Service Availability of the Urban Maglev System in Korea

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ABSTRACT: This paper shows a brief description on the urban maglev system project in Korea composed of 6.1 km long double-track, 6 stations and 1 depot. This paper discusses a study on typical RAM models measuring the service performance of a metro system and on a service availability model including its achievable target of 98% for the urban maglev system project measured by the missed departures at each platform.

1 INTRODUCTION

From December 2006 to December 2012, the Ministry of Land, Transport and Maritime Affairs sponsors a commercialization project of the Urban Maglev System to be constructed in the Yongjong Island in Korea. In support of this effort, Hyundai-Rotem Company performs a RAMS program compatible with EN 50126 and sets up RAMS targets for the project as a part of the system integration program handled by the Korea Institute of Machinery and Materials

The 1st phase of the project consists of 6.1 km long double-track, 6 stations and 1 depot. Table 1 shows the six stations and the distances between them.

From Station	To Station	Distance (m)
Station 101 (Airport Traffic Control Centre)	Station 102	302
Station 102 (International Business Centre 1)	Station 103	550
Station 103 (Air City Park 1)	Station 104	500
Station 104(Air City Park 2)	Station 105	3470
Station 105(Water Park)	Station 106 (Yangyoo Street)	1080

Table 1. Distance between stations.

The Urban Maglev System is a driverless system and based on the 1500 VDC power source supplied by the third rail. Vehicle propulsion is accomplished by Single-sided Linear Induction Motors (SLIM) giving a maximum operational speed of 100 km/h. The propulsion system has the capability of feeding back electrical energy to the supply during braking. Such regenerative braking reduces the total power consumption of the train during operation.

The train starts, proceeds, and stops under levitation condition. Magnetic force generated by the levitation magnet installed on the bogie attracts the steel rail, and the attraction force simultaneously lifts the vehicle too. For levitation magnet failure, landing skid and wheel are installed on the bogie.

The lateral movement is controlled by the magnetic force generated by the levitation magnet too. Magnetic force attracts the steel rail, moving the centre of levitation magnet to the centre of the rail. In addition to limit lateral movement at a curve, lateral skid is installed.

Except the Rolling Stock and the Guideway, all other E&M subsystems should be similar with subsystems for a modern driverless LRT System

2 SYSTEM RAM MODELS

System performances may be measured and estimated by a large number of parameters, each one is focused on an aspect of the system. To make a choice for the parameters should be based on the aspects that are considered more critical-i.e. technical aspects of the equipment, or quality of passenger service, etc.

In order to refine the evaluation to system performances, a set of parameters is defined. A target value is then given to each of them in the system specifications as a requirement for the design and the O&M organization. The most common parameters applied in the performances measurement of metro systems are Service Availability, Train Punctuality and Reliability and Maintainability described below:

- Service Availability (SA): it is a measure of the deviation of the actual achieved efficiency of the service from the nominal service conditions. It is expressed as percentage of the nominal service level and is modelled as the ratio between the actual value and the planned value of such a performance indicator. The pre-requirement for the application of a Service Availability model is a univocal definition of the conditions determining the status of unavailability of the service;
- Train Punctuality (TP): it is a measure of the quality of service offered to passengers. It is focused on the regularity of the train headway and usually is related to minor service disruption being major service disruption in the scope of the service availability;
- Reliability (MTBF) and Maintainability (MTTR): these parameters are strictly related with the technical performances of the system rather than the level of service as perceived by passengers.

However, all the above parameters are correlated, as different measuring criteria of the Metro System Performance. In order to properly evaluate the system performances, the above parameters can be combined and analyzed according to different criteria.

In addition, the principle of mutual exclusion of the failure effects should be always applied: this means that if an event is counted in such a parameter, then it should not be included in any other in order to avoid double-counting of the same failure.

At least, depending on the applied calculation model, the effects of a failure may be split distinguishing the contribution on the Service Availability and on the Train Punctuality. With this aim it is necessary a univocal definition of the applicability conditions of the different parameters to any fault status and service disruption of the system.

2.1 Service Availability Models

2.1.1 Model SA #1

The model presented below is deemed exhaustive for the system performances evaluation both in terms of availability and regularity of the service. In fact each deviation with respect to the regular service scheme exceeding a preset limit in terms of delays at platform is considered leading to an unavailability status of the system. In this case the train punctuality performances are included in the Service Availability calculation model.

The model considers the Service Availability as function of the accumulated delay caused by the system failure in an observation period. The SA calculation formula is:

$$SA = 1 - \frac{DEL}{TOP} \tag{1}$$

Where:

- DEL is the total delay occurred to the system in the observation period due to a subsystem failure. The delay is defined as the amount of time between the planned arrival time at the station and the actual arrival time at the station involved in the failure. The delay is measured on the most delayed train among the delayed trains related to the failure;
- TOP is the Total Operating Time in the reference period.

In many cases Model SA #1 might be adopted into among Model SA #2, #3, #4 or #5.

2.1.2 Model SA #2

The model SA#1 may be modified associating to delays measured in each platform the corresponding number of Missed Departures and to the TOP the corresponding number of Planned Departures. Then it considers the actual departures in each platform against the planned departures as from the scheduled operating scheme.

The formula for the Service Availability is then:

$$SA = 1 - \frac{Missed\ \ Depatures}{Planned\ \ Departures} \tag{2}$$

Missed Departures are calculated as consequences of delays due to technical failures in each platform in a defined time period. Each delay experienced in a platform higher than the current headway leads to Missed Departures. The number of Missed Departure associated to a delay depends on the delay time, the extension of the perturbation and the current headway.

This SA#2 model is based on the principle of comparing at sequential time slots the actual cumulative number of departures with respect to the scheduled cumulative number of departures at each station.

2.1.3 Model SA #3

Another model of Service Availability calculation measures the percentage of total planned operating time in which the service is deemed available, named Up Time. The SA#3 may be also calculated as function of the reliability and maintainability data assuming that the Down Time coincides with the Time to Restore the Service after a service failure occurs and the Up Time is the operating time between service failures; then the planned operating time may be indicated as the sum of the Down Time and the Up Time of the System calculated on the basis of the service failures occurred in the reference period.

The basic calculation formula for SA#3 is:

$$SA = \frac{MTBSF}{(MTBSF + MTTRS)} \qquad (3)$$

Where:

- MTBSF is the Mean Time Between Service Failures and is calculated as the ratio of the Total Up Time out of the total number of failures affecting the service recorded in the observation period;
- MTTRS is the Mean Time to Restore Service and is calculated as the ratio of the Total Down Time out of the total number of failures affecting the service recorded in the observation period.

2.1.4 Model SA #4

The SA#4 is calculated as ratio of the actual kilometres performance of the fleet in a reference time period out of the planned kilometres performance in the same period according to the operating scheme. Each service disruption strictly related to trains circulation is measured in terms of missed Kilometres with respect to the planned Kilometres production on the basis of the nominal operational scheme.

Then the SA#4 is calculated by the following formula:

$$SA = \frac{Total\ \ Actual\ \ Kilometres}{Total\ \ Planned\ \ Kilometres} \qquad (4)$$

This SA#4 model is easy to apply but it mainly represents a measures of the performances strictly related to trains circulation rather than the overall system. It is characterized by a low sensitivity regard to the quality of service (the train punctuality and the service regularity), being a lot of events affecting the passenger service excluded from the system performances evaluation-i.e. station unavailability, minor delays, etc..

2.1.5 Model SA #5

The Model SA#5 measures the system performances as the ratio of the actual trips performed in the reference time periods out of the planned trips in the same period according to the timetable.

Then the SA#5 is calculated by the following formula:

$$SA = \frac{\sum Actual\ Train\ Trips}{\sum Planned\ Train\ Trips} = 1 - \frac{\sum Missed\ Train\ Trips}{\sum Planned\ Train\ Trips} \qquad (5)$$

Where:

- Actual Train Trips are the trips actually performed during the revenue service in the time period taken as reference;
- Planned Train Trips are the trips planned in the nominal timetable for the same reference period;
- A train trip is defined as a complete one direction train run between two terminal stations as foreseen in the planned timetable.

In this model each service delay exceeding the current headway is considered in terms of shift of the current timetable. The trips scheduled in the shifting time interval are then considered not performed.

2.2 Train Punctuality Model

The quality of service offered to passengers is usually measured by a parameter indicating the regularity of the applied headway or schedule named Train Punctuality (TP).

This indicator of the system performances is focused on train delays due to minor technical failures that not affect directly the service availability. It is then often applied in addition to the SA parameter in order to distinguish minor deviation from regular service from major service disruptions.

In order to define a train punctuality model, the train delay must be univocally defined in terms of time deviation and method of measure. The delay definition influences the definition of TP model.

2.2.1 Model TP #1

Train punctuality is calculated as percentage of the delayed trips out of the total actual trips performed in the reference time period.

$$TP = \frac{\sum On\ Time\ Trips}{\sum Actual\ Trips} = 1 - \frac{\sum Delayed\ Trips}{\sum Actual\ Trips} \quad (6)$$

Where:

- Delayed trips are trips with an arrival time to the terminal station exceeding the scheduled headway of a Δt to be defined according to the desired system performances;
- Actual trips are all the trips actually performed during the reference period.

This model is focused on the number of delayed trains rather than the delay extension. For this reason it should be applied in combination with a model of Service Availability-i.e. Model SA #5- aimed at estimating the service disruption in terms of duration.

2.3 Reliability Model

The performances of a system may also be measured by the basic RAM parameters as MTBF and MTTR. This approach usually mainly focuses on the technical aspects of system behavior rather than on service disruptions.

An overall value of MTBF can be defined at system level modelling the system as a series of the subsystems essential for system mission completion. This approach requires an identification of all the mission critical functions and the subsystems or equipment performing them.

System MTBF is calculated in a reference observation period as ratio between the total operating time of the system in planned conditions and the total number of failures leading the system in fault conditions:

$$TechSysA = \frac{MTBF}{(MTBF + MTTR)} \quad (7)$$

- MTBF is the Mean Time Between Failures and is calculated as the ratio of the Total Up Time out of the total number of failures in the observation period;
- MTTR is the Mean Time to Restore Service except administration and logistic time in the observation period.

3 SELECTION OF THE SYSTEM RAM MODEL

The RAM model which is deemed more efficient in the system performances evaluation by both technical and service quality points of view is the Model SA #2.

$$SA = 1 - \frac{Missed\ \ Depatures}{Planned\ \ Departures} \quad (8)$$

The main advantages of the Model SA #2 are the following:

3.1 Flexibility against System Configuration

The model is not sensitive to the system extension such as number of stations or different time table while other models based on the overall operation time may present problems if applied to different system extensions. A unique target then results easily applicable to any section of the system without any other further specification because extending the line such as the number of stations or changing the operating scheme such as planned departures and missed departures changes accordingly, keeping valid the target ratio-i.e. the SA.

On the contrary SA models based on the percentage of the planned operating time are difficult to be extended to further sections or to different level of train trips. In fact, the probability of service disruptions increases with the increasing of the line extension and train trips while the total operating time (i.e. hours per day) in principle does not change. Then the ratio between Total Downtime and Total Planned Operating Time increases and the SA target should be reconsidered.

3.2 High Level of Precision in the System Performance Measurement

Each delay is, in any moment, measured at all platforms without approximations or hypothesis by comparing the actual departures against planed departures.

Other models limit the delay counting to specific location of measurement-i.e. the terminal stations- simplifying the service disruptions and disregarding the effects of the perturbation extension on the rest of the system-e.g. the delay measured on the most delayed train among the delayed trains related to the system failure or the delay measured at the terminal, etc.

3.3 Completeness in the System Performance Evaluation

The model also measures the quality of the train service - train delay at all platforms - perceived by passengers without using a Train Punctuality model. Then major and minor failure effecting on the train service are duly included in the model.

3.4 Easy to Measure the System Performance Using an Automatic Counter Tool

Missed Departures can be easily counted implementing a link between ATS (Automatic Train Supervision) and a special tool for the SA calculation. This tool continuously measures the SA simply comparing the planned departures from the timetable with the actual departures from ATS records.

4 THE SYSTEM RAM TARGET

The target value for SA or any other RAM parameter should be established by the employer after the analysis of RAM data and performance evaluation from similar systems already in operation. In case, adopting new technologies at subsystem level, the minimum level of service performance should be usually required equal to that achieved by traditional solutions.

From a RAM performance point of view, Maglev project arises a set of concerns due to its innovating technology. The application of magnetic levitation technology to the metro system is very recent and still in course of development. Only few young projects around the world are at the moment in operation, many of them are still in phase of testing and have a short line extension.

For these reasons, meaningful and stable data on RAM and service performances for Maglev systems are not still available with sufficient accuracy at the present and the Maglev projects have to be considered also for RAM aspects as pilot project.

Therefore, the System RAM Target shall be then defined starting by the principle that the new technology shall provide a level of service performance comparable with the level of performance achievable by the modern Driverless LRT systems representing the last generation.

From past experiences of Driverless LRT systems application and considering the proposed model for measuring the service performance level, the System RAM Target value for SA that the Maglev should assure is 98%. It should be noted that this value represents the final target to be applied after a running in period when, according with the failure distribution curve such as bathtub curve, the early failures are analyzed and solved and the system operates under RAM steady-state conditions.

5 CONCLUSIONS

The RAM model and target for the urban maglev system project in Korea has been set during the basic design phase of the project.

The RAM model for the urban maglev system project is more flexible against the system configuration, precision and completive in measuring the system performance, and easy to calculate the achievement of the system performance than others are.

Subsystem RAM requirements consisting of quantitative and qualitative requirements should be develop during the implementation design phase of the project; and also be verified, which shows that the RAM target for the urban maglev system project can be achieved.

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