

# Safety Assessment for the Maglev Vehicle TR09 – an approach based on CENELEC railway standards

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**ABSTRACT:** TÜV InterTraffic has been involved in the Safety Certification Process of the Maglev Vehicles operating on the Shanghai Maglev Line and the Transrapid test facility in Emsland, Germany (TVE). As the prototype of the Maglev Vehicle for the Munich Airport Maglev Application (TR09) will initially be operated on the TVE to achieve type approval, TÜV InterTraffic in its role as notified expert for the TVE is responsible for the safety assessment of the TR09 operation on the TVE. The type approval and safety case for the TR09 will be probably based on the CENELEC railway safety standards (EN 5012x) as accepted rules of technology. To ease cross-acceptance, the safety assessment of the safety related electronics and mechanics of the vehicle TR09 for the operation on the TVE will also be based on these CENELEC railway safety standards. The development of the TR09 as an adaptation of the TR08 on local transport requirements implies the implementation of a notable spectrum of modifications, from changed discrete components to new software and architecture in vehicle electronics and to new designs in vehicle mechanics. Due to that notable range of modifications the challenge will be the acceptance based on CENELEC standards of as many existing safety cases with appropriate consideration of all safety implications of modifications. The safety assessment for the vehicle TR09 had just started at the time this paper was written (31.05.2006) and therefore the planned assessment approach is described.

## 1 INTRODUCTION

### *1.1 Role of TÜV InterTraffic on TVE*

#### *1.1.1 General*

The Transrapid test facility (Transrapid Versuchsanlage Emsland, TVE) was built from 1979 to 1987.

From the beginning the TVE was subject to the law for test facilities (Versuchsanlagengesetz /1/). According to this law the relevant approving authority for the TVE is the Technical Supervisory Body (Technische Aufsichtsbehörde TAB) of Lower Saxony (Niedersachsen) within the State Road Construction and Traffic Office of Lower Saxony (Niedersächsische Landesbehörde für Straßenbau und Verkehr, NLStBV).

In the course of the approval of the operation regulations according to §12 (4) of the law for test facilities the approving authority notified experts/expert organisations to monitor the observance of the operation regulations. One of the two notified experts is the TÜV Arbeitsgemeinschaft Versuchsanlage Emsland (TÜV Arge VME), a joint venture of TÜV Rheinland InterTraffic GmbH (TRIT) and TÜV Nord. TRIT within the TÜV Rheinland Group as a member of the TÜV Arge VME is examining the following subsystems: maglev vehicle, operation facilities including service vehicles, operation control system, switches and transfer table, guideway equipment, propulsion, Inductive Power Supply (IPS). Furthermore TRIT is responsible for EMC, system technology, interfaces and the set of operation regulations. The second member of TÜV Arge

VME TÜV Nord is responsible for the electrotechnical equipment of the facilities, of the guideway equipment and of the propulsion, furthermore for ESD and lightning protection.

The second expert notified by the approving authority is Dr.-Ing. S. Droege from the Institut für Baustoffe, Massivbau und Brandschutz (iBMB) at the TU Braunschweig, who examines the main structure of the guideway.

#### *1.1.2 Maglev vehicle TR08*

Testing of the 3-section pre-production vehicle TR08 started in September 1999 at the TVE.

This test site operation is one step within the certification process known as vehicle type approval which is regulated by the Federal Railway Authority (Eisenbahn-Bundesamt, EBA) together with the TVE operator and the industry. EBA is the supervisory and licensing authority for revenue service of Maglev Applications in Germany.

TÜV experts have been involved in the aforementioned process, partly as experts of the state authority for the TVE, partly as experts recognized by the federal authority EBA.

### *1.2 TR09 vehicle prototype on TVE*

The first prototype of the vehicle generation Transrapid 09 (TR09) is currently under development and is planned to start operation on the TVE mid 2007.

The TR09 is an adaptation of the TR08 on local transport requirements.

- Rulebook Maglev-Trains /5/
- General Maglev Systems' Act /6/
- German ordinance on the construction and operation of maglev systems /7/

## 2 ASSESSMENT OF THE TR08 ON THE TVE

### 2.1 General

The Transrapid 08 (TR08) is a prototype vehicle and consists of the three sections endsection E1, middle section M and endsection E2. It operates at the TVE since 7<sup>th</sup> September 1999. In the following the process of conducting the safety case for the authority approval is explained.

### 2.2 Prerequisites for the acceptance by the approving authority

In section 1.1 (5) of the operation regulations (/5/) for the TVE new or modified installations or vehicles can be put into service if the following prerequisites are fulfilled:

“New or modified installations or vehicles, which can influence safety and order of operation, must be – except for examining suitability for use - accepted by the approving authority before being put into operation.”

Furthermore under section 1.2 (2) the following is written: “Installations and vehicles must be constituted according the requirements for safety and order. These requirements are fulfilled if the installations and vehicles are built and operated according to the present operation regulations or, if these do not contain explicit stipulations, according to the accepted rules of technology.”

Basis of the decision of the approving authority for acceptance of the TR08 was an assessment report of the notified experts of TÜV InterTraffic. In this document the experts gave their advisory opinion regarding the question, if the operational safety with the TR08 is ensured

- for trial- and demonstration operation on the TVE
- for commercial service.

### 2.3 Assessment prior to approval

#### 2.3.1 Bases of assessment

The following documents formed the basis of assessment for the inspection of TR08 documentation:

- Law for test facilities /1/
- Operation regulation for the TVE /2/
- System specification Transrapid /3/
- Requirement specification vehicle /4/
- Other applicable norms and standards

Further bases of assessment regarding type approval

#### 2.3.2 Evidence for operational safety

For all safety relevant functions as well as for safety relevant electronic and mechanical components the requirements were defined in the system specification, the requirement specification vehicle and the norms and standards applicable at that time (/12-/14/).

The apportionment of requirements for the subsystems and components as well as architecture and design were laid down by the manufacturer in technical reports, drawings and wiring diagrams.

Evidence of fulfilment of the safety requirements was provided by analyses like FMEA, FTA and strength analysis, which were supplemented by experimental verification as far as needed.

The requirements for analyses and experimental verification were documented in verification specifications for each component. Verification reports and documents for FMEAs, FTAs and stability verification completed the evidence.

For the safety relevant vehicle functions levitation, guidance and braking quantitative requirements were defined in the requirement specification. The tolerable rate for dangerous failures for these safe-life<sup>1</sup> functions was given as  $R \leq 10^{-6} / year$ .

The fulfilment of these quantitative safety targets was demonstrated by fault tree analyses.

#### 2.3.3 Performance of assessment

The assessment for approval regarding sections 1.1 (5) and (6) of the operation regulations was performed by the notified experts.

The system specification Transrapid and the underlying requirement specifications for subsystems like vehicle etc. were assessed by TÜV InterTraffic et al based on expert knowledge.

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<sup>1</sup> safe-life: lifetime availability, realised (a) by failure exclusion based on operation proof design or (b) redundancy

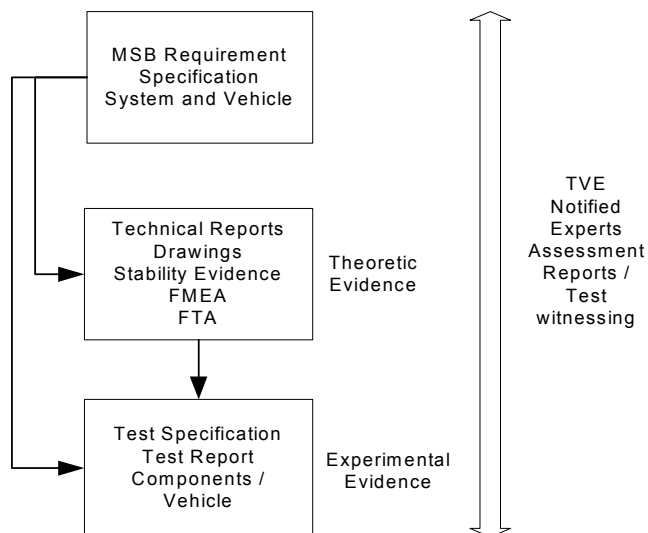


Figure 1: Illustration of Assessment process

The assessment of the vehicle TR08 comprised document inspections as well as inspections on the manufacturer’s site and on the TVE. Furthermore verification and validation tests have been witnessed. The assessment was focused on the evidence of functional and technical safety. Verification and Validation was partly performed by the notified experts. See figure 1.

#### 2.4 Initial operation to determine serviceability

After completion of the essential theoretical examinations the vehicle TR08 started operation on the TVE to demonstrate suitability for use.

The initial operation was performed to verify and validate the TR08 on the TVE based on a test specification which had been agreed between manufacturer and the notified experts.

After test completion and the agreement of the notified experts to start regular operation the initial operation phase was completed in March 2000.

#### 2.5 Approval

After completion of a final assessment report by the notified experts the vehicle TR08 was approved by the authority and the regular operation commenced.

Based on that report EBA agreed to type approval of the TR08 on 12<sup>th</sup> April 2000.

### 3 REQUIREMENTS FOR APPROVAL OF THE TR09

#### 3.1 General remarks

The vehicles TR08 and TR09 differ in a notable range of modifications (see chapter 4.2). Furthermore the relevant system documentation has changed as well as the applicable standards<sup>2</sup>. The assessment challenge will be the acceptance of as many existing safety cases as possible with appropriate consideration of the modified assessment bases and of all modifications which might have impact on safety.

#### 3.2 Operation regulations

The operation regulations remained almost unchanged since approval of the TR08. Hence they are valid for approval of the TR09 on the TVE.

The assessment bases have changed as follows:

- The system documentation relevant for approval of the TR08 has been replaced by the “Ausführungsgrundlagen Magnetschnellbahnen” /8/. The system documents valid for the TR08 had actually been manufacturer documents and hence been part of the safety case. The “Ausführungsgrundlagen Magnetschnellbahnen” in contrast are based on a broad expert opinion and are published as a rule of technology (Regel der Technik).
- The CENELEC- railway standards EN50126 /9/, EN50128 /10/ and EN50129 /11/ have to be applied – also regarding a type approval for the application in Munich

#### 3.3 Risk analysis

For the TR08 and previous vehicles no risk analysis of the operator had been performed to provide tolerable hazard rates (THR) for the vehicle. For the safety relevant functions THRs were agreed between manufacturer and assessor based on expert knowledge.

The MbBO will be the legal basis for a new service application. The MbBO requires to draw up a safety concept. The safety concept has to contain a risk analysis which derives the THRs for safety functions.

To ease cross-acceptance of the TR09 for an application the assessor proposes, that the manufac-

<sup>2</sup> The type approval and safety case for the TR09 will probably be based on the CENELEC railway safety standards (EN 5012x). To ease type approval, the safety assessment of the TR09 for the operation on TVE will already be based on these CENELEC railway safety standards as far as possible.

urer<sup>3</sup> performs a risk analysis for operation of the TR09 on the TVE. The analysis can be used to verify the applicability of the current (TR08) THR<sub>s</sub> for the TR09.

Whether the achieved THR<sub>s</sub> do fulfil the requirements of the Munich project has to be checked during type approval for Munich.

## 4 ASSESSMENT PROCESS FOR THE TR09 ON TVE

### 4.1 General

The following paragraphs describe a proposal from the notified experts point of view, how the CENELEC standards can be applied to the TR09 development, manufacturing and assessment process. It is particularly taken into account, that the TR09 is based on the TR08.

### 4.2 Modifications between TR08 and TR09

The development of the TR09 includes the implementation of a wide range of potentially<sup>4</sup> safety related modifications: Different discrete components, new hard- and software in vehicle electronics and modified or new mechanical design.

In the following table 1 the main differences are illustrated to get an impression about the extent of modifications. Focus of the illustration lies on the differences which might have impact on safety.

Table 1: safety relevant modifications from TR08 to TR09

Feature	Changes
Car body, dimensions	carbody dimensions modified, position of
Entrance doors	doors altered and door width increased
Weight	maximum load capacity increased.
Nose	Driverless operation, therefore omission of front windows
Maglev undercarriage, nose casing	Adaption of the geometry according to modified dimensions of car body
Maglev undercarriage, casing	Optimisation regarding winter conditions
Safe vehicle brake	Adaptation to increased vehicle weight
Onboard power supply shut down	Automatic onboard power supply shut down under certain conditions
Onboard power supply	Contactless onboard power supply at low speed and standstill by inductive power supply (TR08: power rail)

<sup>3</sup> According to EN50126 and EN50129 the system definition as well as the risk analysis have to be provided by the operator. As the TVE is a test facility for industry, these TVE specific documents should be provided by the manufacturer.

<sup>4</sup> The definite decision about safety relevance of modifications must be based on a safety impact analysis.

Feature	Changes
Entrance doors, door control	door control functionality modified
Magnets	Product adaptation <sup>5</sup>
Sensors	Product adaptation
Magnet control electronics	Product adaptation
Onboard power supply	Product adaptation
Onboard control	Product adaptation
Wiring	Product adaptation

### 4.3 Application of EN 50126 - RAMS for railway applications

#### 4.3.1 The Lifecycle according to EN50126

The European railway standard EN 50126

- defines a process, based on the system lifecycle including RAMS-Management (reliability, availability, maintainability and safety) and
- is applicable to modifications of existing systems in operation prior to the creation of the standard (e.g. introduction of the TR09), although it is not generally applicable to other aspects of the existing system.

Figure 3 depicts an example for a lifecycle. For each phase of this lifecycle EN50126 defines the phase related safety tasks, which are summarised in Table 2.

Another common graphical representation of the lifecycle, the V-Model, is given in figure 4. The figure shows the application of the lifecycle model for a system decomposed in subordinated subsystems. In phase 5-*apportionment of system requirements* the system requirements are refined into subsystem requirements. Each subsystem has to pass through its own lifecycle, which ends in phase 9-*validation of the subsystem*. All validated subsystems are integrated in the system (phase 8-*installation*), and the system is validated against the system requirements, which have been defined in phase 4. It has to be noted, that the phases 6-*design* and 7-*manufacture* do also apply for certain aspects of the system lifecycle, e.g. safety management, generic safety case generation and parts of the system which are not split into subsystems. Phase 5 is only applied in subsystem lifecycles if the subsystem is refined further.

Usually subsystems are broken down to components. The lifecycle in figure 5 shows, how the lifecycle can be applied in this case. The subsystem re-

<sup>5</sup> Within the scope of the adaptation of vehicle assemblies the following adaptations are implemented: (a) reduction of production costs by reduction of design complexity and design improvement (b) adaptation of electronic assemblies for marketable electronic components (replacing non-available components and use new improved generations of components)

requirements are refined further to component requirements and the phases 6 and 7 are only applied for the component lifecycle.

Table 2: Safety tasks related to each lifecycle phase according to EN50126

No	Lifecycle phase	Phase related safety tasks
1	Concept	<ul style="list-style-type: none"> <li>Review Previously Achieved Safety Performance</li> <li>Consider Safety Implications of Project</li> <li>Review Safety Policy &amp; Safety Targets</li> </ul>
2	System definition and application conditions	<ul style="list-style-type: none"> <li>Evaluate Past Experience Data for Safety</li> <li>Perform Preliminary Hazard Analysis</li> <li>Establish Safety Plan (Overall)</li> <li>Define Tolerability of Risk Criteria</li> <li>Identify Influence on Safety of Existing Infrastructure Constraints</li> </ul>
3	Risk analysis	<ul style="list-style-type: none"> <li>Perform System Hazard &amp; Safety Risk Analysis</li> <li>Set-Up Hazard Log</li> <li>Perform Risk Assessment</li> </ul>
4	System requirements	<ul style="list-style-type: none"> <li>Specify System Safety Requirements (Overall)</li> <li>Define Safety Acceptance Criteria (Overall)</li> <li>Define Safety Related Functional Requirements</li> <li>Establish Safety Management</li> </ul>
5	Apportionment of system requirements	<ul style="list-style-type: none"> <li>Apportion System Safety Targets &amp; Requirements</li> <li>Specify Sub-System &amp; Component Safety Requirements</li> <li>Define Sub-System &amp; Component Safety Acceptance Criteria</li> <li>Update System Safety Plan</li> </ul>
6	Design and implementation	<ul style="list-style-type: none"> <li>Implement Safety Plan by Review, Analysis, Testing and Data Assessment, addressing: <ul style="list-style-type: none"> <li>Hazard Log</li> <li>Hazard Analysis &amp; Risk Assessment</li> <li>Justify Safety Related Design Decisions</li> <li>Undertake Programme Control, covering: <ul style="list-style-type: none"> <li>Safety Management</li> <li>Control of Sub-Contractors &amp; Suppliers</li> </ul> </li> <li>Prepare Generic Safety Case</li> <li>Prepare (if appropriate) Generic Application Safety Case</li> </ul> </li> </ul>
7	Manufacturing	<ul style="list-style-type: none"> <li>Implement Safety Plan by: Review, Analysis, Testing &amp; Data Assessment</li> <li>Use Hazard Log</li> </ul>
8	Installation	<ul style="list-style-type: none"> <li>Establish Installation Programme</li> <li>Implement Installation Programme</li> </ul>
9	System validation	<ul style="list-style-type: none"> <li>Establish Commissioning Programme</li> <li>Implement Commissioning Programme</li> <li>Prepare Application Specific Safety Case</li> </ul>
10	System acceptance	<ul style="list-style-type: none"> <li>Assess Application Specific Safety Case</li> </ul>
11	Operation and maintenance	<ul style="list-style-type: none"> <li>Undertake On Going Safety Centred Maintenance</li> <li>Perform On Going Safety Performance Monitoring and Hazard Log Maintenance</li> </ul>
12	Performance monitoring	<ul style="list-style-type: none"> <li>Collect, Analyse, Evaluate and Use Performance &amp; Safety Statistics</li> </ul>
13	Modification and retrofit	<ul style="list-style-type: none"> <li>Establish Safety Plan</li> <li>Consider Safety Implications for Modification &amp; Retrofit</li> </ul>
14	Decommissioning and disposal	<ul style="list-style-type: none"> <li>Establish Safety Plan</li> <li>Perform Hazard Analysis &amp; Risk Assessment</li> <li>Implement Safety Plan</li> </ul>

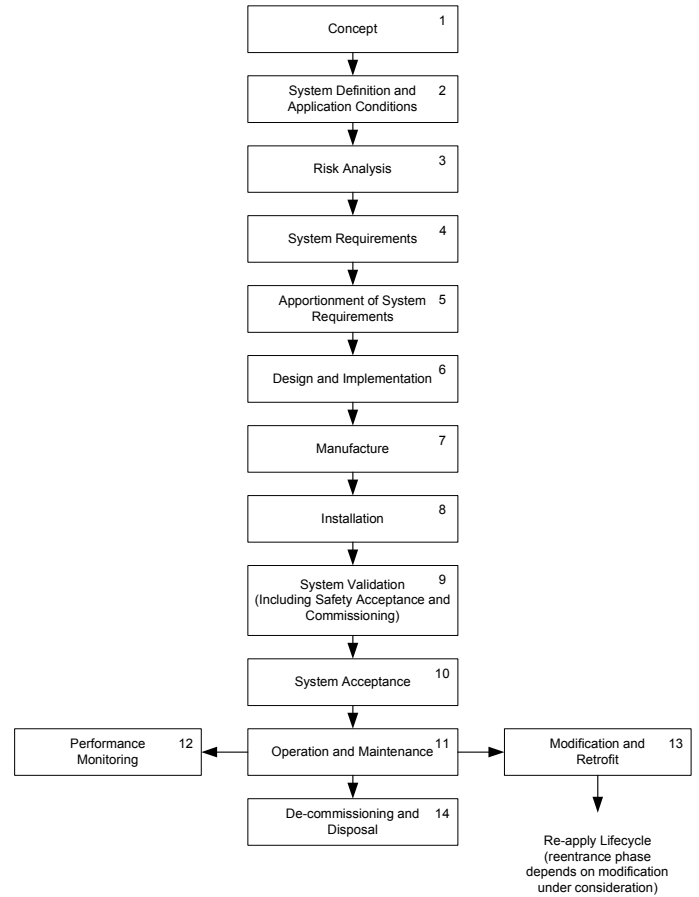


Figure 3: Lifecycle according to EN50126

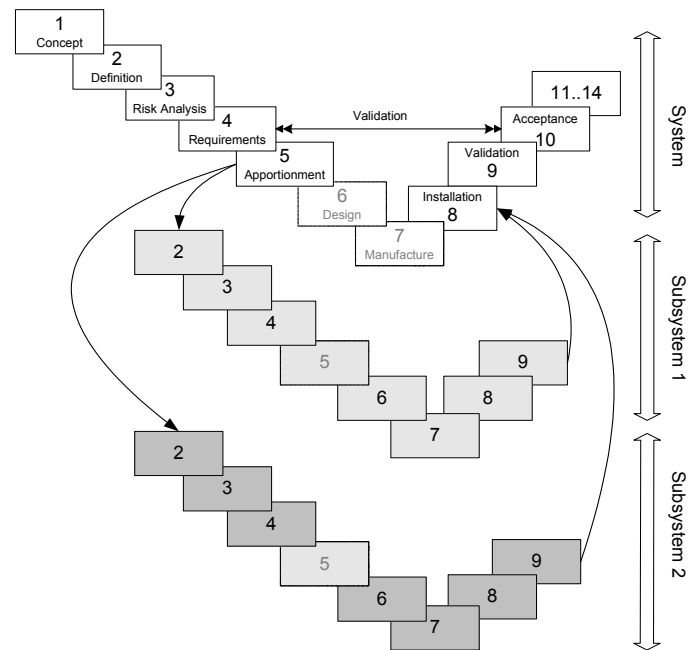


Figure 4: Application of the lifecycle for a system and its subsystems









