Availability and punctuality analysis for the Shanghai Transrapid

No. 45

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ABSTRACT: For more than four years now, the Shanghai Transrapid has been offering a high-quality passenger service. One of the most meaningful criteria for evaluating the service quality of a public transportation system is the punctuality of train operation. The analysis performed on the punctuality and availability of the Shanghai Transrapid service was based on operation and maintenance data of all the subsystems and covering a period of approximately three years. This paper describes the methodology and results of the analysis. In terms of the punctuality of train operation and availability of the technical systems, the Shanghai Transrapid has already reached the highest standards in international public transportation systems.

1 OBJECTIVE TARGETS

The Shanghai Transrapid has been offering a high quality passenger service for more than four years with more than fifteen million passengers by the end of July 2008. One of the most meaningful criteria for evaluating the service quality of a public transportation system is the punctuality of train operation. Particularly in the case of new systems, travelers expect a very high reliability. Appropriate target values are therefore included in the system's design. The punctuality and availability can be measured for the first time after the start of commercial operation.

Thus the first measurements of punctuality and availability for the Shanghai Transrapid were made in 2004. The analysis performed of punctuality and availability was based on operation and maintenance data of all the subsystems over a period of two and a half years.

The analysis ordered by the system's suppliers and performed by the IFB aimed to:

- create a universally valid definition of punctuality and availability criteria based on international standards
- determine punctuality and availability for the current service period
- compare the results obtained with other railway systems, particularly airport links
- highlight improvement potential
- draw conclusions for future projects.

The analysis was based on the relevant standards and guidelines for railway systems relating to availability. The first task was to correctly derive the definitions and computing methods to be used for the analysis. In addition, commonly used international values of punctuality were identified and applied as a basis for comparison.

2 STANDARDS AND DEFINITIONS

2.1 Source and Scope

The normative definitions for the punctuality and availability of railway systems are derived from general standards relating to the availability of technical systems. Table 1 provides an overview of the relevant standards for analyzing the punctuality and availability of technical systems. Because in everyday speech the terms 'availability', 'reliability' and ‘punctuality’ are rarely used consistently. Table 2 shows the various definitions of these parameters in a range of standards.

Table 1. Relevant standards for punctuality and availability analysis.

Standard	Title	Dated
DIN EN 50126 ff.	Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)	2000-03
CLC/TR 50126-3	Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) – Part 3: Guide to the application of EN 50126-1 for rolling stock RAMS	2006-07
IEC 60050-191	International Electronic Dictionary – Chapter 191: Reliability und Quality of Service	1999-03
DIN EN 13306 + DIN 31051	Terms of Maintenance Bases of Maintenance	2001-09 2003-06
DIN 40041	Reliability – Terms	1990-12
DIN 27200	State of Railway Rolling Stock – Bases and Terms of Operation Condition	2003-08
VDI 3423	Availability of Machines and Constructions – Terms, Definitions, Time Registration und Calculation	2002-01
VDI 4001 Blatt 2	Terms of Reliability	2005-03
VDI 4004 Blatt 4	Parameters of Reliability – Parameters of Availability	1986-07
DB KoRil 120.0301	Relevant Classification numbers and Measured values of Reliability and Availability	2004-02
...		
MIL-STD-721C	Definitions of Terms for Reliability and Maintainability	1981-06
MIL-STD-471A	Maintainability Verification/Demonstration/Evaluation	1973-03

Table 2. Definitions of availability in international standards.

Standard	Availability	Reliability	Present availability	Steady availability	Inherent availability	Technical availability	Operational availability	Other
DIN EN 50126 ff	x	x	-	-	-	-	-	-
CLC/TR 50126-3	x	x	-	-	x	x	x	Fleet availability, schedule adherence
DIN EN 13306 + DIN 31051	x	x	-	-	-	-	-	-
DIN 40041	-	-	x	x	-	-	-	-
DIN 27200	x	x	-	-	-	-	-	-
VDI 3423	-	-	-	-	-	x	-	-
VDI 4001 Blatt 2	x	x	x	x	-	-	-	-
VDI 4004 Blatt 4	x	-	-	-	x	x	x	Overall (practical) availability
DB KoRil 120.0301	x	x	-	-	x	x	x	Inherent operational availability
...								
MIL-STD-721C	x	x	-	-	-	-	-	-
MIL-STD-471A	x	-	-	-	-	-	x	-

Figure 1 shows the relationships between availability, reliability and punctuality as derived from the relevant standards. The scope of these parameters is thus clearly defined.

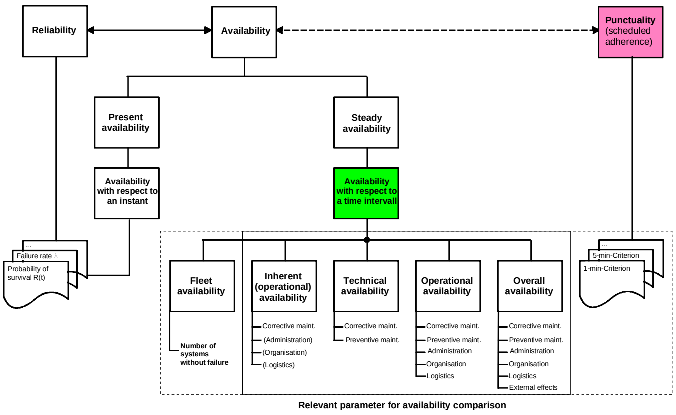

Figure 1. How availability, reliability and punctuality are interlinked

2.2 Availability

Availability is a time- (or distance) based parameter and determined by:

- reliability characteristics (element failure rates; mean time between failures – MTBF, and mean distance between failures – MDBF applied to vehicles) and
- the time required for restoration (element repair rate: mean time to repair – MTTR)

This availability definition is not restricted to transportation systems. It can be applied to a wide range of technical systems.

The technical availability A_{tech} is given by:

$$A_{tech} = \frac{t_{Op,nom} - t_{Maint}}{t_{Op,nom}}$$

$t_{Op,nom}$ nominal operating time (per day / per month / per year)

t_{Maint} standstill caused by preventive and corrective maintenance work (per day / per month / per year)

As the nominal time operating time is not defined in the relevant standards with respect to the time of day, there are different availability values for the same operating state. This is illustrated by the following example:

A system with a daily operating time of 20 h and a 2 h maintenance session during the non-operation period at night can have two different, correct values for the availability:

Case 1: Availability of 100% if $t_{Op,nom} = 20h$.
Here the daily operating time does not include the maintenance at night.

Case 2: Availability of 92% if $t_{Op,nom} = 24h$.
Here the daily operating time includes the maintenance at night.

The two values describe the same state.

Case 2 is usually used for wheels-on-rails systems.

2.3 Punctuality

Punctuality (normative term “schedule adherence”, CLC/TR5026-3) is a schedule-related parameter reflecting the performance of the system from the traveler’s point of view. Punctuality is affected by the:

- availability levels of the technical systems involved
- operating program (headway, time reserves)
- system performance (speed, acceleration and deceleration)

- track layout and operation control system
- number and duration of additional external disruptions.

Punctuality is a parameter only applicable to transportation systems. Unfortunately, there is no standard definition of punctuality at all. The degree of schedule adherence, however, is a characteristic always measured. For this different procedures are used depending on the operator.

2.3.1 *Station-based calculation*

Punctuality is measured with reference to the planned arrival or departure time at stations. There is always a temporal performance criterion as a limit, for instance a delay of 1, 2 or 5 minutes.

The punctuality is expressed in terms of the percentage of train runs within the limit. There is no direct reference to the length of the journey or the speed. Table 3 shows some examples.

Table 3. Percentage of runs without a defined delay (station-based punctuality)

System	Delay criterion	Punctuality
S-Bahn Berlin	departure < 3 min	97.7%
DB Regio / VRR	arrival < 2 min	> 92%
Hong Kong LAR	arrival < 1 min	99.7%
Metro Bangkok	arrival < 5 min	99.0%
Heathrow Express	arrival < 5 min	88.9%
Narita Express	arrival < 5 min	99.3%

2.3.2 *Route-based calculation*

This measurement of punctuality takes the route length and driving speed into account. The punctuality is the ratio of the planned travel time to the actual travel time.

A precise travel time-based calculation of punctuality is applied on the HSL Zuid high-speed line in the Netherlands; here a failure to reach the target punctuality value of 99% is penalized.

2.3.3 *Transferability*

Because of the large number of influencing variables it is almost impossible to transfer punctuality data from one line to another, even if the availability of the technical components is at the same level. There is one exception: if the system design and operating program are comparable, characteristic parameters can be obtained.

3 PUNCTUALITY OF THE SHANGHAI TRANSRAPID

3.1 *Punctuality Criteria*

The calculation of punctuality for the Shanghai Transrapid is based on a fixed arrival criterion. This means that a ride is counted as delayed from a specified time of arrival. The punctuality is calculated as follows:

$$P = \frac{R_{planned} - R_{canceled} - R_{delayed > x\,\min}}{R_{planned}}$$

P	punctuality (“availability” of operation)
$R_{planned}$	planned rides
$R_{canceled}$	canceled rides
$R_{delayed > x\,\min}$	rides with more than x minutes delay

The analysis was based on the operation and fault data of the service period from April 2004 to December 2006 as recorded by the operator and suppliers of the Shanghai Transrapid.

Faults causing slight delays (e.g. < 1 min) were not evaluated. Suppliers, however, simulate faults of components and their effects on punctuality in advance. It was therefore possible to incorporate such non-evaluated cases into the analysis.

The fixed arrival criterion for the punctuality of the Shanghai Transrapid is a delay of more than 5 min.

With the detailed database available it was possible to analyze the punctuality according to fixed arrival criteria or different delays.

The individual causes of delays were associated with several subsystems during evaluation. Thus a detailed database exists for further analyses with possibly modified system structures.

3.2 *Results of analysis*

In the entire service period analyzed of almost three years with 80,000 rides, only one in 400 of which had a delay of more than 20 s and only one in 600 a delay of more than 2 min.

Based on a 5-min arrival delay criterion the punctuality of the overall system of the Shanghai Transrapid is nearly 99.9% over the entire period investigated from April 2004 to December 2006 (Figure 2). All subsystems reached a punctuality level higher than 99.9% during each year of operation.

Figure 3 shows an example of punctuality analysis based on delay; the delays are minor, ranging from 20 s and 2 min (section 3.1).

The analysis shows a typical “learning curve” after the start of operation. Following an increase in operating experience punctuality stabilizes.

The punctuality values of the Shanghai Transrapid – irrespective of the delay criterion – reach a high level and are fully comparable with equivalent wheels-on-rails systems – such as airport links with dedicated tracks. This is all the more significant as this is the first commercial project with Transrapid technology.

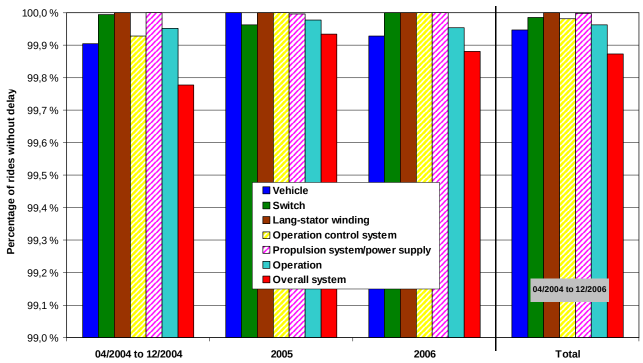

Figure 2. Annual punctuality of the Shanghai Transrapid, delays of more than 5 min

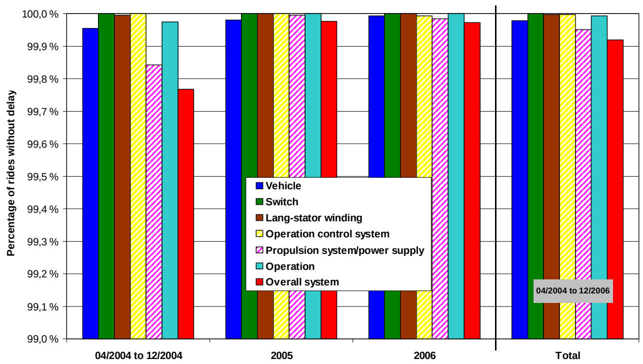

Figure 3. Annual punctuality of the Shanghai Transrapid, delays from 20 s to 2 min

4 AVAILABILITY OF THE SHANGHAI TRANSRAPID

4.1 Conditions

The analysis of subsystem availability for the Shanghai Transrapid was carried out on the basis of the valid standards (Table 2). Jointly with suppliers, a classification (Table 5) of failures was developed based on failure categories (Table 4) defined in CLC/TR5026-3. Failure class 1 (loss of redundancy), failure class 2 (restriction of performance) and failure class 3 (subsystem not available) were evaluated for the analysis of inherent availability. For the punctuality analysis only failure classes 2 and 3 were evaluated. Failure class 1 was not evaluated for the punctuality analysis because it has no impact on the operational sequence and hence the punctuality of the overall system.

Table 4. RAM failure categories

Failure category	Definition
Significant (Immobilizing Failure)	A failure that prevents train movement or causes a delay to service greater than a specified time and/or generates a cost greater than a specified level
Major (Service Failure)	A failure that - must be rectified for the system to achieve its specified performance, and - does not cause a delay or cost greater than the minimum threshold specified for a significant failure
Minor	A failure that - does not prevent a system achieving its specified performance, and - does not meet criteria for significant or major failures

Table 5. Failure classes

		Performance			
	Failure class	**0** (subsystem without failure)	**1** (loss of redundancy, 100% performance)	**2** (subsystem with restriction of performance)	**3** (subsystem not available)
Sub-system	Functional unit				
Track	1 track section	**100%** (section available)	n/a	n/a	**0%** (section locked)
Propulsion	1 propulsion section	**100%** (propulsion available)	**100%** (propulsion available, loss of redundancy)	**< 100%** (propulsion restricted available, in-creased run-ning time)	**0%** (propulsion not available)
Operation Control System (OCS)	1 decentralized control system (DCS)	**100%** (DCS available)	**100%** (DCS available, loss of redundancy)	n/a	**0%** (DCS not available)
Vehicle	1 vehicle	**100%** (vehicle available)	**100%** (vehicle available, loss of redundancy)	n/a	**0%** (vehicle not available)
Switch	1 guideway switch	**100%** (switch passable in both directions)	**100%** (switch passable in both direc-tions, loss of redundancy)	**50%** (switch passable in one direction only)	**0%** (switch not passable)

The inherent subsystem availability analyzed represents the effect of corrective (unscheduled) maintenance work, including logistics, administration and organization (see Figure 1).

The time base for the availability calculation was – as is customary for wheels-on-rails systems – a nominal operating period per day of 24 hours. (section 2.2, case 2).

The availability values thus obtained were represented as mean values for a whole week with 7 days.

4.2 Results of analysis

The availability values analyzed for stationary subsystems (Figures 4 and 5) represent the total downtimes of the relevant components caused by unscheduled maintenance based on the failure classification in Table 5.

The values for the subsystem ‘vehicle’ currently only include replacement times for frequently failed components. Other more minor unscheduled maintenance work has so far not been taken into account because the maintenance times were not fully available.

Driven by the stationary subsystems – ‘OCS’, ‘propulsion system and power supply’ and ‘switches’ – there was an annual increase in the availability of the overall system during the service period investigated. For the entire period analyzed (April 2004 to December 2006) the inherent availability of the overall system was around 96% (Figure 4).

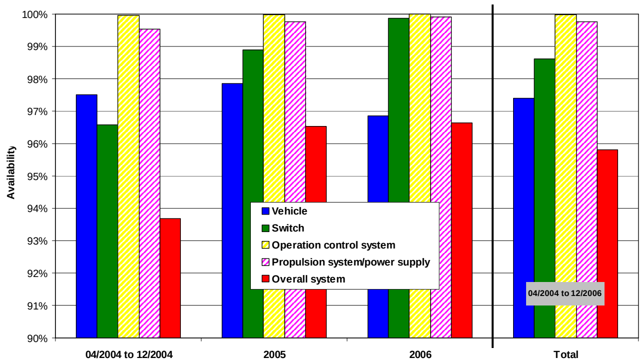

Figure 4. Inherent availability of the Shanghai Transrapid, subsystems and overall system (1)

With increasing daily system operating time (Figure 5) came a reduction in the availability of the vehicle fleet. This was to be expected on account of the higher load of vehicles with more start-up and shut-down processes. By contrast, the availability of stationary subsystems with a non-stop daily operating time of 24 h increased with rising operating performance.

The unscheduled maintenance takes place mostly during operating breaks at night. This way the outage of components or subsystems due to technical faults has hardly any impact on the punctuality of the system.

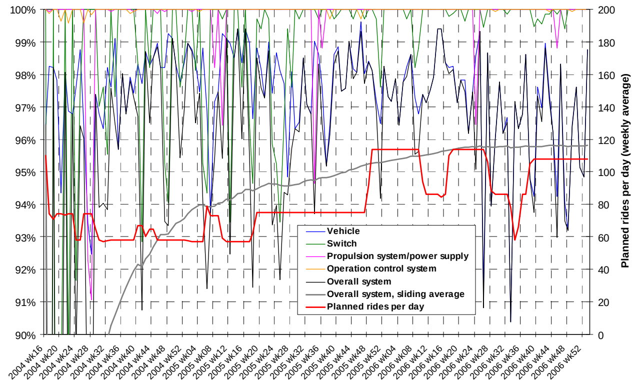

Figure 5. Inherent availability of the Shanghai Transrapid, subsystems and overall system (2)

Altogether the results of the availability analysis do justice to the high expectations. The allocation of individual failures to technical subsystems permits a targeted refinement of the Transrapid technology. The field data obtained from the Shanghai Transrapid constitute a valuable basis for this ongoing development.

5 REFERENCES

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