High-speed maglev availability methodology – adapting the existing availability methodology to an automated transport system using the example of the high-speed maglev line between Munich's central railway station and its airport

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ABSTRACT: The availability of the Munich high-speed maglev line is of great significance. A self-contained availability methodology for high-speed maglev that clearly prescribes the level of availability of the overall high-speed maglev system and the proving and verification procedures required has accordingly been developed and integrated into a Code of Practice issued by DB AG. Summarising this availability methodology, light is in particular shed on the various interesting aspects.

Mr Chairman, ladies and gentlemen, may I express my sincere gratitude to the board of organizers of this meeting for inviting me here today. I would like to talk a little about the high-speed maglev availability methodology.

DB Magnetbahn GmbH intends to market the maglev system as its first application in Germany and a premium product, and to operate the Munich Central Station – Airport maglev link as a commercially viable project. The key product benefit to be achieved in this venture is a regular scheduled service taking just 10 minutes between the two traffic hubs. It will also run every 10 minutes.

This very ambitious promise will only be possible if the fulfilment of the transport task with a correctly functioning, operation-ready and reliable maglev system is made concrete and called for by verifiable functional requirements. These requirements are contained in DB Magnetbahn GmbH's Directive 41601, the "tender specifications for the Munich Central Station – Munich Airport maglev system".

The complete requirements with respect to the technical availability of the maglev system are contained in a separate annex to these tender specifications.

In my presentation, I would like to focus specifically on the availability methodology developed for the maglev system and explain the fundamental principles. Binding figures for the limit and target values of technical availability required on the basis of this methodology will not be finalized until the implementation contract is prepared and can therefore not be dealt with here.

With the aid of a sensitivity consideration shown in Figure 1, I would nevertheless like to give you an idea of the relationship between technical availability and the expected delays.

Technical availability*)	Delays > 20 seconds per diem**)	Delays > 2 minutes per diem**)	Delays > 10 minutes per diem**)
95 %	91	4.197	228
99 %	22	840	0,1
99,9 %	11	84	< 0,1
99,99 %	7	8	< 0,1

*) related to the failure criterion "delay at least 2 minutes"
**) at 230 planned journeys per day

Figure 1: Exemplified sensitivity consideration

In the table shown here, it can be seen that only the number of expected delays with technical or a maintenance-related causes are identified. In addition, there are delays with an operational or external cause, so that the total number of delays will probably be three times this number.

The technical availability is only indicated here for the 2-minute criterion, for which delays are only counted when they exceed a 2-minute period.

The values speak for themselves. It is clear that, to claim to have a premium product, it is necessary to have target values for the technical availability of around 99.99 % or above. Only values in this range ensure stable operation.

1 GOALS FOR THE AVAILABILITY METHODOLOGY

The availability methodology for the maglev system must be capable of deriving in a comprehensible manner limit and target values for the availability that have been modified specifically for the project, of providing easily applied procedures to determine the availability achieved and thus create the prerequisites for contractual regulations on availability.

The availability methodology for the maglev system must meet the following requirements shown in particular (see figure 2):

- **Use of standardized, recognized availability terms**

- **Resource-effective availability data collection**

- **Use of wheel-on-rail experience**

Figure 2: Goals for the availability methodology

a) Standardised, recognised availability terms

The terms to be used must comply with the current state of the art and accepted practice and be used consistently and uniformly throughout Deutsche Bahn.

This requirement can be met by applying Group Directive 120.0301, "Reliability and availability related indicators and parameters", which was approved by the Board of Management of DB AG and has been in use since 1 February 2004. The general definitions contained in this Group Directive are based on the applicable relevant standards, in particular on DIN EN 50126 "Railway applications - specification and evidence of reliability, availability, maintainability, safety (RAMS)" and on DIN 40041 "Reliability; terms".

The consistent and uniform use of standardized definitions both in contractual agreements and in the models used for the collection and processing of parameters ensures the provision of the parameters required for the validation of agreements, e.g. as part of the warranty. Standardized definitions of reliability and availability-related indicators and parameters simplify the wording of agreements.

b) Resource-effective availability data collection

The parameters for the availability are to be collected in a resource-effective manner, if possible using existing process-linked systems.

This requirement, which is taken from the previously mentioned DB AG's Group Directive 120.0301, can be easily met by the maglev system. For this purpose, the parameters to be collected for the availability have been selected in such a way that they are suitable for automatic collection. This collection can be carried out by the online diagnostics systems that are necessary in any case for an automatic transport system. The need for the determination of the causes of delays and failures by experts to ascertain the technical availability is thus reduced to an absolute minimum.

c) Use of wheel on rail experience

Existing empirical experience from wheel on rail research programme on the breakdown of delays and the classification of delays on the basis of their causes is to be used when deriving limit and target values of the availability of the maglev system.

Key preliminary work was done from 1969 onwards by HSB-Studiengesellschaft mbH on behalf of the Federal Minister of Transport as part of the "Study on a high-speed transport system" and documented using a parameterised breakdown of the delays described in mathematical terms. This breakdown of the delays (see Figure 3) is still in line with current experience. It can be modified by a suitable selection of parameters to meet the transport task in question and specific corporate specifications. The breakdown of delays that has been developed in this way can be used to precisely determine the limit and target values of the availability for each individual project-specific failure class specified.
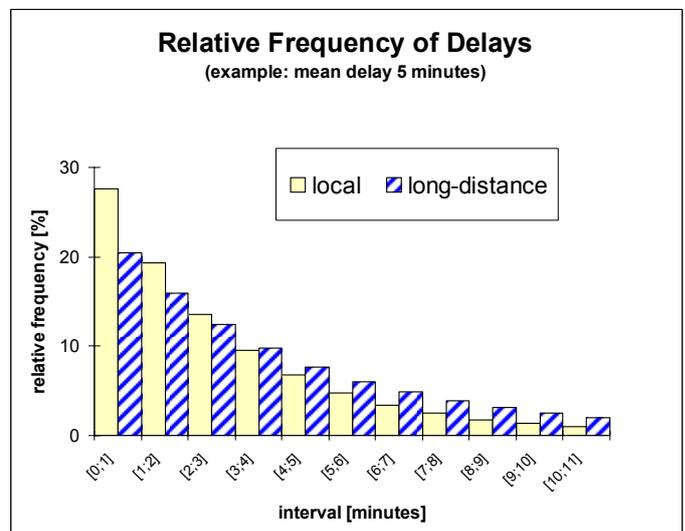

Figure 3: Breakdown of delays on local/long-distance services

Using statistical analyses over a period of several years for long-distance transport services in Germany, it has been possible to confirm that only one third of all delays had a technical or maintenance-related cause. As there is currently no statistically confirmed data for the maglev system available on the influence of technology on the delays, a conservative calculation must now be made for the maglev system using the known values for long-distance services shown in Figure 4.
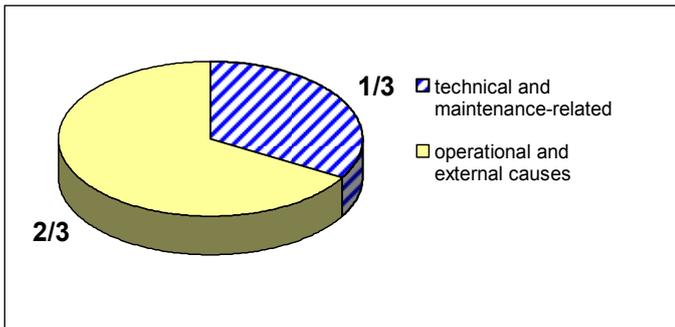
Figure 4: Causes of delay

This means that the limit and target values of the technical availability must be specified such that only one third of the total number of permissible delays and cancelled train journeys may have a technically or maintenance-related cause.

2 ADAPTING THE AVAILABILITY TERM TO THE MAGLEV SYSTEM

DB AG's Group Directive 120.0301 mentioned earlier states in the introduction that the definitions it contains are general definitions. Consequently, these definitions must and may be modified to the application in question and made concrete.

This modification was carried out in compliance with the goals mentioned earlier.

The general definition of availability in the Group Directive is as follows:

"The availability is the sum of incident-free times divided by the operating time."

In order to provide a resource-effective calculation of the times mentioned in this general definition for the maglev system, we have come up with the following regulations, which make the Group Directive more precise:

a) The operating time is calculated as an overall figure as the product of the standard journey time and the total number of journeys planned.

b) The sum of the incident-free times is the product of the standard journey time and the number of journeys that were completed with no availability-related failure.

c) An availability-related failure in a specific failure class is an event in which the failure criterion that applies to this failure class is met.

In the case of the maglev system, this results in the availability being calculated as the ratio of the number of planned journeys completed with no availability-related failure to the total number of planned journeys (see Figure 5).

$$\text{Availability} = \frac{\text{Number of journeys completed with no availability - related failure}}{\text{Total number of journeys planned}}$$

Figure 5: Calculation of availability

This means that, in the case of the maglev system, the availability is calculated on a mission-specific basis by taking into account the observed delays and cancelled journeys. The great benefit of this approach is that it establishes a correlation with the revenues. Each train journey cancellation that is prevented and each avoided delay, based on the mission-specific definition, increases the availability and reduces the risk of loss of revenue. This turns availability into a key factor for financial success. Faults that influence the availability can be roughly characterised as exhibiting technical, operational, maintenance-related or external causes. The following examples demonstrate the specific character: a technical cause can be either the loss of a function, a defective function or the part completion of a specific function due either to the low reliability or life expectancy of a component, while an operational cause can be operating staff arriving late for work, for example, and a maintenance-related cause may be the faulty replacement of a component, with an external cause conceivably being a fire close to the track.

The regulations on availability that must be contractually agreed on are based on the agreed performance. It is assumed in the following that the manufacturers bear the responsibility for the technology and maintenance. This means that they are only required to assume responsibility, apart from the defined availability, for availability-related failures with a technical or maintenance-related cause. The availability that is limited in this way is designated "technical availability" (see Figure 6).

$$\text{Technical availability} = \frac{\text{Number of journeys completed with no availability - related failure *)}}{\text{Total number of journeys planned}}$$

*) with a technical or maintenance - related cause

Figure 6: Calculation of technical availability

If in the Munich project, for example, an extension of the maintenance work beyond the tasks specified in DIN 31051 is agreed within a broader definition of "maintenance", all the statements referring to maintenance mentioned in this presentation could be included.

3 GENERAL CONDITIONS TO BE AGREED ON

As a key factor for the financial success, technical availability is only effective if this agreed on in con-

junction with the key system configuration and the operating and maintenance programmes to be implemented (see Figure 7). Otherwise, it could happen that the agreed technical availability would be achieved by introducing additional redundancies or by increasing the number of maintenance procedures. The manufacturers' goal should instead be to achieve the level of availability by means of a high level of reliability a robust system. Redundancies should only be used if these procedures are cheaper by comparison with the life cycle costs than an increase in reliability.

• **system configuration**
• **operating programme**
• **maintenance programme**

Figure 7: General conditions to be agreed on

It is absolutely essential that these general conditions be contractually agreed on together with the limit and target values of the technical availability, as this is the only way of ensuring that the technical availability can be effective as a key factor for the financial success of the project.

The requirements to be met by the technical availability of the maglev system are focused on the entire system, as it is only possible to ensure that each planned train journey will arrive at its destination on time when all the functional units of the maglev system operate together as they should.

From the requested technical availability of the entire system, requirements and procedures for the provision of evidence for the individual supply and performance parts of the contract can be determined and contractually agreed on.

4 ALGORITHM FOR CALCULATING TECHNICAL AVAILABILITY

The calculation of the actual values for availability is carried out in 4 steps (see Figure 8):

Step 1:	**Record the duration of the delayed arrival of every single train journey**
Step 2:	**Classify all train journeys according to the duration obtained for their delayed arrival into delay classes**
Step 3:	**Calculate the relative frequency of train journeys in each delay class based on the total number of planned train journeys**
Step 4:	**Calculate the technical availability in each failure class**

Figure 8: Algorithm for calculating technical availability

Step 1:
At agreed measuring points at the terminal stations of the train journeys, the arrival time of every single train journey will be recorded to the second using automatic online diagnostics equipment. By comparing the recorded arrival time with the planned arrival time based on the timetable, we obtain the duration time t_v for the delayed arrival of every single train journey, which is then placed in non-transient memory.

Step 2:
All train journeys are classified according to the duration time t_v obtained for their delayed arrival in delay classes.

The creation of delay classes is broken down into train types as specified in Section 0107 of Manual 42001 "DB Netz AG control centres".

The following delay classes were created specifically for the Munich for the maglev project:

▪ The delay class "no delay" for all train journeys with a delay of less than 20 seconds (in accordance with the requested journey time reserve)

▪ The delay class "minor delay" for all train journeys with a delay of at least 20 seconds and less than 2 minutes (for which no hindrance of other trains is expected)

▪ The delay class "disruption of operations" for all delays of at least 2 and less than 10 minutes (for which a hindrance of other trains cannot be excluded)

▪ The delay class "standstill" for all train journeys with a delay of at least 10 minutes (equal to the service frequency), whereby a train journey that is not or only partly completed is classified as a "standstill".

Step 3:
At the end of each quarter, for each delay class, the relative frequency of train journeys in this particular class during this quarter will be calculated based on the total number of planned train journeys.

Step 4:
From the relative frequencies calculated in Step 3, the availability V will also be calculated as a probability for each failure class on a quarterly basis by totalling these frequencies.

The term "failure class" used here comes from DB AG's Group Guideline 120.0301, "Reliability and availability-related indicators and parameters". The definition of the various failure criteria for otherwise identical indicators has resulted in different failure classes. For Munich, 3 failure classes have been specified, which have been defined with the aid of the delay classes.

- Failure class 1 is equivalent to delay class "standstill".

- Failure class 2 covers the delay classes "standstill" and "disruption of operations".

- Failure class 3 covers the delay classes "standstill", "disruption of operations" and "minor delay".

The availability V in failure class 1 is then the ratio of the number of train journeys with a delayed arrival of less than 10 minutes to the total number of planned train journeys.

The availability V in der failure class 2, is then the ratio of the number of train journeys with a delayed arrival of less than 2 minutes to the total number of planned train journeys train journeys.

The availability V in der failure class 3, is then the ratio of the number of train journeys with a delayed arrival of less than 20 seconds to the total number of planned train journeys.

The calculation of the actual values for the technical availability V_t is carried out using the same method as the calculation of the actual values availability V described just now, whereby delayed and not or only partly completed train journeys are classified in the calculation as delayed if the cause of the delay is not of a technical nature.

The additionally required rating of the delayed arrivals on the basis of the cause is made in accordance with a list of codes for the causes of the delay. This list of codes is to be prepared and approval obtained on the basis of Section 9001 of Manual 42001 "DB Netz AG control centres".

For each cause of a delay, the list indicates whether it is a technical cause, a maintenance-related cause, an operational cause or whether is the result of an external influence.

Delays to following trains are rated using the list of codes for the causes of delay as with the initial delay, albeit with the cause of the delays given as for the first delayed train.

In cases in which the unequivocal determination of the cause of the delayed arrival is not possible, the cause is specified schematically on the basis of the initial diagnostics report that involves the first part delay.

In exceptional cases, in which the findings of the diagnostics are not accepted, the cause of a delayed arrival must be determined by experts.

5 PRACTICAL TEST OF THE AVAILABILITY METHODOLOGY

(see Figure 9)

The roots of the availability methodology I have presented here today were laid during the planning of the Berlin-Hamburg maglev project with the drafting of tender specifications for the availability of the maglev system. At the time, in terms of the methodology, fundamental agreement on this draft was achieved with the system industry.

During EXPO 2000, the availability methodology was tested for the first time on regular scheduled services throughout the "Transrapid in Emsland" EXPO project.

The results of these tests were presented to a large group of experts as part of a Critical Design Review (CDR) in the summer of 2001 and were also emphatically confirmed on the industry side.

Since then, the availability methodology for the maglev system, despite modifications of the terminology to DB AG's new Group Guideline mentioned earlier on the reliability and availability-related indicators and parameters, remains unchanged in terms of its basic elements.

- **agreement on the "Availability" draft tender specifications for the Berlin - Hamburg project**

- **testing of the availability methodology throughout the EXPO 2000 "Transrapid im Emsland" project**

- **presentation of these tests as a part of a Critical Design Review (CDR) in mid-2001**

Figure 9: Testing of the availability methodology

6 NEXT STEPS

In view of the progress made on the Munich maglev project, the following activities in particular are to be planned with regard to availability:

a) Confirmation of the calculation of technical availability on a quarterly basis

b) Agreement on the limit and target values of technical availability for the first 2 years from the start of commercial operations and higher values for the subsequent period

c) Agreement on the list of codes for the causes of delay with appointment of a specific person responsible for each cause

d) Agreement on the supplementary limit values for the reliability of individual functional items requested in the tender specifications for the

maglev system that are particularly important for operations, e.g. vehicle doors and turnouts

e) Calculation and assessment of the risk regarding the maintenance of the limit values of the technical availability of the entire system and the reliability of selected functional items

f) Preparation of and agreement on procedures designed to reduce such risk

g) Agreement on availability-related evidence, which must be submitted before implementation

h) Use of the availability methodology in trails

i) Use of the availability methodology in commercial operations

Thank you for your time and attention!