTBF _(.) *
Significant	total failure	operation not possible	
Major	critical functional failure	emergency operation 1	
Minor	non-critical functional failure	emergency operation 2	
Negligible	negligible functional failure	normal operation	

* MTBF_(.) in hours, years or km.

Type of Revision	MTBM _(.)	MTTM _(.)
R0		
R1		
R2		
R3		

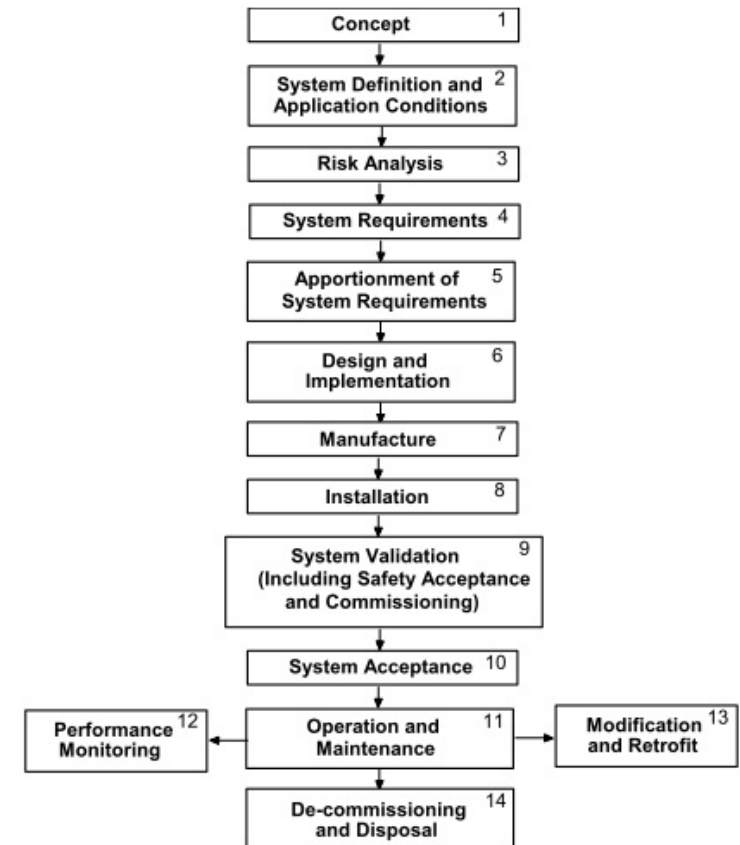
MTBM: Mean Time Between Maintenance (hours, years or km)

MTTM: Mean Time To Maintain (mean duration of revision in hours or days)

Safety related function / unit	Specification of safety related failure	MTBSF* (years or km)
Braking		
Coach door		

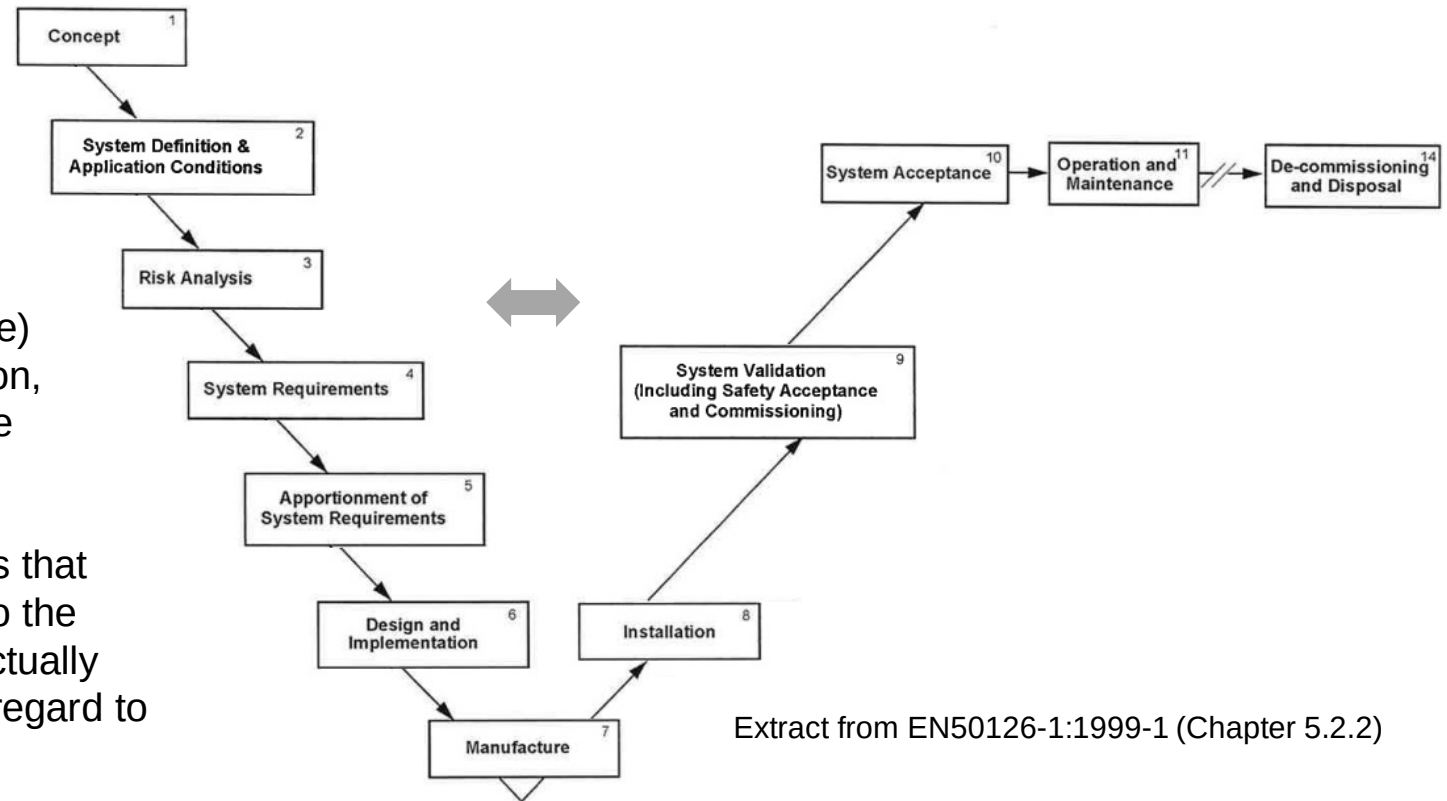
* Mean Time Between "Safety System Failure"

- EN 50126 introduces a system life cycle which is a sequence of phases, each containing tasks.
- The tasks cover the total life of a system from initial concept through to decommissioning and disposal.
- The life cycle provides a structure for planning, managing, controlling and monitoring all aspects of a system, including RAMS.
- The life cycle concept is fundamental to the successful implementation of EN 50126 and helps to deliver ***the right product*** at the ***right price*** within the ***agreed time*** scales.



Extract from EN50126-1:1999-1 (Chapter 5.2.2)

- The top-down branch (left side) is called development.
→ Refining process ending with the manufacturing.
- The bottom-up branch (right side) is related to assembly, installation, receipt and then operation of the whole system.
- The "V" representation assumes that acceptance phases are linked to the development phases: what is actually designed has to be checked in regard to requirements.



Extract from EN50126-1:1999-1 (Chapter 5.2.2)

- Validation activities for acceptance should be planned in the earlier stages (i.e. starting at the corresponding development phases of the life cycle) because validation and acceptance is based on the system specification.

As a general guideline, for a typical railway project, the following applies:

- Requirements are usually established by the customer or a regulatory (legal) authority.
- Approval and acceptance is similarly carried out by the customer or the regulatory authority.
- Solutions, their results and verifications are normally elaborated or performed by the contractor.
- Validation is normally performed jointly.
- The matrix gives an example of responsibilities for a typical arrangement applied to railway systems.

	Customer/ Operator	Approval Authority	(Main) Contractor	Sub- Contractor	Suppliers
Concept Phase	X				
System Definition & Application Conditions	X				
Risk Analysis	X		X		
System Requirements	X	(X)			
Apportionment of System Requirements	(X)		X		
Design and Implementation			X	(X)	
Manufacture			X	X	X
Installation			X	(X)	
System Validation	X	X	X	(X)	
System acceptance	X	X			
Operation and Maintenance	X		(X)	(X)	
Performance Monitoring	X		(X)	(X)	
Modification and Retrofit	X		X	X	
De-commissioning and Disposal	X		(X)		

X full responsibility and participation

(X) specific responsibility and/or partial participation (e.g. on sub-contract or on standby basis)

Matrix from EN50126-1:1999-1 (Annex E)

EN 50126 – Life Cycle Phase Related Tasks

LIFECYCLE PHASE	PHASE RELATED GENERAL TASKS	PHASE RELATED RAM TASKS	PHASE RELATED SAFETY TASKS
1. CONCEPT	- Establish Scope and Purpose of Railway Project - Define Railway Project Concept - Undertake Financial Analysis & Feasibility Studies - Establish Management	- Review Previously Achieved RAM Performance - Consider RAM Implications of Project	- Review Previously Achieved Safety Performance - Consider Safety Implications of Project - Review Safety Policy & Safety Targets
2. SYSTEM DEFINITION AND APPLICATION CONDITIONS	- Establish System Mission Profile - Prepare System Description - Identify Operation & Maintenance Strategies - Identify Operating Conditions - Identify Maintenance Conditions - Identify Influence of Existing Infrastructure Constraints	- Evaluate Past Experience Data for RAM - Perform Set RA	Evaluate Past Experience Data for Safety
3. RISK ANALYSIS (see Note 6)	Undertake Project Related Risk Analysis		
4. SYSTEM REQUIREMENTS	- Undertake Requirements Analysis - Specify System (Overall Requirements) - Specify Environment - Define System Demonstration & Acceptance Criteria (Overall Requirements) - Establish Validation Plan - Establish Management, Quality & Organisation Requirements - Implement Change Control Procedure	- Specify - Define - Define - Establish - Establish	
5. APPORTIONMENT OF SYSTEM REQUIREMENTS	- Apportion System Requirements - Specify Sub-System & Component Requirements - Define Sub-System & Component Acceptance Criteria	- Apportion System RAM Requirements - Specify Sub-System & Component RAM Requirements - Define Sub-System & Component RAM Acceptance Criteria	- Apportion System Safety Targets & Requirements - Specify Sub-System & Component Safety Requirements - Define Sub-System & Component Safety Acceptance Criteria - Update System Safety Plan
6. DESIGN AND IMPLEMENTATION	- Perform Planning - Perform Design and Development - Perform Design Analysis and Testing - Perform Design Verification - Perform Implementation and Validation - Perform Design of Logistic Support Resources	- Implement RAM Programme by Review, Analysis, Testing and Data Assessment, covering: - Reliability & Availability - Maintenance & Maintainability - Optimal Maintenance Policy - Logistic Support - Undertake Programme Control, covering: - RAM Programme Management - Control of Sub-Contractors & Suppliers	- Implement Safety Plan by Review, Analysis, Testing and Data Assessment, addressing: - Hazard Log - Hazard Analysis & Risk Assessment - Justify Safety Related Design Decisions - Undertake Programme Control, covering: - Safety Management - Control of Sub-Contractors & Suppliers - Prepare Generic Safety Case - Prepare (if appropriate) Generic Application Safety Case

a) the system mission profile, including:

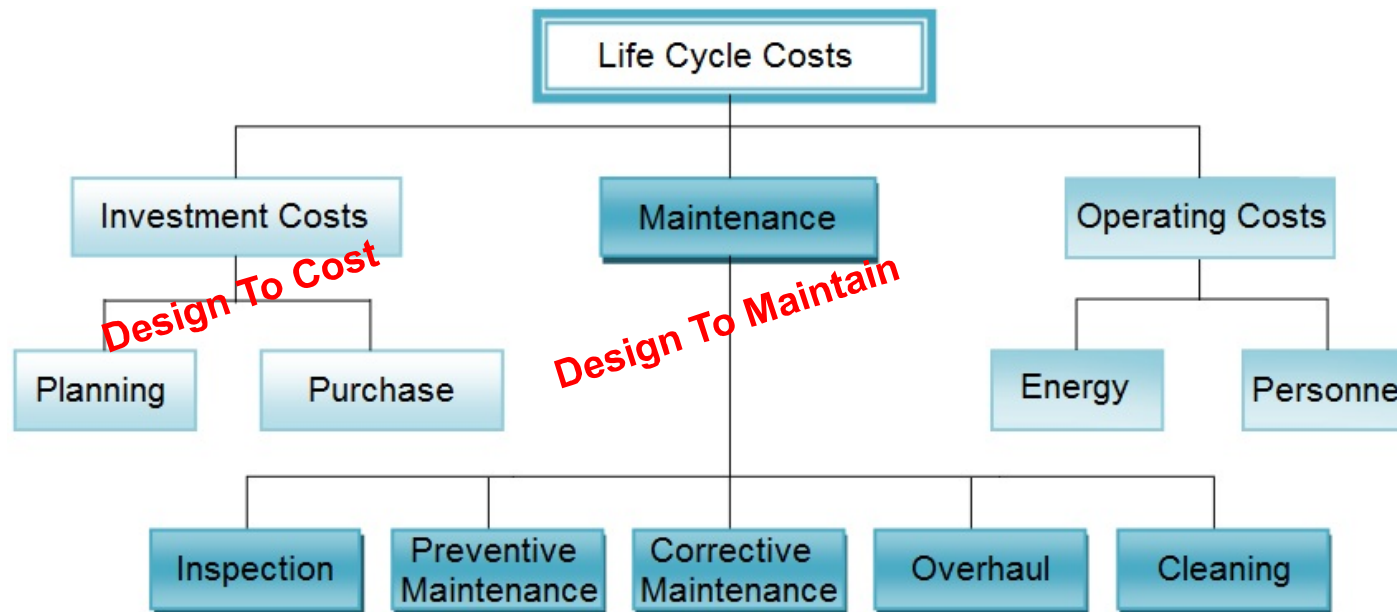
- performance requirements;
- RAMS targets;
- long term operating strategy and conditions;
- long term maintenance strategy and conditions;
- system life considerations, including life cycle costing issues
- logistic considerations.

EN 50126 – Life Cycle Phase Related Tasks

LIFECYCLE PHASE	PHASE RELATED GENERAL TASKS	PHASE RELATED RAM TASKS	PHASE RELATED SAFETY TASKS
7. MANUFACTURING	- Perform Production Planning - Manufacture - Manufacture and Test Sub-Assembly of Components - Prepare Documentation - Establish Training	- Perform Environmental Stress Screening - Perform RAM Improvement Testing - Commence Failure Reporting and Corrective Action System (FRACAS)	- Implement Safety Plan by: Review, Analysis, Testing & Data Assessment - Use Hazard Log
8. INSTALLATION	- Assemble System - Install System	- Start Maintainer Training - Establish Spare Parts and Tool Provision	- Establish Installation Programme - Implement Installation Programme
9. SYSTEM VALIDATION (INCLUDING SAFETY ACCEPTANCE AND COMMISSIONING)	- Commission - Perform Probationary Period of Operation - Undertake Training	Perform RAM Demonstration	- Establish Commissioning Programme - Implement Commissioning Programme - Prepare Application Specific Safety Case
10. SYSTEM ACCEPTANCE	- Undertake Acceptance Procedures, based on Acceptance Criteria - Compile Evidence for Acceptance - Entry into Service - Continue Probationary Period of Operation (if appropriate)	Assess RAM Demonstration	Assess Application Specific Safety Case
11. OPERATION AND MAINTENANCE	- Long Term System Operation - Perform On Going Maintenance - Undertake On Going Training	- On Going Procurement of Spare Parts & Tools - Perform On Going Reliability Centred Maintenance, Logistic Support	- Undertake On Going Safety Centred Maintenance - Perform On Going Safety Performance Monitoring and Hazard Log Maintenance
12. PERFORMANCE MONITORING	- Collect Operational Performance Statistics - Acquire, Analyse and Evaluate Data	Collect, Analyse, Evaluate and Use Performance & RAM Statistics	Collect, Analyse, Evaluate and Use Performance & Safety Statistics
13. MODIFICATION AND RETROFIT	- Implement Change Request Procedures - Implement Modification and Retrofit Procedures	Consider RAM Implications for Modification & Retrofit	Consider Safety Implications for Modification & Retrofit
14. DECOMMISSIONING AND DISPOSAL	- Plan Decommissioning and Disposal - Undertake Decommissioning - Undertake Disposal	No activity for RAM	- Establish Safety Plan - Perform Hazard Analysis & Risk Assessment - Implement Safety Plan

Extract from EN50126-1:1999-1 (Chapter 5.2.2)

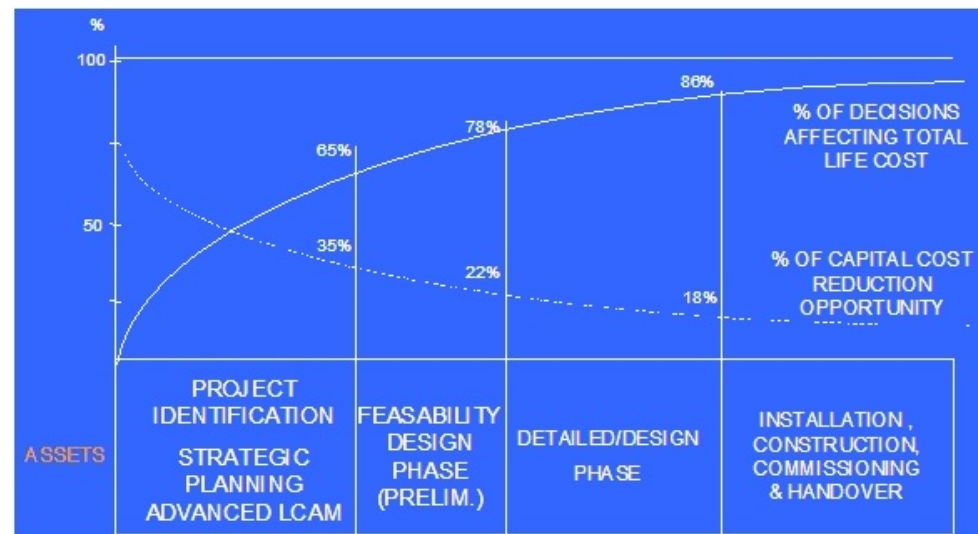
Why to consider costs in a railway system's life cycle?



→ To obtain the sum of all recurring and one-time costs over the full life span of a railway system, which does not include the investment costs only but also operating and maintenance costs!

When to consider costs in a rail system's life cycle?

The early decisions made in the design phase of the rail system and in the definition of operations and maintenance requirements commit a large percentage of the life cycle costs for that system.



Knowing with certainty the exact costs for the entire life cycle of an asset at the beginning is not possible. Future costs can only be estimated with varying degrees of confidence.

➔ The use of European standards supports the estimation of LCC

Definition according to EN 13306 (2001):

The maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of a unit.

Calculation of preventive maintenance costs per lifecycle (CY_MP):

$$CY_MP = \sum_{i=1}^X No_MP_i \times QT_i \times (CM_MP_i + MH_MP_i \times CMH)$$

CM_MP: Average costs of material per preventive action

MH_MP: Working-hours per preventive action

CMH: Costs per working-hour

No_MP: Number of preventive maintenance actions per life cycle

i: Maintenance action

QT: Total quantity of item

The following are not considered:

- Time for organizational, admin. or logistics processes
- Time for filling up operating supplies
- Time for emptying wastewater tanks
- Technical waiting times and set-up times
- Time for disposal
- Time for exterior and interior vehicle cleaning

Definition according to EN 13306 (2001):

The maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function.

Calculation of corrective maintenance costs per life cycle (CY_MP):

$$No_MC_i = IN_FAI_i \times OT$$

$$CY_MC = \sum_{i=1}^X No_MC_i \times QT_i \times (CM_MC_i + MH_MC_i \times CMH)$$

CM_MC: Average costs of material per corrective action

QT: Total quantity of item

MH_MC: Working-hours per corrective action

OT: Operating time or operating distance per life cycle
(depending on the unit of the failure rate)

CMH: Costs per working-hour

IN_FAI: Failure rate

No_MC: Number of corrective maintenance actions per life cycle

MH_MC: Working-hours per corrective action

i: Maintenance action per item and failure mode

Where are the input values for a LCC data analysis from?

- RAMS targets:
 - Service Life: xx years
 - Operating distance per vehicle per year: xx km
 - Mean operating time per vehicle per year: xx h
 - Mean set-up time per vehicle per year: xx h
 - etc.
 - Specifications / technical manuals from component or subsystem supplier (e.g. FIT rate, MTBF rate).
 - Identifying, collecting and utilizing historical project data (e.g. failure rates at vehicle, repair efforts, behavior of worn parts, etc.)
 - Simulating / modeling component or subsystem behavior.
 - Databases and CMMS.
 - Reliable statistical statements.
- ➔ If a sufficient quantity of data available, LCC data analysis can be performed.

Field Data Evaluation for RAM and LCC Calculation

Exemplary for a pantograph



Component: PANTOGRAPH
Type: XXX-XXX-XXX

Manufacturer: XXXXXX
Project: Locomotive

Data quality: Field data

Note: Lifetime of carbon strips
Failure-free carbon strips have a life time of about 100,000 pantograph kilometer

Operation conditions:

Mileage of fleet during observation period: 48,987,555 km
Avg. number of vehicles during obs. period: 168
Avg. vehicle operation hours during obs. period: 1,166,370 h
Avg. velocity: 42 km/h

Operation-relevant failure modes on subsystem level

Category 3 (delay > 5 min): 18862 fit 22 cases
Category 4 (SOS, rescue loco): 6859 fit 8 cases
Target value reliability (Cat. 3 + 4): 5000 fit (from requirement spec)

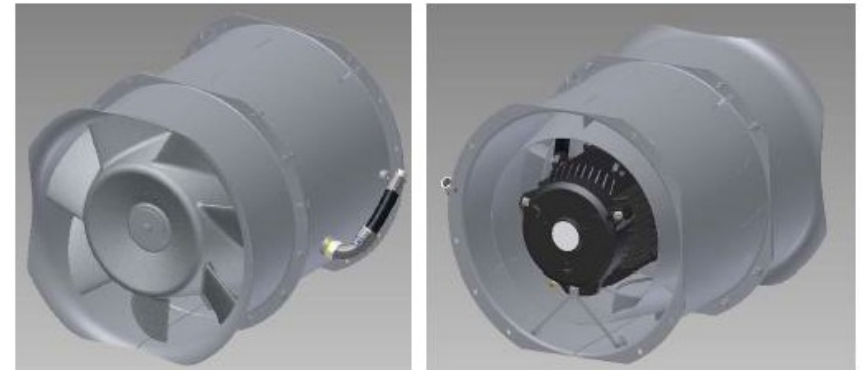
Pantograph kilometer									Level of confidence 0.9		Corrective Maintenance CM			Pantograph kilometer
Observation period 01.05.14 - 31.12.14				t (average) [h] 6.943		Locos in service: 168		Confidence limit		Efforts from field		Prediction (from offer)	Remarks	
monitored failure rates														
Failed Component	Code Event List	Part number	Number of active Panto per Loco	Outage n	N	N * t average [h]	Prediction if values available	Failure Rate Lambda observed	Lambda [Fit]	Lambda [Fit]	Rep. time MTTR/ Replace	Rep. time MTTR or Replace	Rep. time MTTR/ Replace	
							FIT	FIT			mh	mh	mh	
3.1.1 Pantograph														
Pantograph (total)		254349834545	1	310	168	1166370		265.782	241.449	291.987	1,99	1,26		(15 kV, 16 ² /3 Hz)
Carbon strip monitoring (air routing at panto)	1	ohne	1	51	168	1166370		43.725	34.165	55.216	2,23	1,65		
Pneumatic control (rise and drop times, contact pressure)	2	ohne	1	11	168	1166370		9.431	5.289	15.610	6	1,66		
Pneumatic control (pressure valve 0-7 bar)	3.1	95.3	1	17	168	1166370	1.346	14.575	9.287	21.862	1,63	1,42		
Pneumatic control (valves for lift drive, single components not addressed)	3.2	95	1	13	168	1166370		11.146	6.593	17.720	1,75	0,95		
Pneumatic control (over-pressure valve)	3.3	95.6	1	3	168	1166370	670	2.572	701	6.648	2,26	1		
Pneumatic control (pressure switch)	3.4	95.9	1	1	168	1166370		857	44	4.067	2,75	0		
Pneumatic control (pressure gauge for valve control 0-6 bar)	3.6	95.4	1	6	168	1166370		5.144	2.240	10.153	0,81	0		
Pneumatic control (fast-lowering equipment, mainly the lowering valve)	3.6	95.4	1	4	168	1166370		3.429	1.171	7.848	1,52	0		
Pneumatic control (air hose at basic frame) Lift drive	3.7	95.4	1	1	168	1166370	134	857	44	4.067	1,42	1,75		
Pneumatic control (air hose at basic frame) Carbon strip monitoring	3.7	95.4	1	4	168	1166370		3.429	1.171	7.848	1,42	1,75		
Lift drive	4	95.4	1	4	168	1166370	268	3.429	1.171	7.848	3,75	0		
Parallel guide rod	5	95.4	1	6	168	1166370	428	4.287	1.689	9.013	2,75	2		
Rack damper	6	95.4	1	4	168	1166370	896	3.429	1.171	7.848	1,42	0		
Bow suspension	7	95.4	1	2	168	1166370	1.072	1.715	305	5.398	3,75	0		
Parts not able to be assigned, will be assigned to pantograph (total)	8	95.4	1	4	168	1166370		3.429	1.171	7.848	4,5	0,75		
Carbon strip (abnormal wear and tear)	9	95.4	1	180	168	1166370	1.340	154.325	135.904	174.630	1,66	1,11		
							6.114	265.782						

Life Cycle Costs (LCC) – Real Life Example: Brake Resistor Fan

During the first article inspection on the brake resistor for an electric multiple unit, it was found the BR fan could only be replaced after removing the BR from the vehicle (actual time for replacement approx. 8.6 h).

The specification for the BR stipulated a max. time requirement of 2 h for replacing a defective fan.

- Each BR has 2 fans.
- Each vehicle has 8 BRs.
- The fleet consists of 10 vehicles.
- The vehicles are in service approx. 6,000 h/a



Question: How much higher is the additional cost of corrective maintenance over a period of 30 years service compared to the specification (hourly rate €60)?

Life Cycle Costs (LCC) – Real Life Example: Brake Resistor Fan

Excerpt from BR system analysis:

Component	typical type of failure / typical damage	Impact of the failure to the system	corrective maintenance measure	Number of compon. per brake resistor	Duration powered on [%]	Total failure rate of the comp.	Unit	Failure probability in terms of category and damage event			
								1 [%]	2 [%]	3 [%]	4 [%]
CM_COMP	TM	IR	CM_MEAS	CM_NF,1	CM_RC	IRIIRTH	PR_UNIT	PC_1	PC_2	PC_3	PC_4
perlinks zur Anleitung	Failure mode		Successtate-link		Rate at	Failure at	Rate	Rate	Rate	Rate	Rate
axial fan right WPSUW02 WPSUW02WPSUW02WPSUW02	damage to the impeller and/ or guide wheel	Power reduction, reducing of the air flow volume leads to an increase of the resistance temperature.	exchange of the component	1	100	200	FIT		50	50	
motor	bearing damage possible by exceeding the prescribed maintenance interval of max. 40,000 hours / 80 months	defective motor and thus failure of the fan	exchange of the component	1	100	800	FIT		50	50	
vibration damper WPSUW02 Typ: WPSUW02WPSUW02	change of the shore hardness (aging)	deterioration of vibration isolation	exchange of the component	4	100	125	FIT				100
motor-bearing drive end	engine failure due to overheating	defective motor and thus failure of the fan	exchange of the component	1	100	250	FIT		50	50	
motor-bearing not drive	engine failure due to overheating	defective motor and thus failure of the fan	exchange of the component	1	100	250	FIT		50	50	

Life Cycle Costs (LCC) – Real Life Example: Brake Resistor Fan

- The total fault rate of the BR fan is: 200 fit + 800 fit + 4x125 fit + 250 fit + 250 fit = 2.000 fit

with: Failure rate λ $\lambda = \frac{1.000.000.000h}{MTBF}$ Unit: FIT

results in: MTBF = 1.000.000.000 h / 2.000 fit = 500.000 h

- That is says, from a statistical point of view, we have a failed BR fan every 500,000 h
- The fleet has 2 fans per BR x 8 BRs per train x 10 trains = 160 BR fans
- With an annual operating time of 6,000 h, each fan attains an operating time of 30 x 6,000 h = 180,000 h in 30 years.
- The sum of all installed BR fans will therefore reach an operating time of 160 x 180,000 h = 28,800,000 h in 30 years.
- Since, from a statistical point of view, a BR fan fails every 500,000 h, this results in 28,800,000 h / 500,000 h = **57.6 failures** in 30 years.

- According to the specification, the time requirement for the replacement of one fan is 2 h max.
- The actual replacement time during the first article inspection was 8.6 h.
- This results in an additional time requirement of $(8.6 \text{ h} - 2 \text{ h}) \times 58 \text{ failures in 30 years} = 383 \text{ h}$ for corrective maintenance.
- Assuming an hourly rate of 60 euros, this results in additional costs in the amount of $383 \text{ h} \times 60 \text{ euros/h} = \mathbf{22,980 \text{ euros}}$ (for corrective maintenance)
- In addition there are costs for preventive maintenance as the BR fans need to be replaced after an operation time of approx. 8 years.



Thank you for your attention!

Contact: policy@eabc-thailand.eu



Thinking the Future
Zukunft denken

INTERNATIONAL RAILWAY SYSTEMS ENGINEERING INITIATIVE

Meeting OTP: Office of Transport Planning - Thai Ministry of Transport
11.07.2016



INTERNATIONAL
ACADEMY

RWTHAACHEN
UNIVERSITY

RWTH Aachen University

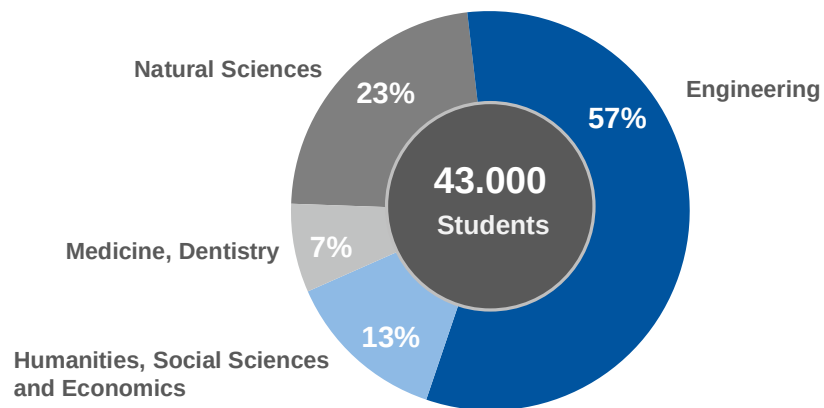
The Integrated University of Technology

RWTHAACHEN
UNIVERSITY

- **Budget:** 894 M €
- **Third-party funds:** 354 M €
- **Affiliated institutes:** 66 M €

- 43.000 Students
- 152 Degree Courses

- 9 Faculties
- 260 Institutes and 15 Affiliated Institutes
- 538 Professorships
- 6000 Ph.D. Candidates
- 8 Collaborative Research Centers (SFB)
- 25 Research Training Programs (14 DFG Research Training Groups)
- 1 Graduate School
- 3 Clusters of Excellence



RWTH International Academy gGmbH



- Founded: May 2000 as non-profit organization
- Associates: 50% RWTH Aachen, 50% proRWTH

RWTH International Academy gGmbH: A strong academic education partner

- RWTH International Academy is the **official and highly experienced organization** for post-graduate and professional academic education at the RWTH Aachen founded as a **non-profit organization**.
- The core competencies are **conception, certification and implementation** of excellent courses in various education formats
- The International Academy has **full access to institutes, teaching body and infrastructure** of the RWTH Aachen.
- The International Academy is entitled institution to issue the **RWTH Certificates** as executive and academic certificates.



RWTH Aachen University:

A competent academic partner in railway technologies

18 experienced RWTH institutes with interdisciplinary know-how
in railway vehicle technologies and practical applications!



INSTITUT FÜR ELEKTRISCHE ANLAGEN
UND ENERGIEWIRTSCHAFT



INSTITUT FÜR
KUNSTSTOFFVERARBEITUNG
IN INDUSTRIE UND HANDWERK AN DER RWTH AACHEN



Institut für
fluidtechnische
Antriebe und
Steuerungen



Institut für
Regelungstechnik



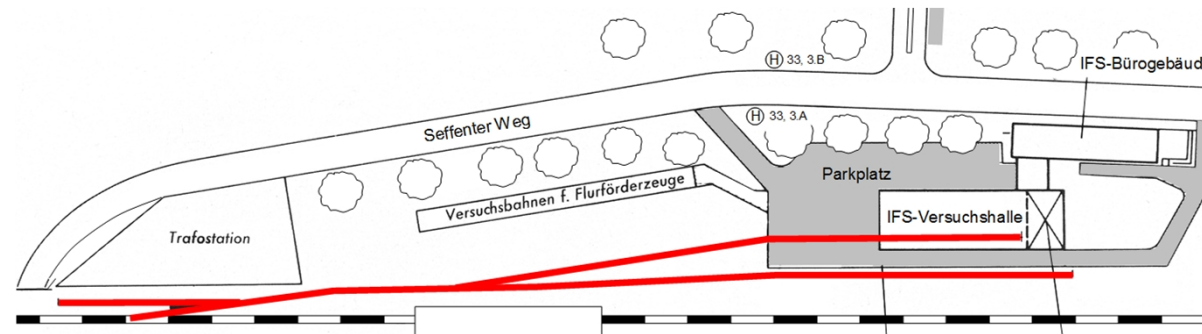
RWTH Aachen as an outstanding location for practical training programs as part of the railway education program



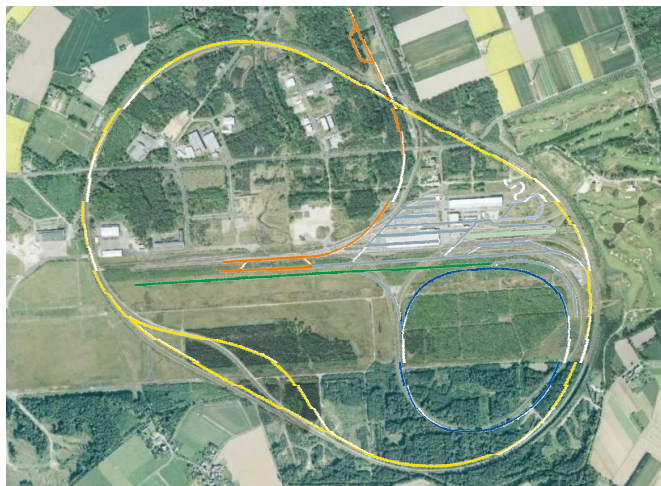
Railway-oriented R&D labs at several RWTH institutes:

- RWTH Aachen – Talbot Services GmbH Aachen:
7,5 km
- RWTH Aachen – ATC Aldenhoven Testing Center:
28,6 km
- RWTH Aachen – Rurtalbahn Düren:
40,6 km
- RWTH Aachen – Siemens Test- and Validationcenter Wegberg-Wildenrath:
59,0 km
- RWTH Aachen – Siemens Production and Engineering Center Krefeld:
98,2 km

Accessible large-scale Test Facilities



IFS owned track layout with connection to DB-network



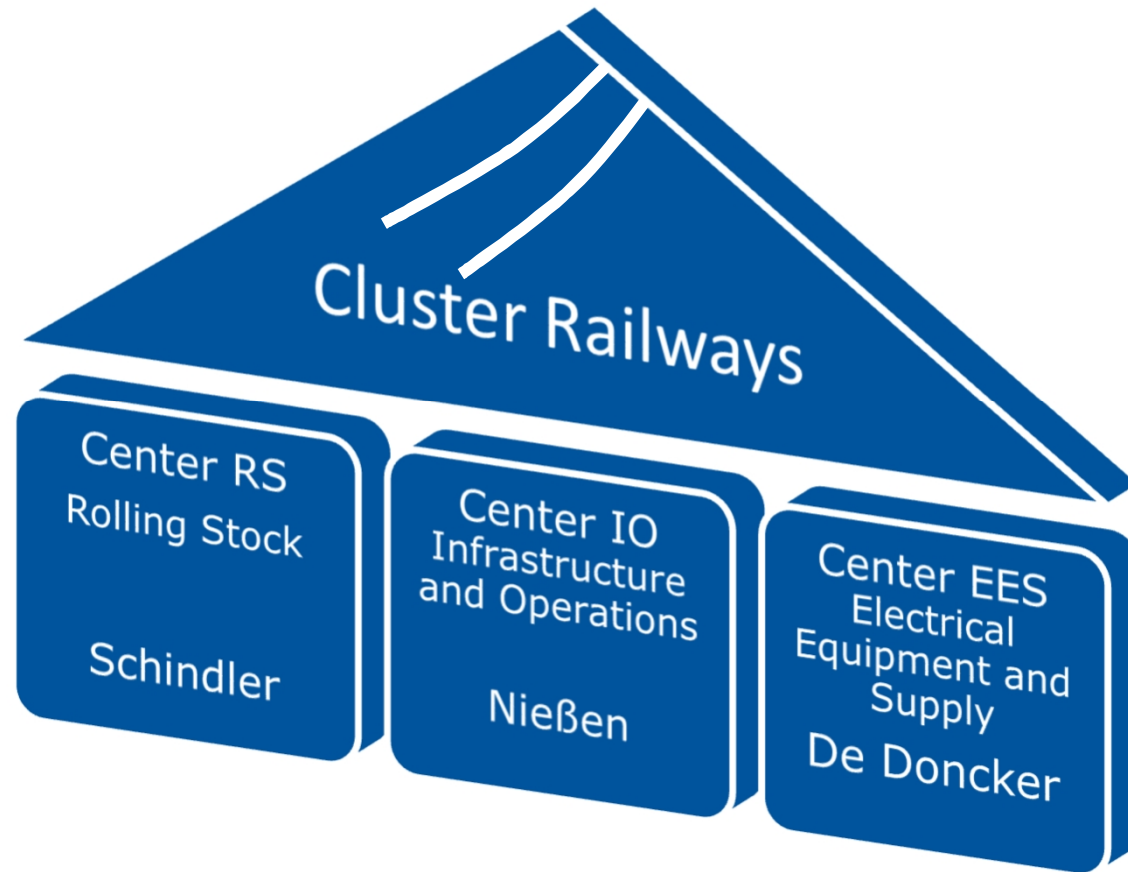
Quelle: Siemens, tim-online.nrw.de

SIEMENS Test- and Validation Center
in Wegberg-Wildenrath near Mönchengladbach



RWTH owned Automobile Testing Center
in Aldenhoven near Aachen

Research Cluster



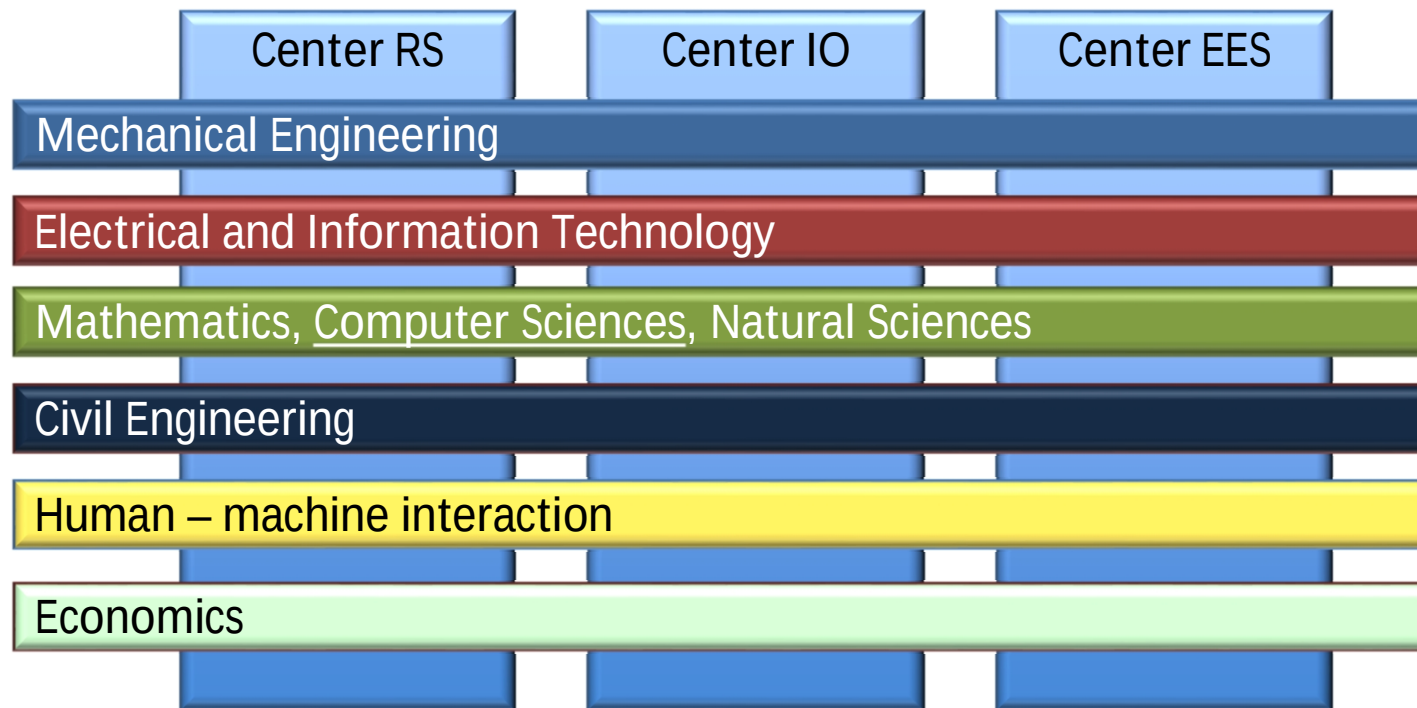
Virtual, later real, institution, where committed colleagues do research on railways.

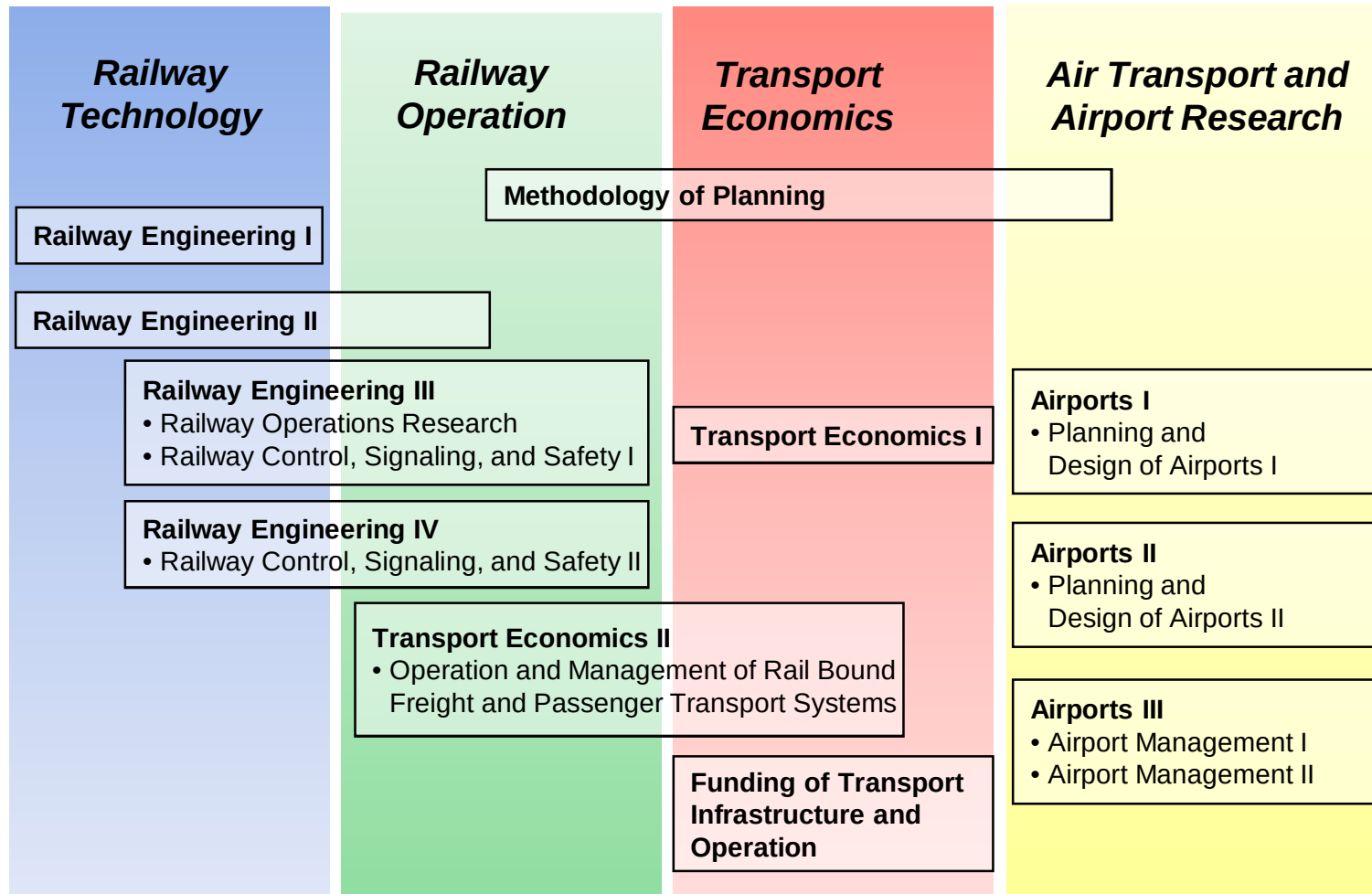
International railway systems education initiative at RWTH Aachen University: Background

- Topic of high interest due to worldwide efforts for improving infrastructure and transport systems
- Upgrading of railway systems in large cities (Metro) and construction of high-speed trains for long distances
- High investments in planning, construction of route networks and train systems
- Numerous technological innovations in the last two decades to be taken into account
- Necessary expertise for operation and maintenance is lacking in many countries
- High potential for cooperation and education programs in railway technology and in training of professionals

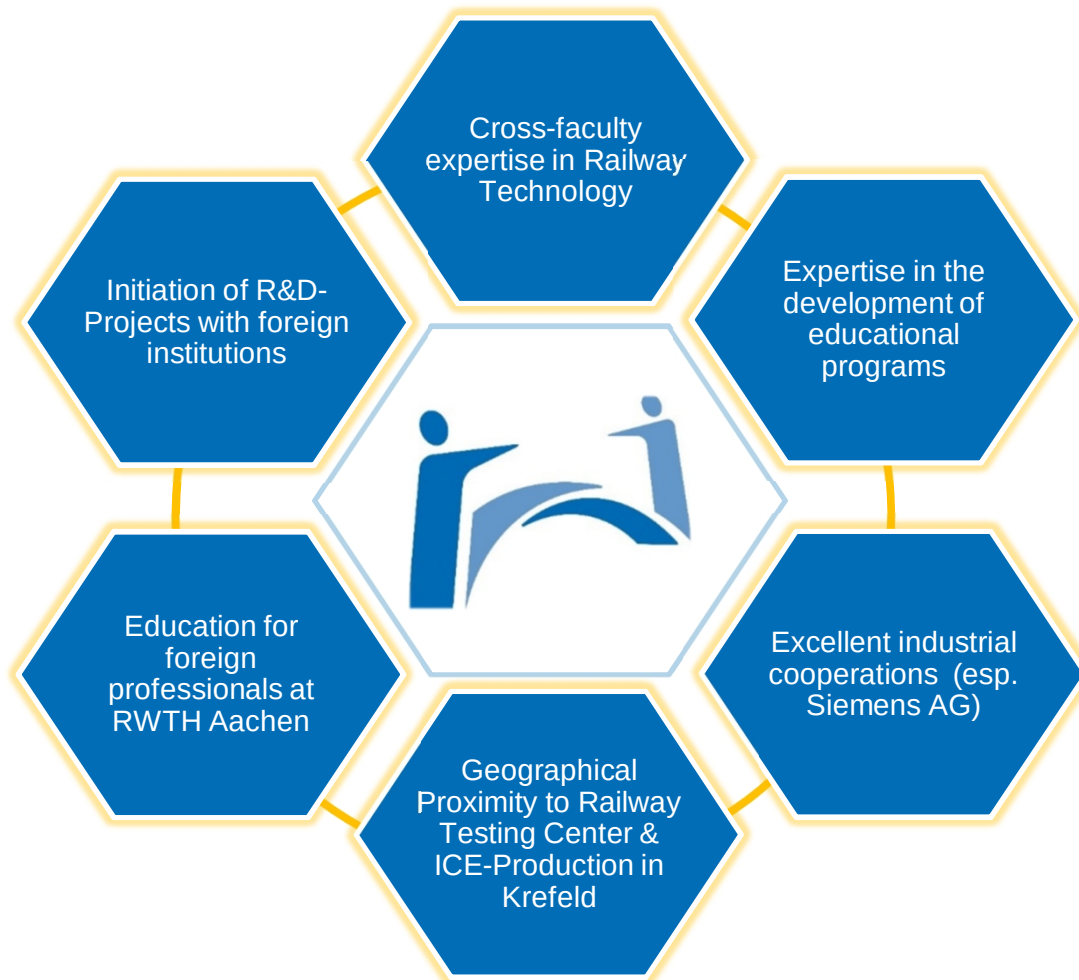


Fields of Competence





Continuing education in railway technology: Cooperation with RWTH Aachen University – Reasons why



Continuing education in railway technology: Cooperation with RWTH Aachen University – Reasons why (detailed)

- High cross-faculty expertise in Railway Technology (FB 3, FB 4, FB 6)
- High level of expertise in the development of educational programs (RWTH International Academy)
- Excellent cooperation with industry, especially Siemens AG
 - Practice sites: Close to the Railway and Validation Testing Center in Wildenrath, Siemens Production of ICE in Krefeld and Talbot Aachen to enable practical training components
- Opportunity for foreign institutions to join hands in Railtech-R&D with RWTH Aachen
- Opportunity to train foreign employees at RWTH Aachen University on high technical level



Example for RWTH Certificate Course

Course format and didactics are adaptable according to needs of target group

<u>Monday</u>	<u>Tuesday</u>	<u>Wednesday</u>	<u>Thursday</u>	<u>Friday</u>
Introduction ▪ Track guiding ▪ Lateral acceleration and compensating superelevation ▪ Clearance ▪ Slab tracks	Track laying and superelevation ▪ Curve radius and superelevation ▪ Transition curves ▪ Gradient due to superelevation ▪ Track warping	Design of transport corridor ▪ Cross sections ▪ Side of track ▪ drainage ▪ Bridges ▪ Tunnel	Vehicle technology and rolling stock ▪ Vehicle technology ▪ Electrification and power supply ▪ Tractive unit ▪ Rolling stock	Calculation of running time ▪ Fundamentals ▪ Movement at constant speed ▪ Movement at constant acceleration ▪ Methods of running time calculation
Track construction ▪ Fundamentals ▪ Track superstructure ▪ Track substructure ▪ Track components	Line routing and longitudinal gradient ▪ Slopes and gradient ▪ Change in gradient ▪ Line routing in horizontal and vertical projection	Track construction ▪ Machines for track renewal and track laying ▪ Track maintenance	Basics of rail bound vehicle dynamics ▪ Train resistance force ▪ Tractive force ▪ Train dynamics of tractive units	Test
Accompanying practice: radii and superelevation, transition curves, gradients due to superelevation, change in gradient, train dynamics, running time calculation				

Post graduate and professionals education in railway technologies: Your contacts at RWTH Aachen



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Scientific coordinator (Rolling Stock)
Prof. Dr.-Ing. Christian Schindler
RWTH Aachen University
Chair of Railway Vehicles and Transport
Systems (IFS)
schindler@ifs.rwth-aachen.de



Scientific coordinator
Prof. Dr. ir. Rik W. DeDoncker
RWTH Aachen University
Institute for Power Electronics & Electrical
Drives (ISEA)
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Prof. Dr.-Ing. Rolf H. Jansen
RWTH International Academy gGmbH
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Dr. Helmut Dinger
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Academy gGmbH
Managing Director
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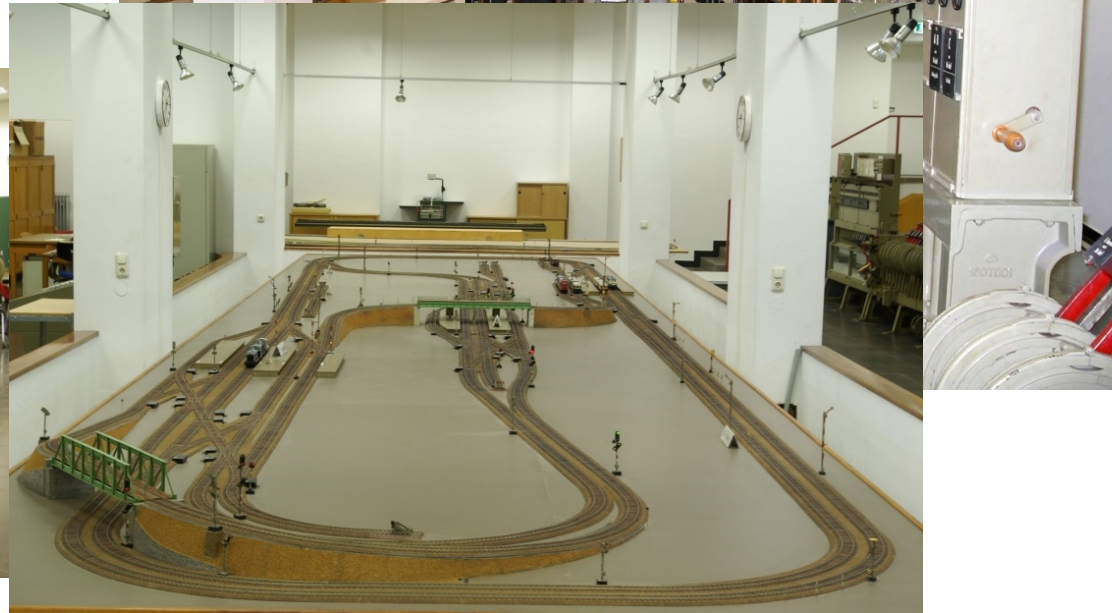
Dr. Yves Gensterblum
RWTH International Academy gGmbH
Business Unit Manager
Engineering and Natural Sciences
y.gensterblum@academy.rwth-aachen.de

RWTH Aachen University - Railway Signaling Laboratory

Technical railway teaching and testing plant (ELVA)

Available interlocking boxes

- Mechanical interlocking
- Electromechanical interlocking
- Relay interlocking
- Electronic interlocking



Example for possible teaching didactics

Integrated practical part at testing and validation Center Wegberg-Wildenrath

Use of the “Testing and Validation Center“ in Wegberg-Wildenrath

- Test ovals and test tracks, test equipment
- ESTW, ETCS, GSM-R
- Cooperation agreement with RWTH Aachen University



Example for possible teaching didactics

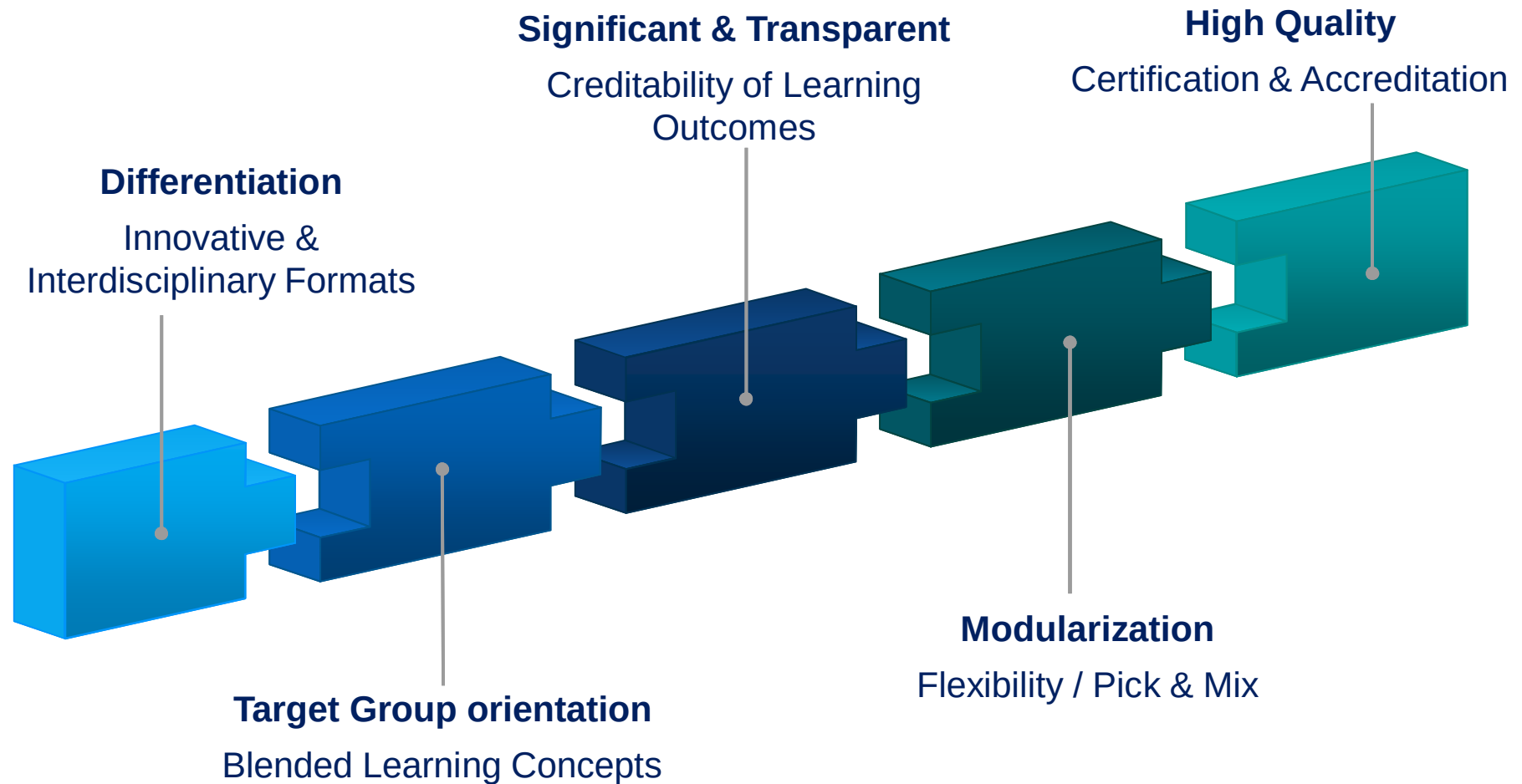
Integrated practical part at ATC Aldenhoven Testing Center



Facts and figures

- inaugurated in April 2014
- subsidiary of Düren County and RWTH Aachen University
- Supported financially by The state of North Rhine-Westphalia and the European Union
- Testing center for automotive and autonomous driving train units

5 Principles of Executive Training from RWTH Aachen



Position

RWTH International Academy at RWTH Aachen University

Faculties of the RWTH Aachen University

Business units of the International Academy

TECHNOLOGY,
PRODUCTION & SERVICES

MEDICINE & HEALTH

MANAGEMENT

INTERNATIONAL
STUDENT PROGRAMS

CONFERENCE OFFICE

1 Mathematics, Computer
Sciences and Natural
Sciences

2 Architecture

3 Civil Engineering

4 Mechanical Engineering

5 Georesources and
Materials Engineering

6 Electrical Engineering
and Information
Technology

7 Arts and Humanities

8 Business and Economics

10 Medicine

9 Faculties

260 Institutes

550 Professorships

Very large pool of scientific knowledge with an infinite
number of possible interdisciplinary combinations!

Official Certificates of RWTH Aachen University

Executive
Certificate

RWTHAACHEN
UNIVERSITY

Zertifikat-Reg.-Nr.
AA 001

Name **Frau Monika Mustermann (geb.**

Geburtsdatum
Geburtsort XX.Monat.,Jahr
Musterstadt

Durchführende Institutionen RWTH Aachen University und die
Moscow Higher School of Engineering

Zertifikats-titel **RWTH Executive Certificate
Dual Industrial System Engineer**

Gesamtnote X,X (ausgeschrieben)

ECTS Note X,X (ausgeschrieben)

Kreditpunkte nach dem
European Credit Transfer System (ECTS) 2

Qualifikationsniveau nach
Europäischem Qualifikationsrahmen (FQR) Stufe 7 (Master)


Aachen, den xx. Monat, Jahr

Univ.-Prof. Dr.-Ing. Achim Kempker
Lehrstuhl Production Engineering of L-Mobility Components
RWTH Aachen University

Dr. Helmut Dinger
Geschäftsführer
RWTH International Academy gGmbH

Walter Rätz
Geschäftsführer
Moscow Higher School of Engineering

RWTHAACHEN
UNIVERSITY

Academic
Certificate

RWTHAACHEN
UNIVERSITY

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Moscow Higher School of Engineering

Zertifikats-titel **RWTH Academic Certificate
Dual Industrial System Engineering**

Gesamtnote X,X (ausgeschrieben)

ECTS Note X,X (ausgeschrieben)

Kreditpunkte nach dem
European Credit Transfer System (ECTS) 5

Qualifikationsniveau nach
Europäischem Qualifikationsrahmen (FQR) Stufe 7 (Master)


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RWTHAACHEN
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Expert
Certificate

RWTHAACHEN
UNIVERSITY

Zertifikat-Registrier-Nr.
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Durchführende Institutionen RWTH Aachen University und die
Moscow Higher School of Engineering

Zertifikats-titel **RWTH Expert Certificate
Dual Industrial System Engineering**

Gesamtnote X,X (ausgeschrieben)

ECTS Note X,X (ausgeschrieben)

Kreditpunkte nach dem
European Credit Transfer System (ECTS) 15

Qualifikationsniveau nach
Europäischem Qualifikationsrahmen (FQR) Stufe 7 (Master)


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Walter Rätz
Geschäftsführer
Moscow Higher School of Engineering

RWTHAACHEN
UNIVERSITY

Current activities and status quo (since 2014)

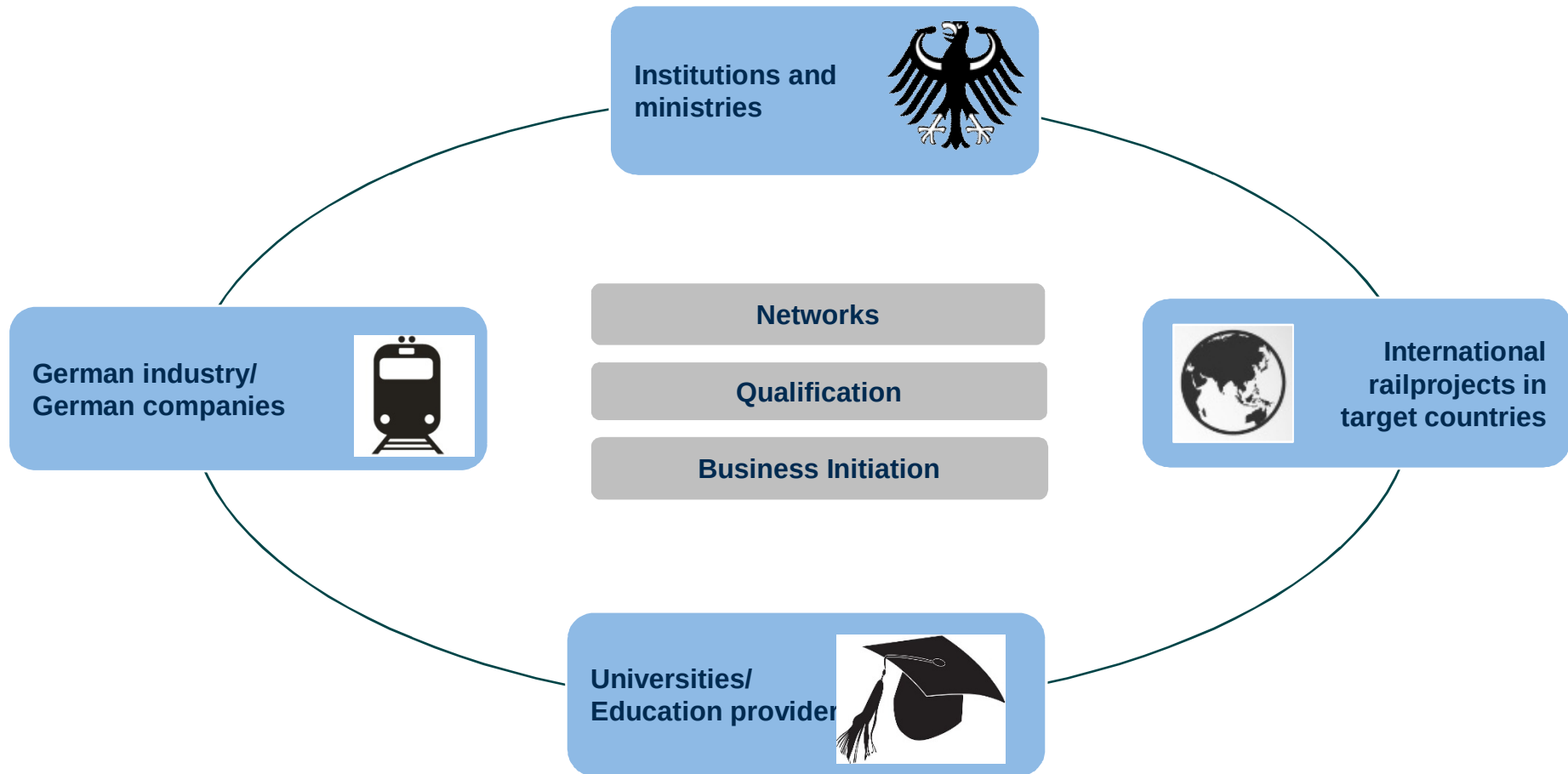
- High Speed Trains Russia
- Railway Initiative Thailand
- Metro Project Saudi-Arabia
- Metro Project Malaysia
- High Speed Trains India

Motivation of Stakeholder

- **State:**
Export support for German industry in the field of railway in dynamic and growing international markets
- **German companies:**
Development of new attractive markets and positioning in major international projects
- **University:**
Qualification of technical experts and executives as well as decision makers from emerging countries while using all competencies, resources and networks



Connecting the possibilities



How?

- **Idea**

Development and implementation of qualification and networking programs for railway stakeholders in emerging countries

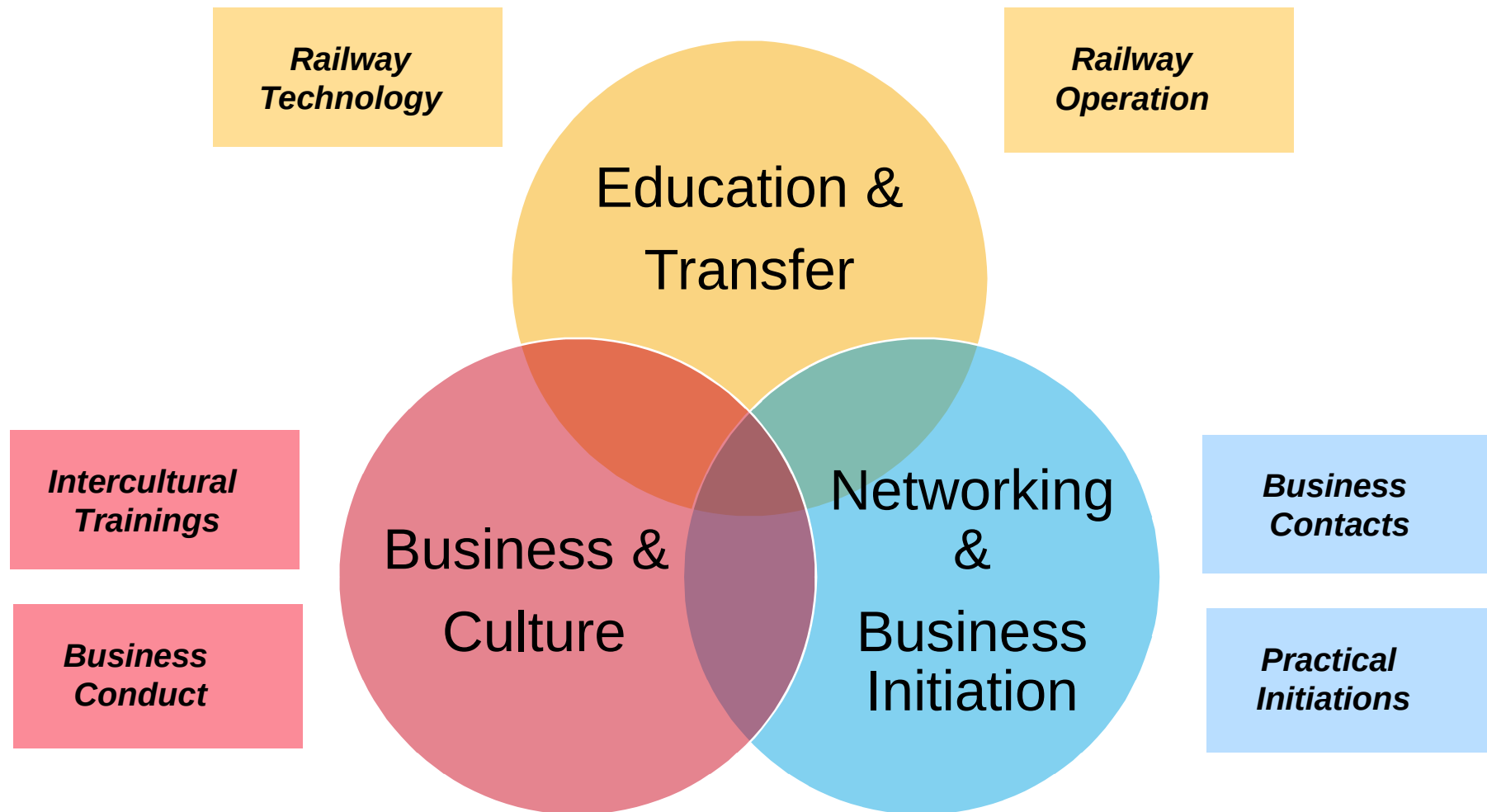
- **Target group**

Railway companies (production, service), chambers, governmental organisations from emerging countries

- **Objectives**

Qualification of experts and executives following German standards as well as offering experts and executives concrete business initiations with German companies

Connecting the modules





The EUROPEAN ASSOCIATION for business and commerce



Supported by the
European Union





Supervisory Commission for Planning, Tender Specification and Central Rail Authority

Typical Project Objectives

- Safe
- Modern Functionality and Image
- Reliable
- Affordable: Whole Life Costs Under Control
- Compatible with Existing Systems
- Environmentally Friendly

How Do We Best Achieve These?





Supervisory Commission for Planning, Tender Specification and Central Rail Authority

Specification Good Practice:

- Make Specifications Less Prescriptive Technically
- Describe Operations and Maintenance Goals
- Specify only:
 - Desired Outputs: Functionality, Performance, Safety
 - Mandatory Constraints: Interfaces, Environment, Standards
- Require:
 - Modern Project Support Systems
 - Planning
 - Requirements Management
 - Configuration Management





Supervisory Commission for Planning, Tender Specification and Central Rail Authority

Following Good Practice Allows Contractors to Make Innovative Proposals Based on Latest Proven Technology

However, the Approach Requires:

- Clarity in Policy Objectives
- Change in Specifications
- Identification and Dissemination of Evaluation Criteria
- Experienced Competent Technical Support for Production of Specifications and Review of Submissions

Preferably Supported by Ongoing Independent Verification and Validation





Supervisory Commission for Planning, Tender Specification and Central Rail Authority

Central Rail Authority: Roles and Responsibilities

- Possible Role Model: European Rail Agency as Supported by National Authorities eg ORR in UK, EBA in Germany
- ERA Scope: Safety and Interoperability
 - Common Safety Method
 - Technical Standards for Interoperability
- ORR Scope examples:
 - Promoting Improvements in Railways
 - Protecting Rail Users
 - Value for Money
 - Securing Safe Construction and Operation/Maintenance
 - Safety Approvals





Supervisory Commission for Planning, Tender Specification and Central Rail Authority

Central Rail Authority: Possible Way Forward

- Will Require Core Team of Competent Experienced Railway Professionals
 - Operations
 - Maintenance
 - Engineering
 - Safety
- Training Could be Provided Externally
- Must be Independent, so Full Time
- Initially Support Required from Internationally Accredited Bodies (eg Notified Bodies, IV&V Companies)





Supervisory Commission for Planning, Tender Specification and Central Rail Authority

EABC will be pleased managing the contact with the responsible directors of European Railway Agency and National Authorities in EU Member States like German: EBA-The Federal Railway Authority UK: Office of Rail Regulation (ORR)



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European Union





EUROPEAN ASSOCIATION for BUSINESS and COMMERCE



Supported by
the European Union



Design of the Viaduct for Elevated Rail Line

**Improvements
whose careful examination
we strongly recommend**

Bangkok, July 11th 2016

Georg WOLFF, georg.woff@civeng.sg, T +66 84 555 8781



Structural Design Rules - Verification Management

- Traditional Concept: Global Safety Factor
- State-of-the-Art Concept: Partial Safety Factor (“New Approach”)
- Global safety factor verification select the worst load case and applies one general safety factor.
-
- Partial safety factor verification considers many load cases and applies specific safety factors.



Partial Safety Factor Concept - New Approach

- What's the **advantage**?
 - Gain in **safety** (RAMS concept - risk control)
 - Better **life cycle management**
(deeper knowledge of structural elements)
 - Reduction of **cost** (~30%)





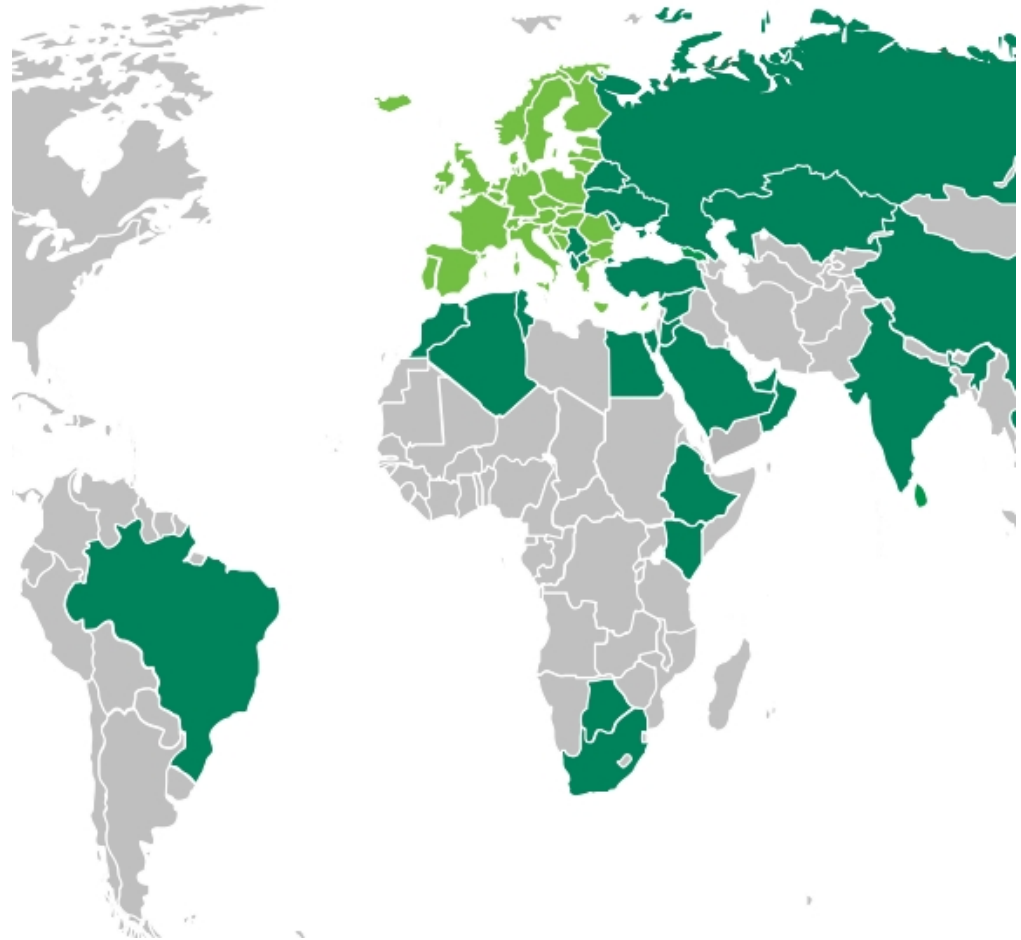
New Approach

How to implement the New Approach?

The **Eurocodes** - EN 1990 family - are the right framework of standards.

Developed since 1980 with the know-how of the leading European countries, they provide options for national values.

They are in use in many countries.





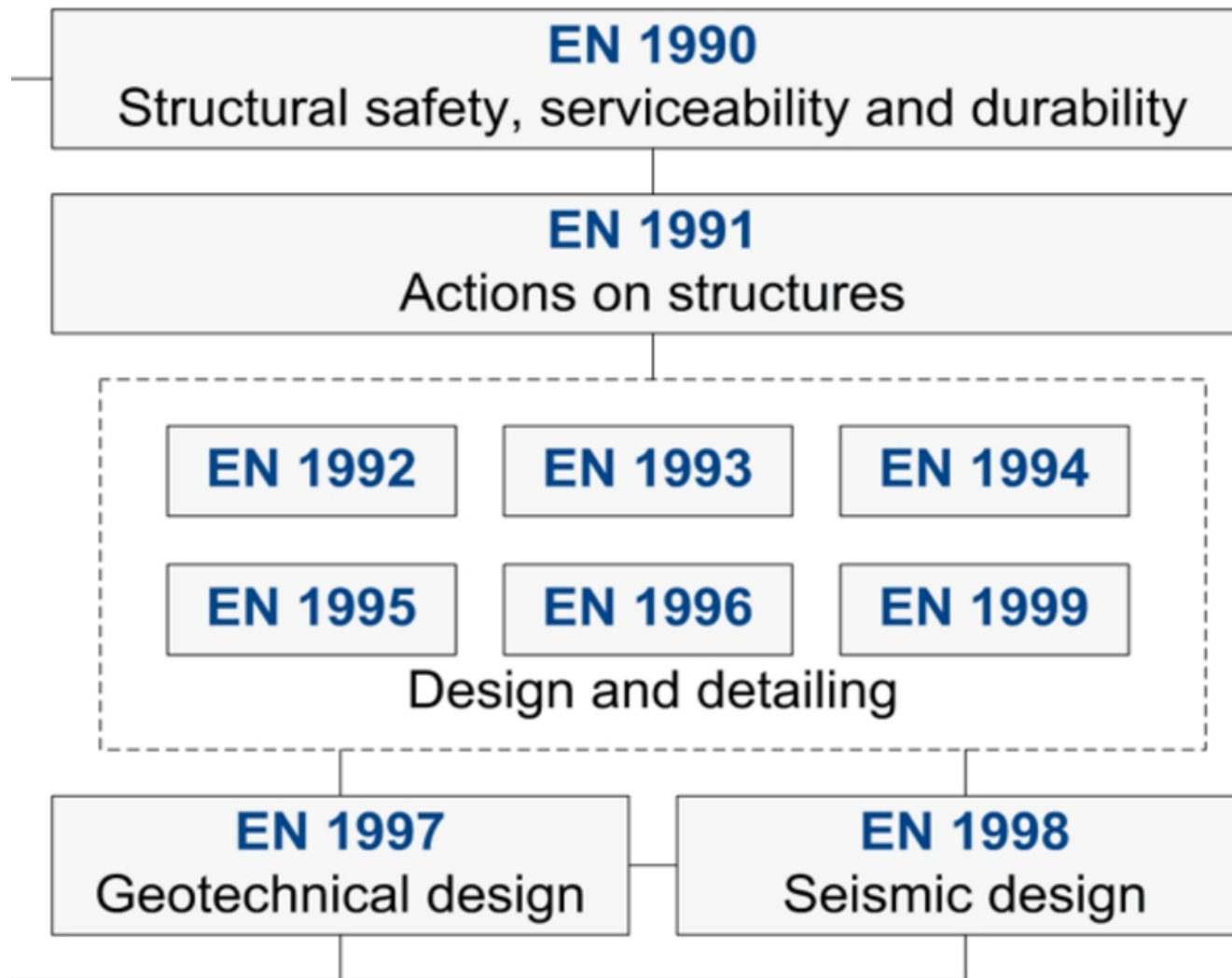
The European Standards Organisation CEN is prepared for cooperation with Thailand

CEN and CENELEC propose different models of cooperation for the National Standardization Bodies:

- Partnership: Partner Standardization Bodies
For National Standards Bodies that are a member of ISO, but are unlikely to become CEN Members or CEN Affiliates for political or geographical reasons.
- Cooperation Agreements
with National Standardization Bodies.

EABC will be pleased managing the contact with the responsible CEN/CENELEC directors.





Design Comparison

EABC strongly recommend a **comparative study**.

We will gladly arrange the contact to a European engineering firm with proven experience with comparable rail viaducts.

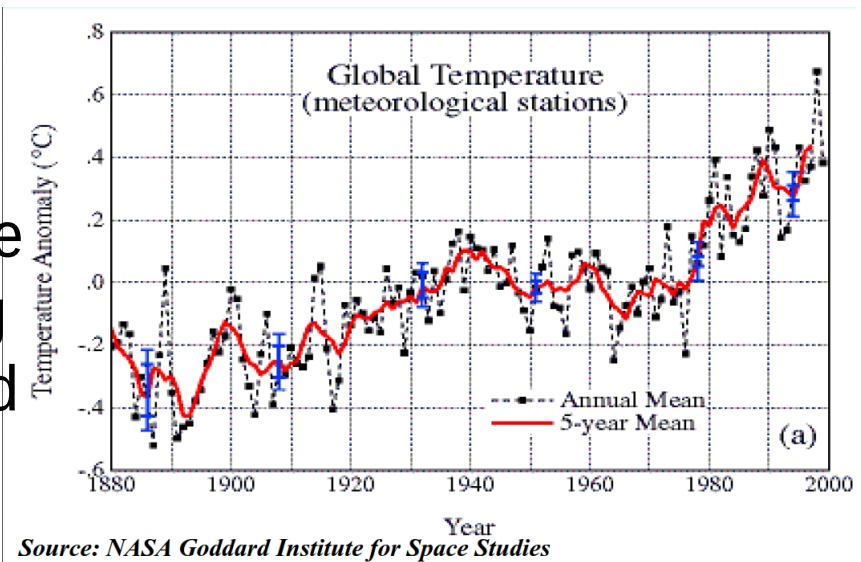
A **recalculation of a single, typical field** of an ongoing project can demonstrate very clearly the benefits of the design according to Euro Code.



Design Consideration: Temperature

Railway bridges shall be designed for a life span of 100 and more years. Available civil engineering standards mostly consider only mean **shadow** temperatures of the **past**.

As the railway bridges are often exposed to direct sunlight and provisions for future temperature increase are needed, considering at least $+60^{\circ}\text{C}$ shall be considered for “ULS” bearing operating temperature in Thailand.



Design Consideration: Interaction Viaduct - Track

- There is an **interaction** between the **deck** of a railway bridge/viaduct and the continuous **track/rail**. If not carefully considered this will cause serious long-term troubles to train operation and life cycle cost.
- Deck displacements shall be minimized in order not to overstress the rails.



Interaction Viaduct - Track

- During the planning the **interaction** of foundation, bearing system, post tensioning and structural stiffness must be considered.
- **Data exchange** between civil engineering and track engineers shall be established.
- **Wrong** design to be **corrected** (see examples).
- **Behaviour** of viaduct to be **evaluated** prior to installation of track.



Example 1: Bangkok Mass Transit System Green Line Mo Chit - Saphan Mai Section

Box Girders are designed with free **floating**, not anchored Elastomere Bearings.

A system copied from road bridges, not applicable for railway bridges.

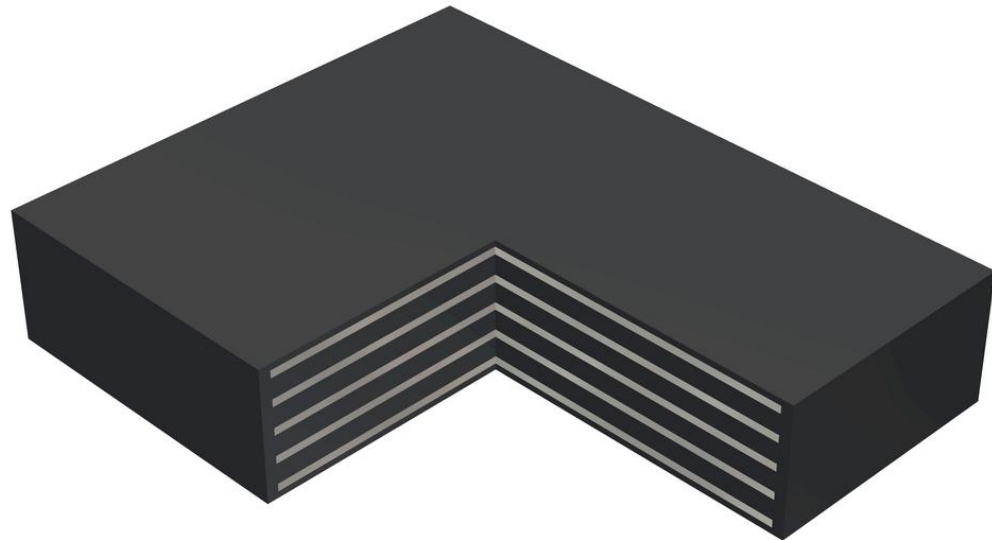
Blacklisted in US and EU.



Bearing reaction force transmitted by friction only - no anchorage. This is strictly prohibited for railway bridges. Long term effect endangers structural security: bearings may slip out of their position.

Example 1: Bangkok Mass Transit System Green Line Mo Chit - Saphan Mai Section

Rails overstressed as bearings do **not take horizontal forces** and **deflect** at train loads.
Rails have to guide and hold the bridge!



Example 1: Bangkok Mass Transit System Green Line Mo Chit - Saphan Mai Section

For precast segment spans **POT BEARINGS** are specified.

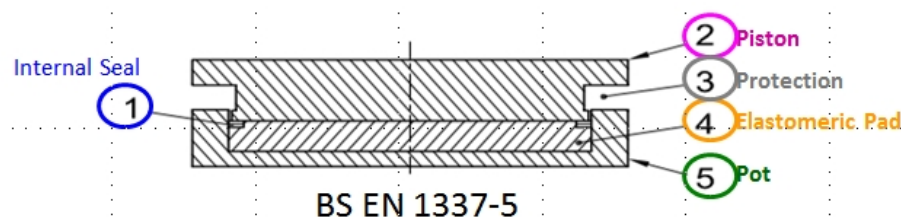
State-of-the-art knowledge since decades:
This design has serious disadvantages. There is a **critical internal seal**, subject to wear, but cannot be inspected during service!

Numerous damages worldwide.
Design **blacklisted** in US and EU for railway bridges.



AREMA standard and Deutsche Bahn blacklisted pot bearings due to wear and check problems

Pot bearing: wear of internal seal:



DEUTSCHE BAHN use only elastomeric bearings (for very small structures) and UHMWPE spherical bearings

Example 2: Track Doubling Project Chira Junction - Khon Kaen

Pot Bearings are specified.

Inconsistent requirements regarding standards:

Drawings specify pot bearings acc. AASHTO.

But AASHTO is for road bridges only! Pot bearings acc. to AASHTO are equipped with internal seals not capable for cyclic railway loads!

TOR requires pot bearings acc. to BS 5400: part 9.

This standard was withdrawn in the year 2000!

Replaced by EN 1337.

To use Pot Bearings for such investment is a
programmed disaster!



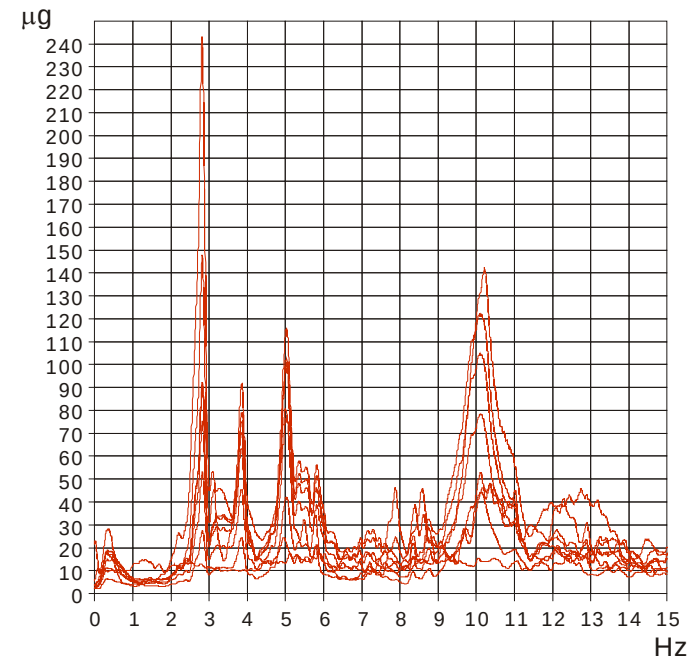
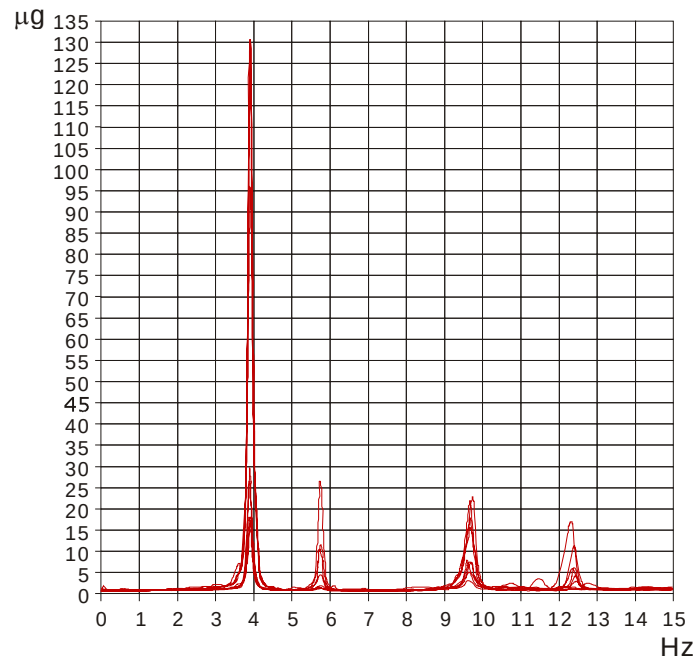
Design Consideration: Evaluation

State-of-the-art is to evaluate the behaviour of the viaduct prior by Ambient Vibration Monitoring test.

High precision accelerometers are set on the deck and connected by wireless. They allow acquiring knowledge on the current condition of the examined structure very quickly.



The vibration signal is measured in three dimensions with high precision and is saved on the internal data loggers.



Sound vs. Disturbed Deck

EABC will be pleased giving you access to the technology called BRIMOS, to allow you a trial of this rapid and inexpensive method for **quality evaluation**.

navis®

TT CLUB
established expertise

BRIDON · BEKAERT
THE ROPES GROUP

LSL
APPLICATIONS

LIEBHERR 1-stop

VST ECS

VAHLE

LCB
CONTAINER
TERMINAL 1 LTD.

LCMT
LCMT Company Limited

EVERGREEN
CONTAINER TERMINAL (THAILAND) LTD.

Schneider
Electric

THLE
新华起重工具

ESCO

Hutchison Port Thailand

KRANUNION
KIRON ARDELT ROCKS

**L
C
I
T**

14th ASEAN PORTS & SHIPPING

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THE LANDMARK BANGKOK, THAILAND
THURSDAY 14 AND FRIDAY 15 JULY 2016

5TH ANNUAL SHOW

SMART RAIL ASIA

CONGRESS & EXPO

TRANSPORT INFRASTRUCTURE ASIA

1st-2nd December 2016

EXPO HALL | MAKKASAN AIRPORT RAIL LINK
BANGKOK | THAILAND

HIGHLIGHTS

Part of the State Railway of Thailand creates a unique hosting of the events at Makkasan Airport Rail Link Expo Hall from 1-2 December 2016. Smart Rail Asia will co-locate with the recently launched Transport Infrastructure Asia expo, occupying both Expo Halls of the new state rail Link venue at the interchange station with Petchaburi MRT.

Smart Rail Asia 2016, co-located with Transport Infrastructure Asia 2016, is set to double in size as it attracts an Asian wide audience covered by rail professionals and infrastructure specialists.



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