The Transrapid Munich Airport Link
System Engineering and System Layout

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Abstract

The German "Munich Airport Link" Transrapid Project is progressing according to schedule. In addition to the technical planning involving the route alignment and the environment, the maglev system layout is being planned in detail.

At the end of September 2003, Transrapid International (TRI), as the general contractor together with Siemens and ThyssenKrupp, was awarded the contract by the *Bayerische Magnetbahnvorbereitungsgesellschaft* (BMG) for the completion of the system layout for all Transrapid subsystems. The planning work is to be completed by September 2004. TRI's scope of delivery includes all technical documents required by German law and regulations to obtain the legal planning approval for the project from the public authorities. In accordance with the original feasibility study from 2003, the total project costs are estimated to be 1.6 billion Euro. The 38 km long line is to commence scheduled operation at the end of 2009. The following report summarises the current planning status and the most important results of the maglev system planning.

1 Introduction

Based on the feasibility study of potential German Transrapid projects prepared by the Federal Government in 2003, in-depth planning for the Transrapid maglev link between Munich city centre and airport started in September 2003.

The project planning focuses on the goal of covering the 38 km distance in 10 minutes with 10-minute headway. To achieve this goal, operating speeds of 350kph are necessary.

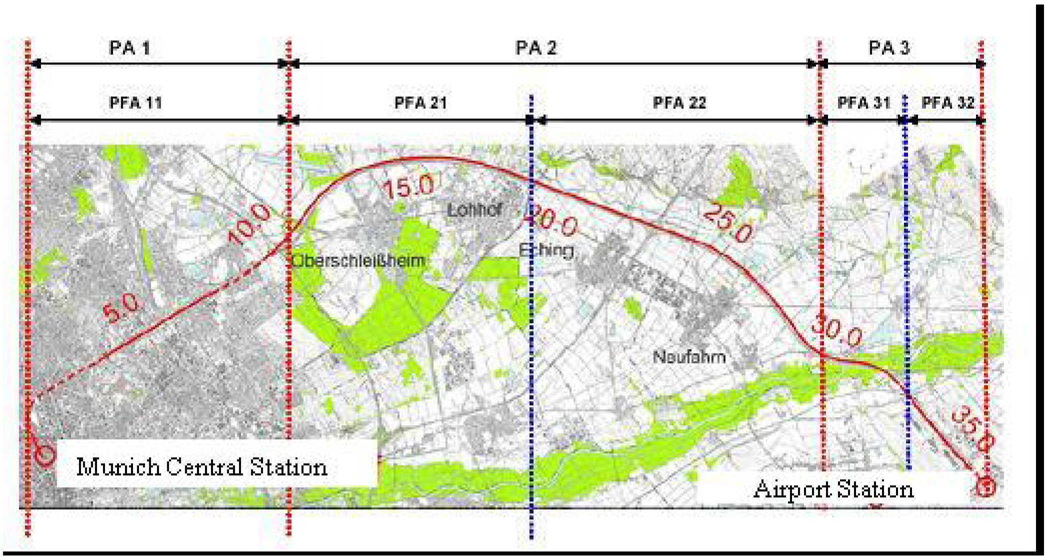


Figure 1: Route Alignment.

Route length	37.4 km
Planning sections (PFA)	5
Bundling with freeway	18.7 km (50%)
Bundling with road/rail	2.9 km (8%)
Tunnels	7.2 km (19%)
Max. speed	350 km/h
Trip time	10 minutes
Number of stations	2
Number of tunnels	3
Number of vehicles (sections)	5 (15)
Number of seats per vehicle	140
Stopping time at the stations	2 minutes
Headway	10 minutes
Forecast traffic volume Source: 2002 feasibility study	7.86 million/year
Daily service	4 a.m. to midnight

Table 1: General Project and Operation Data

In the run-up to the planning, the client, *Bayerische Magnetbahnvorbereitungsgesellschaft* (BMG), invited extensive Europe-wide tenders.

In addition to the general technical planning and the consideration of the environmental effects, the planning of the system layout is a focus of project planning.

Transrapid International (TRI), a joint venture of Siemens (SAG) and ThyssenKrupp (TKT-TR), tendered for the system layout including the provision of the public legal planning documents and was awarded the contract by BMG as the general contractor in September 2003.

2 System Layout in the Planning Process for the Munich Airport Link

As in the case of conventional railroad, the systems engineering design is an essential step in the planning of Transrapid routes, which occurs in parallel with the route alignment and environmental planning activities.

In comparison with other transportation systems, the Transrapid's vehicle, guideway, propulsion, operations control and safeguarding systems are more strictly functionally interlinked. Essential components of the propulsion and safeguarding technology are located along the route and installed both in the vehicle and in the guideway. The operation control system provides the data connection between all stationary and mobile facilities and the control centre from where the entire operation is automatically controlled and technically safeguarded.

The functional interconnection requires an integrated system layout including the safety concept, the operating concept, the track scheme definition and the dimensioning of the subsystems in all project phases. As a consequence, changes in the requirements that existed at the start of the project quickly result in extensive iteration loops and additional expenditure with regard to system layout planning.

2.1 System Layout Planning Phases

The planning of the Munich Transrapid operating system is currently organised in three planning phases:

	Start:	Completion:
Project Phase 1: Determination of Project Basis	October 2003	December 2003
Project Phase 2: Preliminary Planning	December 2003	May 2004
Project Phase 3: Design Planning	May 2004	September 2004

Table 2: Project Phases

The planning of the system layout is done with the quality necessary to be able to start the approval procedure provided for by German law (public works planning procedure) in August 2004.

On completion of the documentation in September 2004, TRI will accompany the approval process in phase 4, participate in public hearings and answer the system engineering questions both of the authorities and of concerned citizens.

2.1.1 Project Phase 1 – Determination of Project Basis

System layout needs to take account of the client's requirements and specifications, in particular with regard to economic aspects concerning the system's investment and operating costs, its availability, transport capacity and trip times.

The planning of the feasibility study had to be taken into account and relevant rules and regulations observed. Depending on the particular case and the country of application, project-specific framework conditions apply. For instance, the regulations regarding construction work and service operation in China are different from those in the US or Germany. The operating authority has different requirements on a relatively short airport shuttle link compared to a long-distance line.

In Germany, the government and the federal states as financiers and builders, and DB AG as the operator of the system have extensive requirements which are documented in a so-called project requirements catalogue (PRC) and in the operator's requirements. Moreover, legal foundations such as the *Magnetschwebebahn Bau- und Betriebsordnung* (MbBO) [Maglev Construction and Operation Ordinance] and framework conditions from the public works planning procedure are to be observed.

Planning phase 1 served to investigate and analyse those project bases and framework conditions and transfer them to the Munich airport link. To this end, the existing documents and project specifications had to be examined.

Other activities included:

- Revision of the track scheme as project requirement and first project milestone jointly with the track planners in several iteration loops in accordance with the prerequisites of route alignment, the route alignment limiting values, the ride comfort values and the operational requirements.
- Creation of an extensive guideway specification with exemplary representations of special cases based on guideway types I, II and III. Taking account of the results from the guideway development program which was financed by the German government as part of the Transrapid "Further Development Program". As a consequence, switch positions and the layout of the airport station were changed.

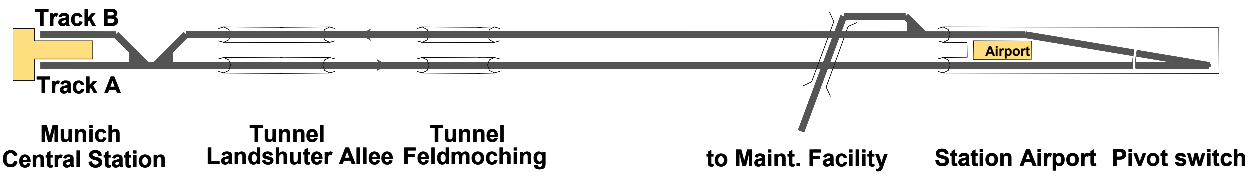


Figure 2: Munich airport link track scheme

2.1.2 Project Phase 2 - Preliminary Planning

Based on the revised track scheme, operations simulations were run in phase 2 to be able to guarantee safe operation with regard to regular and special operations taking account of the requirement of "every ten minutes in ten minutes". Based on that work, the so-called route alignment definition was made. Among other things, the route alignment is developed with the help of specifications for the route and the stations, observing the system engineering route alignment limiting values and taking account of comfort guidelines. In iterative steps, the route and track scheme are coordinated and then defined.

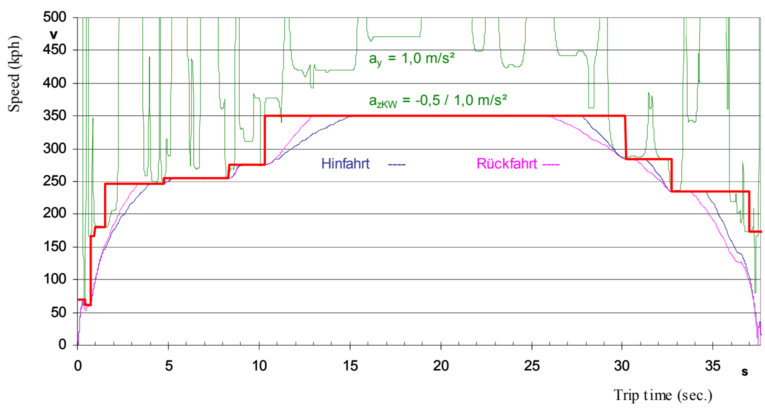


Figure 3: Travel Profile – round trip

Superordinate subjects such as the winter operations concept, the maintenance concept and a first draft of the safety concept were also issues of this planning phase.

The essential environmental issues such as electromagnetic influence, as well as noise and vibration emissions were included in the planning and dealt with jointly with BMG for critical areas of the track, in particular the tunnels inside Munich.

Additionally, work started on the layout of the operating system including the following subsystems:

- Vehicle
- Power supply and propulsion system
- Operation control system
- Operation and maintenance facilities
- System consulting for the guideway planning

2.1.3 Project Phases 3 and 4 - Design Planning and Project Approval Procedure

In phase 3, all activities of phase 2 are continued and the system is optimised and planned in depth. With the help of the existing system layout of phase 2, the operator's (DB AG) requirements are assessed and included in the planning. The project documentation is updated to prepare the approval procedure in accordance with German planning law regulations.

Based on the in-depth planning, an initial cost estimate is developed.

The essential work in the context of the system dimensioning in the individual subsystems for the Munich airport link is described in the following chapter.

3 Operation Concept

3.1 Input Data

The following route data are relevant input data for the development of the operations concept:

- Route length
- Track scheme of the main route and the operating and maintenance facilities and the limit speeds

Based on this, the operations concept was developed with the following parameters:

- System data such as vehicle data, propulsion and safeguarding areas, location-dependent acceleration capability; route creation and clearance times, technical headway, data transmission times, switch setting times
- Operational data such as service operation times, trip times, cycle times, line concept, stopping, looping and buffer times, operational procedures for cleaning and maintenance

3.2 Regular Operations

Following the determination of the input data, regular operations with minimal headway was established as circulation operations on the main line. Operational movements for start-up, fade-out and shunting of vehicles in the Maintenance Area and on the Line were also planned.

The timetable for a regular operations day was drawn up from individual runs taking account of the variation of the traffic volume in the course of an operations day.

The hours between midnight and 4 a.m. are reserved for maintenance work. All vehicles are sent to the maintenance area (MA) in the night hours.
The basis for the calculation of the Munich fleet is the necessary number of vehicles in operation (resulting from traffic volume and cycle time) and the operational and maintenance reserve.

3.3 Operation Simulation

In order to examine the stability of scheduled regular operations, simulations were performed immediately after the creation of the first track scheme variants (Figure 4).

With the help of dynamic simulations with random operational delays it was possible to examine and optimise the elasticity of service operations and the efficiency of counter-measures to return to the normal timetable. Operational irregularities could be examined with regard to their effect on regular operations.

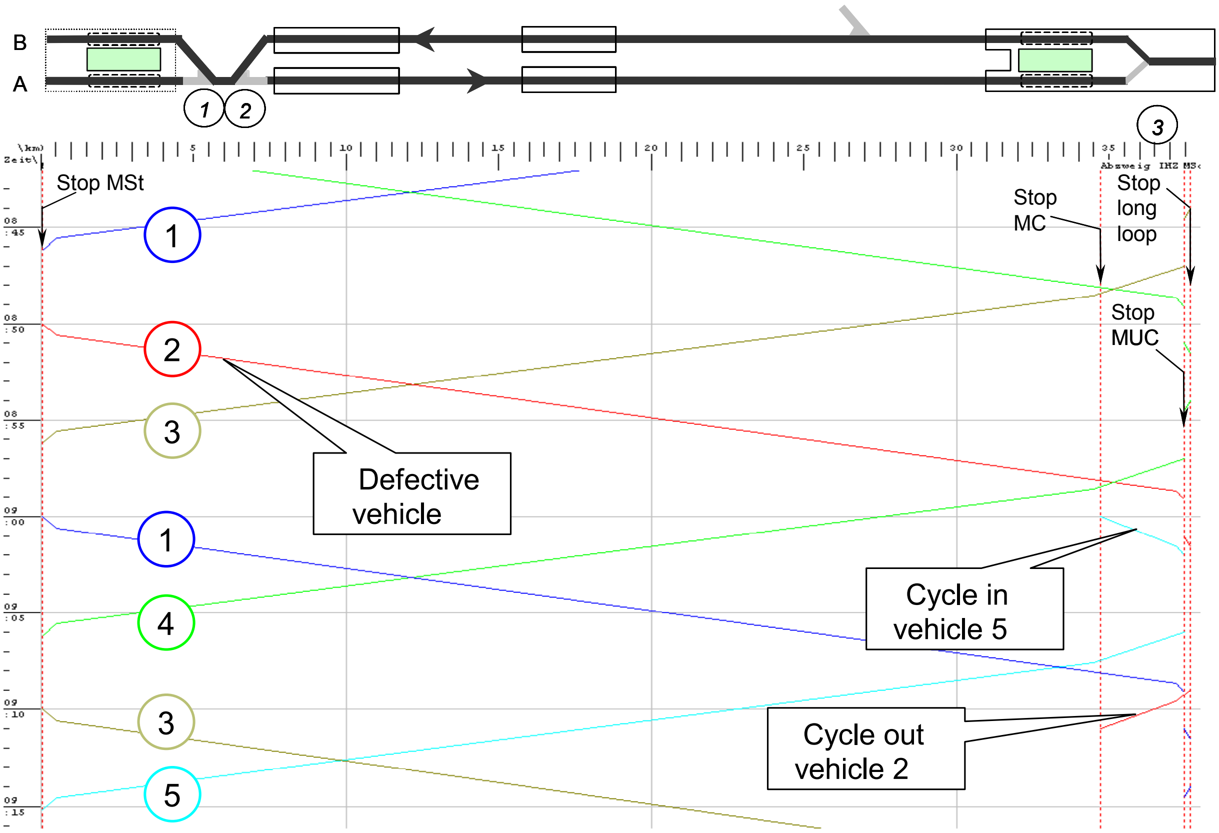


Figure 4: Operation simulation fade in/out of a vehicle into normal operation

4 Safety Concept

An essential task within the system dimensioning is the development of a safety concept. The procedure for the development of the safety concept for the Munich application route complies with standard EN 50126 (specification and proof of the reliability, availability, maintainability and safety of railroad applications – RAMS).

The safety concept provides location-related requirements for the planning of fixed track installations and protective measures along the route.

The safety concept consists of hazard analysis, definition of measures and risk assessment. Furthermore, the requirements for fire protection and the rescue concept are defined.

The hazard analysis provides a collection of project-specific hazard sources. These are classified into groups and the risk arising from the frequency of occurrence of and extent of damage by each hazard is assessed. This includes the following:

- System-specific events
- Interaction with other transportation means and the surroundings
- Internal influences
- Events during waiting, boarding or alighting and/or endangering of third parties or staff

The assessment is based on standardised analysis schemes. Input data also include local influences such as bundling with other transport carriers or crossing structures. The results of risk and measure analysis were compiled, assessed and coordinated with the construction planning for the route in such a way that the overall risk of the route was minimised and the effects on the fixed track installations were optimised.

For instance, a result of the measure analysis is the erection of a protective barrier between the guideway and road as a requirement for the construction planning.

5 Dimensioning of the Overall System

5.1 Stopping Area Concept

Despite the high reliability of the components, the system's inherent redundancy and the high requirements on fire protection in the vehicle, additional stopping areas along the Line (outside the stations) were planned where the vehicle may safely stop if required were planned. These are known as auxiliary stopping areas.

These stopping areas are arranged along the route in such a way that a station or other stopping area can always be reached by braking or coasting under any operational condition (e.g. malfunction). An overview of the route speed profile with the stopping areas is shown in Figure 6.

The positions of the auxiliary stopping areas are determined on the basis of the propulsion speed profile, the vehicle's braking and coasting characteristics and the topographic conditions along the route. The spacing between the stopping areas is typically 1 - 3 km depending on the vehicle speed in the route segment.

Stopping areas are located in areas of level, dry ground with access to public roads to allow for disembarkation and alternative transportation of the passengers, should the maglev vehicle become stranded.

In the rare case that a vehicle needs to be evacuated quickly (e.g. fire in the vehicle), some stopping areas are designed as emergency stopping areas. Those areas are equipped with an accompanying footbridge for faster evacuation and a water reservoir for use by the fire department.

5.2 Vehicles

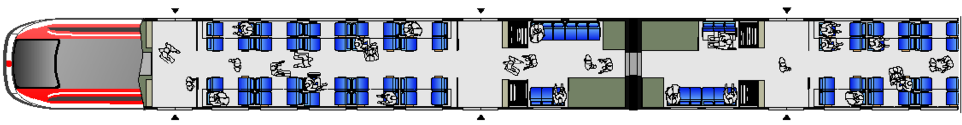
The number of vehicles required can be derived from the forecast of passenger volume, trip time and cycle time. The vehicle configuration, i.e. the number of sections per vehicle, is determined by the passenger capacity, the requirements on the design of the passenger compartment and the requirements on baggage handling.

The project dimensioning foresees a vehicle configuration with three sections (two end sections and one centre section) and the necessary capacity including baggage handling is to be provided in regular operations with four vehicles. One additional vehicle is held as a reserve.

Similar to the Shanghai vehicles, the vehicle layout was modified for the Munich application according to the project requirements, e.g. shorter end section, wider doors (minimum 1.2 m, pressure-sealed), increased vehicle height to allow air ducting and provide space for sound-insulation measures. The preliminary interior layout including concept fittings is shown in Figure 5.

Seat size and spacing and the number of seats and standing room per vehicle section were determined on the basis of the comfort and operator's requirements. The guideline for the dimensioning of the standing room is 2 persons/m^2 at normal load and 4 persons/m^2 at full load.

Vehicle Layout



148 Seats:	with 112 in open seating areas
	with 36 in entrance areas
Standing Areas:	for approx. 150 people (with 2 people per m²)
	for approx. 300 people (with 4 people per m²)

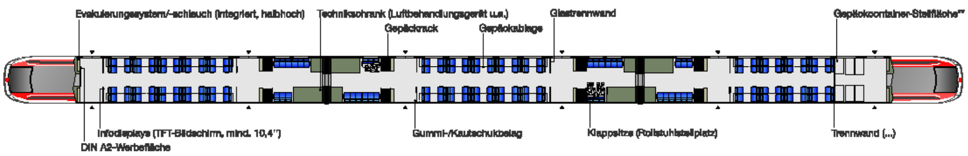


Figure 5 :Preliminary Vehicle Layou

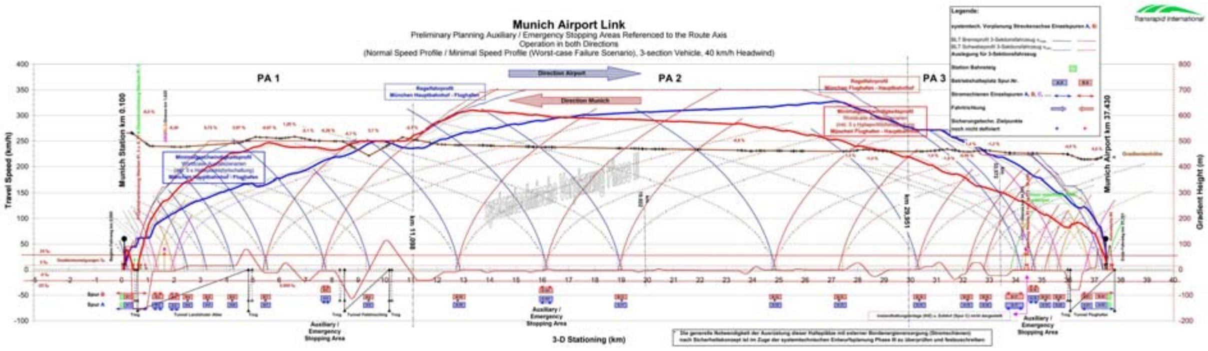


Figure 6: Route speed profile with stopping areas

In the context of the planning of the Munich project, a baggage logistics concept was drawn up which also has to be taken into account for the vehicle layout. Each vehicle has a separate area for baggage in the front area of its first section. Passengers will be able to check in at counters or check-in machines at the main station and hand over their baggage their for transferral to the relevant flight.

The vehicle layout was checked with regard to the forecasted passenger volume taking account of the number of passengers boarding and leaving at both stations and the changing time per person and door and with regard to the admissible vehicle weight by calculating a weight balance. Then the layout was assessed also under economic aspects in close conjunction with the operator.

5.3 Propulsion and Power Supply System

In contrast to conventional means of transport, the Transrapid's propulsion system is not installed in the vehicle, but in the guideway, stretched out along the entire length of the track. Arrangement and dimensioning of the components of the propulsion system determine the acceleration and deceleration capacity, the maximum speed, the energy consumption and the headway. The dimensioning of the propulsion system is therefore an important starting point for system planning, in addition to route alignment definition.

The propulsion and power supply system comprises the following components:

- Substations which provide the traction energy for the propulsion sections from the public electricity supply system
- Route cables which distribute the propulsion energy between the substations and the long-stator's switching sections
- Wayside switch stations which connect the motor switching sections with the route cables
- Transformer and rectifier stations which supply energy to all wayside consumers

The following are the general parameters needed for propulsion dimensioning:

- Minimal distance spacing between vehicles
- Route alignment with gradient profile and setting speed profile
- Location of the stations, minimum stopping times
- Comfort parameters such as maximal acceleration and jerk
- Minimum overall trip time
- Vehicle configuration

Firstly, propulsion areas and thus the locations of the substations were defined with the help of the minimal necessary interval between vehicles and the speed level. Substation 1 is located near the main station, substation 2 near the airport on the premises of the maintenance facility. The are each equipped with two high power inverter blocks ("H") and have a redundant power supply structure for the main route. An additional low power block "L" inside the maintenance facility allows independent operation at low speeds for vehicle movement for maintenance. An overview of the propulsion layout is shown in Figure 7.

To establish an optimised concept, the propulsion system was dimensioned in several iterative steps. This results in optimised

- speed profile;
- acceleration/deceleration values

along all segments of the route.

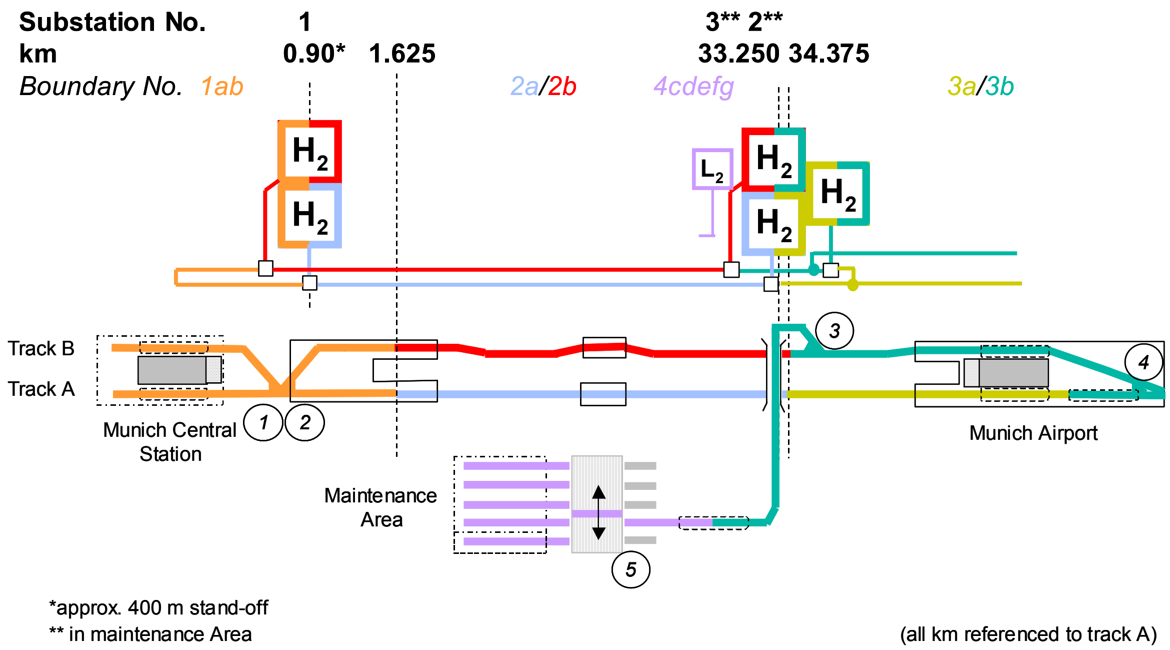


Figure 7: Munich Propulsion Layout

5.4 Operation Control System

The operation control system (OCS) guarantees safe and automatic operation of the Transrapid. All subsystems are monitored and controlled. Additionally, among other things, the operation control systems takes over the functions of

- driving process control,
- operating and indication,
- vehicle localisation and safeguarding and
- guideway and switch safeguarding .

The OCS meets the high signalling safety standards of state-of-the-art railroad technology.

A distinction is made between centralised, decentralised and line-side installations and the mobile operation control installations in the vehicles. Additionally, the operation control system provides the data interfaces to other systems such as propulsion and power supply, vehicle, maintenance and infrastructure (emergency call system, operational communication, fire alarm system).

The buildings of the operations centre are Relevant to the planning for an approval procedure. In the case of the Munich project these are located on the premises of the maintenance Area and the locations of transmitting and receiving installations.

An overview of operation control and safeguarding equipment planned for the Munich project is shown in Figure 8.

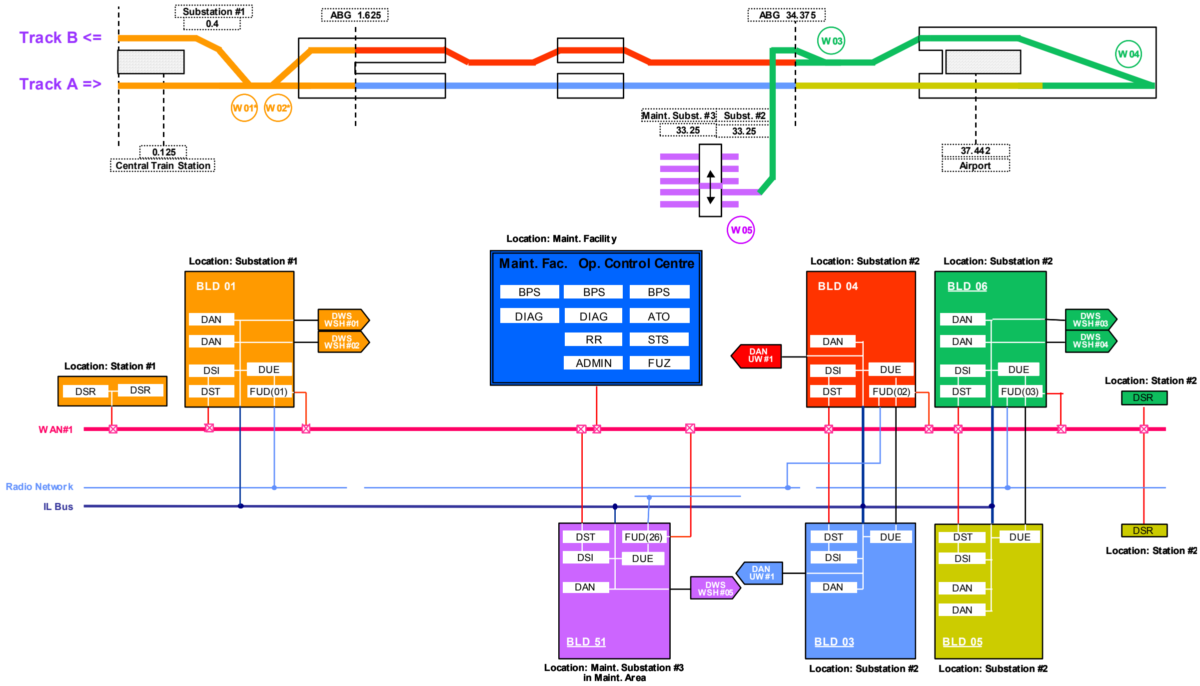


Figure 8: Operation control and safeguarding equipmen

5.5 Environmental Impact

The effects on the environment need to be described in the context of the planning process.

The system's emissions with regard to noise, vibration and electromagnetic fields had to be described in the context of the local speed. Necessary protective and reduction measures had to be assessed from a system engineering point of view.

The system's emissions were assessed with the help of experts in the local situation (vicinity to residential areas, soil conditions, etc.) and represented as emissions.

Figure 9 shows the noise assessment levels of the Transrapid in dependence on speed and distance from effected areas. Figure 10 shows an overview of the magnetic field strength in the vehicle and Figure 10 near the guideway.

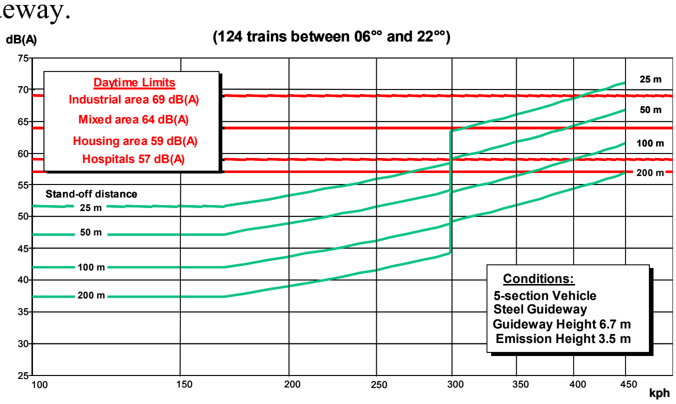


Figure 9: Noise assessment levels for Transrapid

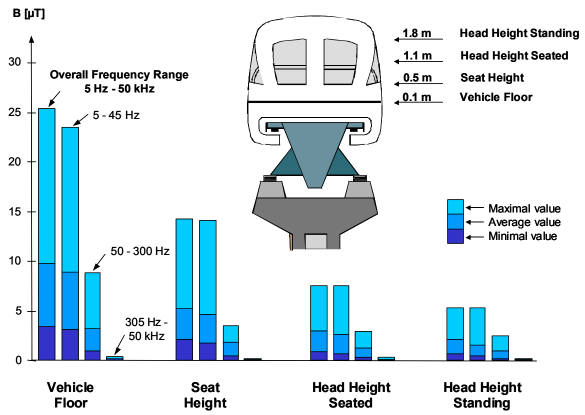


Figure 10: Electromagnetic field strengths in vehicle

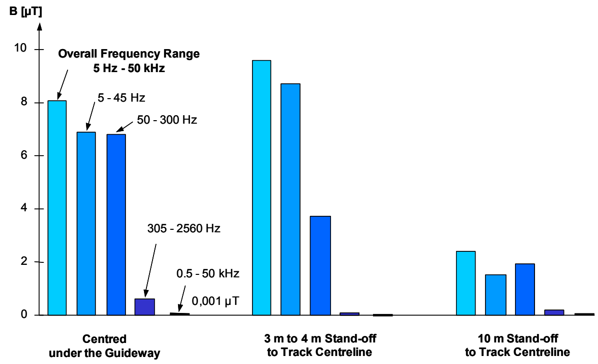


Figure 11:Electromagnetic field strengths at guideway

5.6 Operations and Maintenance Facilities

As part of the system layout planning, TRI also developed the complete planning of the maintenance area (MA). As a first step, several alternative locations were examined and assessed.

Following the determination of the location in the immediate vicinity of the airport, coordination negotiations on location and architecture of the building had to be held with the competent authorities and the airport in addition to the integration of the system engineering requirements into the planning of the building.

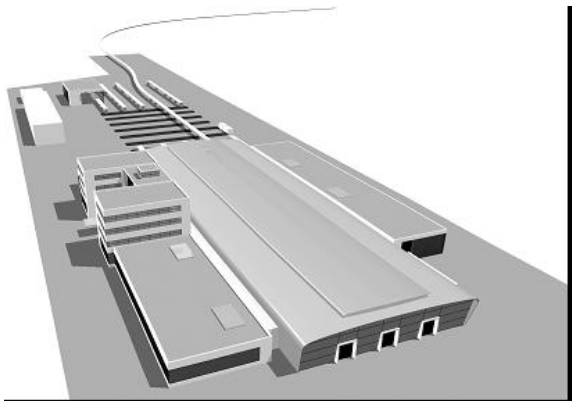


Figure 12: Maintenance Area

The basis of the dimensioning is the maintenance concept with its requirement to transfer all vehicles to the MA during the nightly operational break and the resulting occupation of the available tracks. Another important requirement is to wash all vehicles every day. Figure 12 shows the Maintenance Area with substation, washing equipment, operation control centre and parking tracks for special vehicles.

The building is equipped with five maintenance tracks on which the vehicles can be serviced during the nightly break and larger repair work can be carried out. The tracks are connected by means of a transfer table. Furthermore, the planning foresees the locating of the parking tracks for special guideway vehicles, the washing equipment and the operation control centre in the MA.

5.7 System Engineering Consulting for the Guideway

The functions of the vehicle, propulsion, and operation control system (radio system) of the Transrapid maglev system are very closely connected with the guideway design. Taking account of these interfaces, the system engineering guideway consulting provided in the planning process by TRI had to define the relevant requirements on the route alignment.

Those requirements were documented in the extensive project-specific guideway specifications in which the system engineering experience from development, execution and operation of various guideway construction types over the last 25 years were integrated.

In the Munich planning process, three types of guideway are utilised independent of the construction material and to a certain degree allowing flexible design due to the use of a common guideway envelope. The guideway envelope allows economic leeway with regard to design in the context of the invitation to tender and the realisation.

The guideway types available for Munich are:

- type I, elevated guideway beam with span width of 25 m (82 ft.)
- type II, elevated guideway beam with a span width of 12.4 m (40.7 ft.) and
- type III, at-grade guideway beam with a span width of 3.1 m (10 ft.).

The current plan is to install 20% of guideway type I, 50% of type II and 30% of type III on the 38 km long route. Figure 8 shows an overview of the planned guideway types.

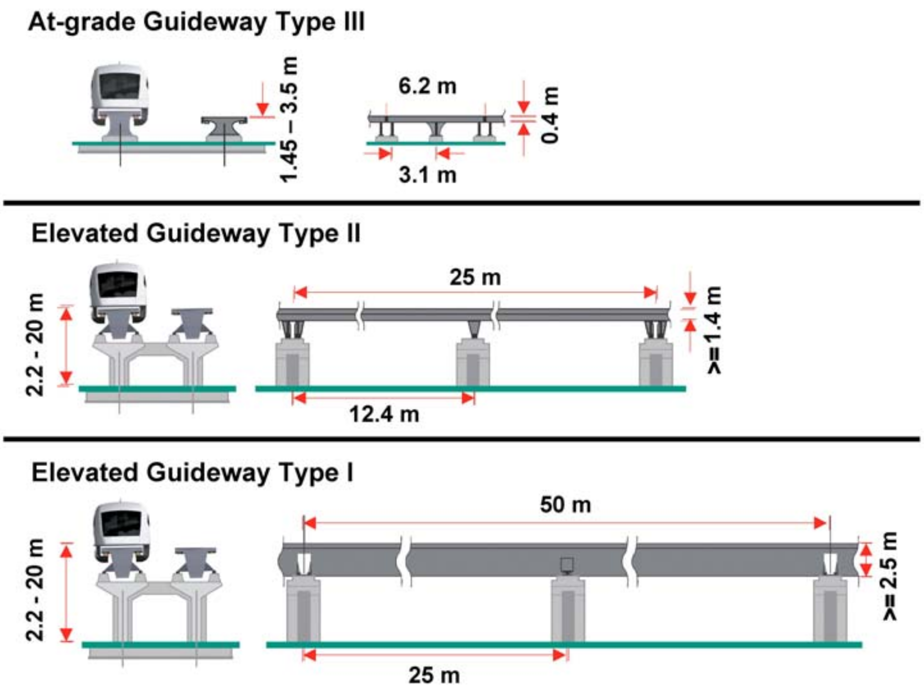


Figure 13: Guideway types available for the Munich Project

In the context of the planning, the client was presented alternative track changing devices for on- and off-line use. For instance, a pivot beam switch will be installed in the long loop at the airport and a transfer table in the maintenance facility.

The tasks of TRI also included the development of a winter operations concept for keeping the guideway clear of snow and ice in accordance with the specifications specifically tailored to the climatic conditions in Munich.

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