# System FMECA for Korea Urban Maglev Program

Yong-Jun Seo
*Hyundai Rotem Company, System Engineering & Sales Team, 231, Yangjae-dong, Seocho-gu, Seoul, 137-938 Korea, andrea@hyundai-rotem.co.kr*

Gyung-Su Jeong
Hyundai Rotem Company, System Engineering & Sales Team, 231, Yangjae-dong, Seocho-gu, Seoul, 137-938 Korea, rudtn5890@hyundai-rotem.co.kr

ABSTRACT: This paper discusses the system FMECA for the Korea Urban Maglev Program. The service availability target of the urban maglev program was previously discussed at the Maglev 2008 conference in San Diego, USA. Since that time, many RAMS issues including failure criticality class has been discussed and agreed among parties involved in the program in order to support verifying if system and subsystem meet the RAM requirements allocated. System and subsystem level RAMS activities for the program will continue until the commercial operation of the program starts.

## 1 INTRODUCTION

This paper discusses the integration at system level of the FMECA for the Korea urban maglev program supported by the Ministry of Land, Transport and Maritime Affairs in order to provide;

- an overall overview of the failure modes and their potential criticality for service disruption
- an useful set of information on the system behavior and its failure tolerance aimed at evaluating the overall design and identifying critical single point failures, if any
- a support for the development of the system RAM analysis.

This paper incorporates and consolidates all the information provided in the subsystems FMECAs and is aimed at providing high level indications on the functional and operating aspects of the subsystems/equipment failure modes. These can help in performing the detailed RAM analysis to verify and validate if the program to be constructed can meet RAMS requirements.

## 2 TECHNOLOGY DEVELOPMENT

### 2.1 Service Availability

RAM requirements of the Korea urban maglev program are expressed in terms of Service Availability as follows;

$$SA = \frac{PlannedDepartures - MissedDepartures + \frac{1}{2}UnplannedDepartures}{PlannedDepartures}$$

Where:

- MD (Missed Departures) is 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 MD. The number of MD associated to a delay depends on the delay time, the extension of the perturbation and the current headway;
- UD (Unplanned Departures) depends upon the catch up plan of the maglev system operator;
- PD (Planned Departures) is all planned departures in each platform in a defined time period.

The minimum target value for Service Availability that the Korea urban maglev program has to assure is:

$$\text{Service Availability} \geq 98\%$$

### 2.2 Urban Maglev Program

Incheon international airport, Seoul's primary international airport, agreed with the Korea Institute of Construction and Transportation Evaluation and Planning to construct a Korea urban maglev program as a project running from the Airport Traffic Control Center to Yongyoo Station of AREX operated by Airport Railroad Company.

The project is divided into three phases and when completed, the final track will be 53.2 km long. However, the Phase 1 will be only 6.1 km long. The Phase 1 consists of six stations and one depot. Table 1 shows the six stations and the distances between them.

| Location | Station Name | Distance | Remark |
|---|---|---|---|
| Airport Transport. Center | 101 | 28 m | Island platform |
| Air terminal 2 | 102 | 330 m | Island platform |
| Air city park | 103 | 880 m | Separate platform |
| Fashion island | 104 | 1,380 m | Separate platform |
| Water park | 105 | 4,850 m | Separate platform |
| Yongyu station | 106 | 5,930 m | Separate platform |
| Rout length of the 1st phase | – | 6,113 m | – |

Table 1. Station-to-station distance for the 1st phase

The project is a driverless system and is based on the latest technologies available such as levitation by electro-magnets (EMS) and propulsion by SLIM (single-sided linear induction motors). The following detailed explanations of the system development and subsystem design can be changed during the following processes.

The system operates on a 1500 VDC power source supplied through the third rail. Vehicle propulsion is accomplished by SLIM giving a maximum operational speed of 100 km/h. The propulsion system has the capability of feeding back electrical energy to the Electrical Power Supply System 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.

8 mm gap between the top of the levitation magnet and the rail bottom is maintained by a controller, which also keeps the 11 mm gap between the bottom of the linear motor and the top of reaction plate.

For levitation magnet failure, 12 landing skids are installed near by the linear motor. The lateral movement is controlled by the magnetic force generated by the levitation magnet too. Magnetic force generated by the levitation magnet 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 skids are installed. The lateral skids have 10 mm gap from the rail side in the normal operation condition.

Except for the Rolling Stock and the Guideway, all other E&M systems should be similar with a driverless LRT System. In particular, the Signalling System consists of following subsystems, each of which is independent from the others:

- Signaling System onboard (ATP, ATO);
- Wayside Signaling System (ATP, ATO);
- Control Centre System (ATS including scheduler).

ATP operation is based on a series of adjacent block sections. The ATP system secures the safety of train operation through its control function. Since system safety is of the highest importance in transportation, the ATP system is fully independent from the other subsystems, and it has the highest priority over subsystems in the train operation.

The ATP system is of a design and manufacture based on long and proven experience. The ATP equipments are designed according to fail-safe and checked-redundancy principles. Because the ATP system is a closed system, its safety and reliability is not influenced by other systems.

In the ATP system, a pre-determined ATP signal is continuously transmitted (based on the position of the preceding train and the route condition). This signal is received by the on-board antenna, whereby a ATP signal is identified.

The Signaling System should have a dedicated Fibre Optic Cable Network between Control Centre and a station consisting of central and local Data Distribution Systems, Radio Communication System, and a UPS for the essential equipment.

The following table 2 presents a high level breakdown of the maglev system in its major subsystems.

| Level 1 | Level 2 |
|---|---|
| Vehicle (VEI) | Carbody |
| | Bogies (included levitation system) |
| | Propulsion system |
| | Doors |
| | Auxiliary Systems (including on board electrical power circuits) |
| | Brake system |
| Signalling system (SIG) | Wayside signalling equipment |
| | On Board Signalling equipment |
| | Central Signalling equipment |
| Power Supply | Traction Power |
| | Power Rail |
| | Power Supply |
| | SCADA |
| | Lighting (Station and Depot) |
| | Fire Detection System |

| Level 1 | Level 2 |
|---|---|
| Telecommunication (TLC) | Digital Transmission System |
| | Radio System |
| | Public Address and Passenger Information Systems |
| | Telephones (including emergency call points) |
| | CCTV system |
| | Access Control System |
| | Network Management System |
| | Electric Clock |
| | Automatic Fare Collection |
| Track | Track |
| | Switching Machine |
| Mechanical Building Service | Platform Screen Doors |
| | Escalator and Lifts |
| | Building Automation System |
| | Fire Fighting System |
| | Ventilation system |
| | Other E&M equipment (water pumps, GAS supply, etc.) |
| Depot Facilities | Workshop facilities |
| | Computerized Maintenance Management System (CMMS) |

Table 2. High level system breakdown

### *2.3 Failure Criticality*

In railway RAMS, to determine the failure criticality class sometimes can be one of the big activity since railway RAMS is slightly different from military RAMS concerning what un-availability is.

Historically RAMS developed by military field after the 2nd world war provides the ways of analysis and assessing Reliability, Availability, Maintainability and Safety of part, unit, equipment, and subsystem composing a system by statistics, mathematics, and engineering considerations. Now that in Military Standard as MIL-STD-882C helps the RAMS relations among units, equipment, and subsystems composing a system be described in mathematical equation, Reliability, Availability, Maintainability and Safety of a system can be calculated and verified by mathematical ways.

In military field, the arms shall always be ready in order to immediately be operated when they are needed although they are not working or in combat. Then the locations of the arms, the possible battle fields, the maintenance shops, and possible spare parts become crucial.

Also to increase the availability of the arms, they need to shorten the duration of defect state and the period of maintenance time that is called un-available time. Therefore Maintainability as MEAN TIME TO REPAIR" including logistic supporting becomes very important. I argue that due to the reasons above the availability equation for arms in MIL-STD-882C is very useful in the military field.

However, in railway field there is a clear difference between in service time and out of service. A maintenance activity normally is done during out of service time that is not considered as un-available time.

Therefore, RAM activity can focus on fast recovery time of train service and on failure's effects on train service in order to increase the availability of a railway system under the limited budget, resources and time-schedule. Of cause the REPAIR TIME in railway field, which usually is done in a maintenance shed also is important to reduce the labor cost on maintenance but not to increase the system availability itself. Suppliers of the project can consume more share of the limited budget on resolving the more critical failures on train service and/or passenger safety.

Then we need to also focus on failures having critical or major effects on train service and reducing the recovery time caused by it. As a result we need a suitable failure class definition for the project as follows.

In the FMECA herein presented, the effect of a failure is evaluated both at local and system level which is compatible with the category in IEC 62278. The failure criticality is evaluated on the basis of the potential consequences on train service disruption and assessed accordingly to the failure consequence classes adopted in the project.

| Failure Class | Description |
|---|---|
| SG (Significant Failure) | Failure events impacting on service with a restore time > 30 min. Typical Significant failures are those that require the intervention of the maintenance staff or that cause the immobilisation of a train or that required withdrawal of multiple trains from service |
| MJ (Major Failure) | Failure events impacting on service with a restore time ≤ 30 min but greater than 4 min. Typical Major failures are those that require a train to be withdrawn form service or that can be solved in less than 30 minutes. Failures that can be reasonably solved in such a short time are those that require local staff intervention to clear or reset failed equipment |
| Mi (Minor Failure) | Failure events potentially impacting on service with a restore time lower or equal than 4 min but greater than 90 seconds. Typical Minor failures are those that can be cleared remotely by Safety Attendant on board or Roving Rapid Personnel in a station or OCC via software or automatic procedure |

Table 3. Failure class description

| Failure Class | Restoration Time as reference | Logistic Time as reference | Admissible MD | Maximum admissible Failure Rate (1/yr) |
|---|---|---|---|---|
| SG | 60 min | 20 | 723 | 0.492 |
| MJ | 30 min | 2 | 4489 | 6.10 |
| Mi | 4 min | - | 7052 | 71.96 |

Table 4. Failure criticality classes

### *2.4 FMECA Analysis*

The System FMECA is presented in the Table 5 including descriptions of the content for each field of the FMECA format is provided.

| HEADING | DESCRIPTION |
|---|---|
| System / Subsystem \| System / Subsystem ID | The name of the System / Subsystem under analysis as well as the related PBS code |
| Item ID | Identification PBS code of the Item |
| Item Description | Brief description of the Item |
| Function | Main operating function performed by the item under analysis |
| Failure Mode ID | Identification number of the failure mode that should have a clear logical reference to the Item ID |
| Failure Mode | All probable failure modes for each item / function under analysis |
| Failure Effect (Local, Subsystem, System) | - Local: the primary effects on the item related function,<br>- Subsystem: possible extended impacts on other parts of the subsystem,<br>- System: possible effects at system and operational level; |
| Failure Detection Method | A description of the methods by which occurrence of the failure mode is detected by the operator. The failure detection means, such as visual or audible warning devices, automatic sensing devices, sensing instrumentation or none will be identified. |
| Existing Design Safeguard | Design solutions adopted (or in this case to be adopted) by the subsystem in order to reduce the failure occurrence rate or its consequences on the service (please note that this aspect shall be accurately completed by the subsystem designer) |
| Failure Consequence Class | The expected failure consequences criticality classified according to the failure consequence classes model applied to the project |
| Remarks | Observations or clarifications regarding the content of the previous cells. |

Table 5. FMECA format fields description

## 3 CONCLUSIONS

A system level FMECA, performed by integrating the data and analysis provided by each subsystem supplier, will be developed upon the completion of the subsystem analyses.

The present document has provided the Failure Modes, Effects and Criticality Analysis for the project. Main outcomes of the System FMECA are the following:

A total of 758 failure modes have been analyzed and among them 57 failure modes (for a total of 48 LRU) leads to Major Failure class and 29 failure modes (for a total of 19 LRU) leads to Significant Failure class;

| Subsystem | #Fail Modes | #SG | #MJ | #Mi | #Ne |
|---|---|---|---|---|---|
| Rolling Stock | 521 | 2 | 18 | 195 | 306 |
| Signaling | 49 | | | 49 | |
| PSD | 34 | | 16 | 8 | 10 |
| Switching Machine | 34 | 11 | 13 | | 10 |
| Power Supply | 12 | 1 | 4 | 7 | |
| Third Rail | 21 | 6 | | | 15 |
| SCADA | 63 | | | 45 | 18 |
| Telecommunication | 15 | 8 | 5 | 2 | |
| Depot | 6 | | 1 | 3 | 2 |
| Mechanical Buildings | 3 | | | | 3 |
| Total | 758 | 29 | 57 | 311 | 361 |

Table 6. Result of system FMECA

## 4 REFERENCES


The European Standard “EN50126 (Railway applications-The specification and demonstration of Reliability, Availability, Maintainability and Safety”, BIS, 1999, pp. 60-61.

Yong-Jun Seo and Hyun-Jong Lee, “Basic Study on RAMS Applications to the Urban Maglev Systems”, International Conference on Electrical Machines and Systems 2007, Seoul, Korea, October 8-11 2007.

Yong-Jun Seo and Hyun-Jong Lee, “RAMS Program for the Urban Maglev System”, The Korean Society of Mechanical Engineers 2007 Fall Conference, Seoul Korea, Oct 31-Nov 2 2007.

Florian Steiner & WinFried Steinert “Safety Assessment for the Maglev Vehicle TR09 – an approach based on CENELEC railway standards”,2001, pp. 5-6.

Rotem Company, “Busan-Gimhae LRT System RAMS Plan” 2007, pp. 18.

Yong-Jun Seo, “Service Availability of the Urban Maglev System in Korea”, Maglev 2008, San Diego USA, 2008.12