# A CASE STUDY ON THE IDENTIFICATION AND CONTROL OF URBAN MAGLEV INTERFACE USING VEHICLE ORIENTED FUNCTIONAL ANALYSIS

No.

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ABSTRACT: Even though maglev technology and a prototype vehicle have been developed and successfully performed a trial run on a test track, the commercialization of maglev trains to be used in public transportation system requires significant development. This includes system integration in relation to complicated interactions between maglev train and external factors. Also, unpredicted situations that may occur during the trial run on a main line should be anticipated and pre-adjusted by analyzing operational scenarios of practical services. Therefore, the fundamental tasks of recognizing system interfaces and resolving interface problems play a key role in system integration for commercialization.

Functional analysis based on operational scenarios indicates to be a very useful tool in system integration such as interface identification and control. In this paper, we present an application study on vehicle oriented functional analysis focused on the case of commercial application project of an urban maglev train in Korea. We also provide a case study in system interface control using functional architectures drawn from the results of functional analysis on the maglev system.

## 1 INTRODUCTION

Today, the trend in the specifications of railroad systems has gradually become bigger and more complicated. Because the technology of existing vehicles system has improved, new functions have been added to signals, communication, electric power, stations, and depot systems for a much efficient, convenient and safer service. The maglev system is designed to be driverless, or an unmanned system, and interfaces between the vehicle and rail system is different from the wheel-based system. Therefore, to discriminate and manage the interface between subsystems is embossed heftily.

The scope of urban maglev program in Korea includes all equipments and facilities that are needed in the operation. The identification and management of interfaces between subsystems, including diapason, is required. This checks for conflicts and omissions of the interface that may take place during the system integration process after design and manufacture, in case some changes in design or problems should be examined, the functions of other subsystem connected to it can be traced.

We can find interfaces between functions of different subsystems by traceability derived from functional analysis. In this paper, we present an application study on the vehicle-oriented functional analysis focused on the case of commercial application project of urban maglev train in Korea. Also, we provide a case study in system interface control using functional architectures, which was drawn from the results of functional analysis on the maglev system.

## 2 FUNCTIONAL ANALYSIS

### 2.1 *Definition*

Functional analysis is an examination of a defined function to identify all the sub functions necessary to the accomplishment of that function. The subfunctions are arrayed in a functional architecture to show their relationships and interfaces (internal and external). Upper-level performance requirements are flowed down and allocated to lower-level subfunctions.

This activity should be conducted to define and integrate a functional architecture for which system products and processes can be designed. Functional analysis/allocation must be conducted to the level of depth needed to support the required synthesis efforts. Identified functional requirements must be analyzed to determine the lower-level functions required to accomplish the parent requirement. All usage modes must be included in the analysis. Functional requirements should be arranged so that lower-level functional requirements are recognized as part of higher-level requirements. These functional requirements should be arranged in their logical sequence; their input, output, and functional interface (internal and external) requirements must be defined, and traceable at its conditions from the beginning to the end. Time critical requirements must also be analyzed.

The performance requirements should also be successively established from the highest to lowest level for each functional requirement and interface. Time requirements that are prerequisite for a function or set of functions must be determined and allocated. The resulting set of requirements should be defined in measurable terms and in sufficient detail for use as design criteria. Performance requirements should be traceable from the lowest level of the current functional architecture, through the analysis by which they were allocated, to the higher-level requirement they are intended to support.

### 2.2 Method

#### 2.2.1 Input Criteria

The more that is known about the system the better. Ideally, Functional Analysis should begin only after all system requirements have been fully identified. This means that the Requirements Analysis must be complete before beginning this task. Oftentimes, this will not be possible, and these tasks will have to be done iteratively by further defining the functional architecture as the system requirements evolve. The output of the Requirements Analysis task may be incomplete, and omissions may be well understood or not be recognized at all. The Functional Analysis task should help reveal any missing requirements and refine or clarify others.

#### 2.2.2 Major Steps in Functional Analysis

Even within a single stage in the system life cycle, the Functional Analysis process is iterative. The functional architecture begins at the top level as a set of functions that are defined in the applicable requirements document or specification, each with functional, performance, and limiting requirements allocated to it (in the extreme, top-level case, the only function is the system and all requirements allocated to it). As shown in Figure 9-1, the next lower level of the functional architecture is developed and evaluated to determine whether further decomposition is required. If so, then the process is repeated. If not, the process is completed and System Synthesis can begin.

## 3 FUNCTIONAL DECOMPOSITION AND ANALYSIS OF THE URBAN MAGLEV PROGRAM IN KOREA

### 3.1 Top Level Functions

Top-level functions for a system vary according to the extent of development work. If a project is to develop a railway vehicle, the function given from the viewpoint of vehicles may have to be defined. In the case of this project, because all infras required for commercial service are included in scope of the project, top-level functions, including the entire system, need to be defined. We arranged functions and sorted items based on engineering data of the existing railroad system, and drew three top-level function requirements indicated in Table 1.

Table 1. Top-level Functions in Urban Maglev Program in Korea

| No | Top-level function | Description | Related functions |
|---|---|---|---|
| 1 | Transport function | Function that transports passenger and freight to destination | Propulsion, braking, levitation, boarding, velocity control, etc. |
| 2 | Operation and control function | Function that allows several trains to operate safely without collision and interference | Driverless driving, train protection, manipulation of courses, emergency driving, operation control, etc. |
| 3 | Monitor and accident function | Function that monitors operating conditions of the entire system and deals with accidents | Electric power supervision, blue light system, monitoring passenger system, etc. |

Top-level functional requirements of the Maglev train are similar to other railroad systems although it is different from general railway vehicles, at the point by which it is levitated and propelled by magnetic force. Basically, most Maglev trains need a transport function, and require a control function in order to operate several vehicles simultaneously without collision and interference.

Finally, functions that monitor vehicles, signal, communications, electric power, rail tracks, stations and depots during operation are also required to cope with various situations and deal with other possible occurrences.

A case study to decompose a transport function will be introduced later in this paper because of the difficulty in introducing the functional analysis of all functions.

### *3.2 Second Level Functions*

The "transport function" is a functional requirement for the entire operation of vehicles. This function moves passengers from a station to their destination. Because passengers can move through vehicles, subject of transport function are vehicles. These vehicles analysis of the transport function is focused on behavior of these vehicles. Trains that stop in the rolling stock base have to be moved to a station to achieve transport function. In this process, the sub-level functions of that train receive a command and plan to service if needed to check what is necessary. Even if trains are engaged on the main line, operation may begin depending on the planned driving schedule. In general, the train executes driverless operation, but manual operation is also executable by an officer depending on the situation. Manual operation consists of emergency operation and rescue operation. Emergency operation is carried out in a reduced mode by abandoning infra equipment to support vehicles during natural disasters. Rescue operation is achieved in a state where a train can no longer be driven normally by another train. Finally, transport function ends by finishing the operation at the main line and moving to rolling stock base. Transport function according to the repeated behavior of vehicles consists of service preparation function, normal operation function, emergency operation function, rescue operation function and operation completion function. The process is shown in Figure 1.

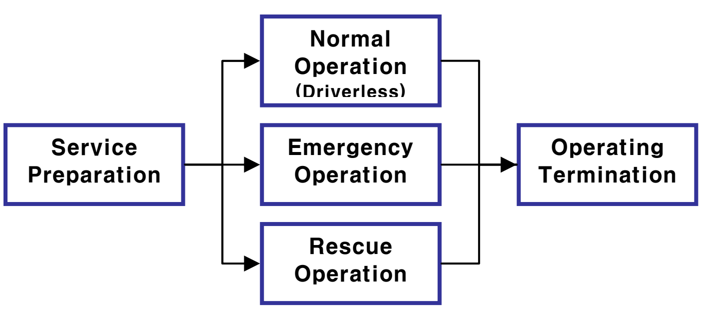



Figure 1. Decomposition of Transport Function

### *3.3 Third Level Functions*

Sub-functions defined in the second level are not enough to identify the interface between sub-systems. Each function should be analyzed and further decomposed to identify more interfaces.

First of all, in the service preparation function, the key point is a function that inspects and wakes up infra equipments related to the operation of trains. Signal and communication fields of infra equipment are excluded in this analysis because it belongs to operation control and accident monitoring function that are not included in the transport function. After the electrical power system is turned on, vehicles system is awakened in the service preparation function. In this process, the system checks the functions necessary to for a secure and safe operation.

Emergency operation and rescue operation are manual driving modes. The urban maglev train program in Korea will include a driverless operating function, but an officer will be aboard for a few years after the launch of the service. If rescue operation is required, the operation control center assigns a rescue train for the disordered train. The rescue train will then approach the disordered train by manual operation.

When an operation is terminated, the operation control center transmits a command to terminate operation to each train, and the train that received the command moves to rolling stock base through the incoming line. In the case of route demonstration of the urban maglev program in Korea, because incoming line is only a single line, only one vehicle can occupy the line.

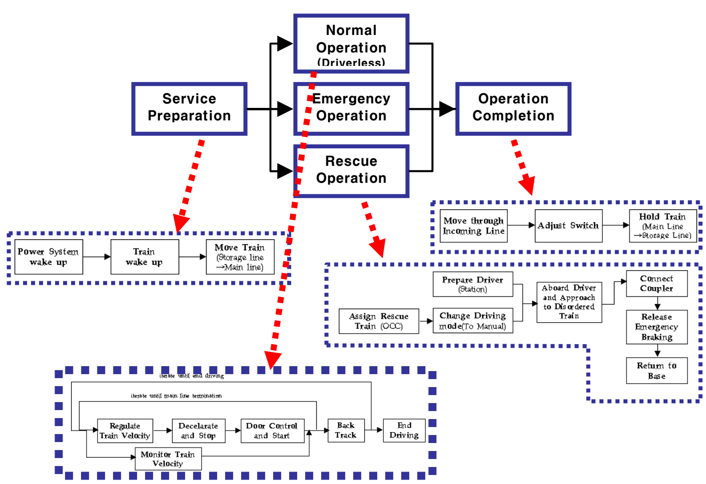



Figure 2. Third level decomposition

Therefore, it must use the incoming line after confirmation of whether or not another train is on the same line. Finally, the operation control center decides the storage line number and adjusts the switch in base. The train then moves to the storage line and the transport function of that train is discontinued to end driving.

Functional analysis is enforced throughout the transport function, but this paper introduces a case study about normal operation mode. Normal operation begins that accelerate in suspension state and runs depending on the predetermined operating velocity at each route. As the train approaches a station, it receives position information through the interface with a signal device installed on the track and produces deceleration data. After stopping, the doors open and passengers board and alight. In this process, the affinitive interaction with vehicles, signal, and rail track is required.

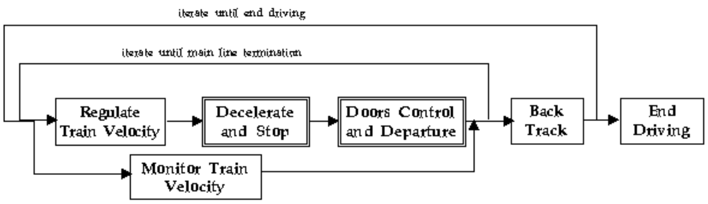



Figure 3. Decomposition of “Normal Operation” Function

Each function explaining the "normal operation" is expressed through the behavior diagram in Figure 3 above. However, the functional analysis about the present level does not yet concretely cover the interface between vehicles, rail tracks, and signal systems. We need to analyze functions at the lower level to confirm exactly the interfaces between subsystems. We are going to analyze the "decelerate and stop" function and "door control and depart" function to illustrate an example about the fourth level in this paper.

### *3.4 Fourth Level Functions*

Due to space limitations and technical security, it is difficult for this paper to introduce all cases of functional analysis. Therefore, we selected the "decelerate and stop" function and "door control and depart" function as an example for the fourth level functional analysis since they provide a good view about interfaces between vehicle and external systems.

#### *3.4.1 Case 1 – Decelerate and Stop*

Requirement for the "Decelerate and Stop" function:

| |
|---|
| <Requirement><br>Train must decelerate properly as it approaches the station and stop in the correct position. |

If we break down the above requirement to lower level functional requirements, it will be as follows. The system must figure out the velocity of train to achieve proper deceleration and calculate the deceleration amount that follows to the variation of position (distance from the station). Also, it must be able to stop at a specified position so that passengers can board and alight easily from the vehicles at the station. The platform screen door is established for passenger safety when going to station; therefore, the position of the train after stopping should be correct. Stopping accuracy target is within ± 25 ~ 35cm from the base position according to the urban maglev train program in Korea. If the train is not within this limit, an adjustment of its position will be made, either moving forward or backward.

Generally, a common system engineering process presents that specification decided upon according to the result after achieving functional analysis. However, because a legacy system exists in the railroad field, specification is often predetermined by applicable technology. Design specification connected with upside functional requirements is further explained below.

General trains with wheels calculate the velocity by measuring the number of wheel rotations. However, a maglev train uses another method to obtain velocity because it does not use wheels. Various methods can be applied, such as measuring the velocity of vehicles through the radar Doppler effect in the urban maglev train program in Korea. Because the Radar Doppler system needs a counterpart for the Radar Doppler sensor of vehicles, interface between vehicles and rail track additionally takes place.

Also, to discriminate the train’s present position, a TAG is established to track them down. A TAG antenna is installed under trains which recognize information of TAG on the rail track and find its current position and the target velocity if a train passes on TAG. A proximity plate is also established on stop position in a station stop the trains correctly. The train senses its correct stopping position through its interaction with the proximity plate.

Functional requirements and specification explained in this clause are summarized in Table 2.

Table 2. Functional Requirements and Specification of the “Decelerate and Stop” Function

| Functional Requirements | | Specification |
|---|---|---|
| Level 3 | Level 4 | |
| Train shall decelerate | Train shall obtain velocity. | Radar Doppler system |

| | | |
|---|---|---|
| and stop exactly as it approaches the station. | Train shall decide the deceleration amount by position | Installation of TAG |
| | Train shall be able to stop correctly in specified position | Installation of proximity plate |

We can consider the procedure and input/output relation of function and draw the Enhanced Functional Flow Block Diagram. While Functional Flow Block Diagram is diagram that express contents and procedure of functions, the Enhanced Functional Flow Block Diagram expresses input/output of data, energy or material between functions. Enhanced Functional Flow Block Diagram about the "Decelerate and Stop" function is shown in Figure 4.

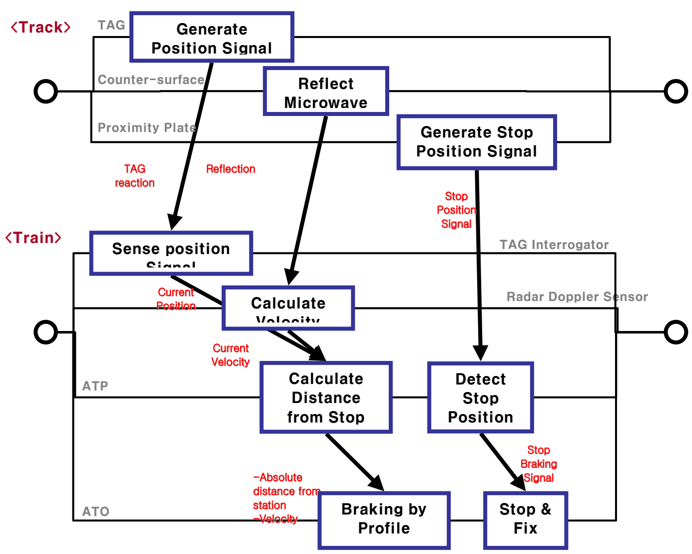



Figure 4. EFFBD of "Decelerate and Stop" Function

### *3.4.2 Case 2 – Door Control and Departure*

Requirements on "Door Control and Departure" function are the following.

<Requirement>
System shall enable passenger to board and alight by manipulating doors and shall depart safely.

After vehicles arrive at the station through the deceleration and stopping function, it shall open doors and guide passengers when boarding and alighting. Doors opening at the vehicles need interface because it is interlocked with the screen door of the platform. Also, the train needs to be controlled through the external signal system regarding the opening time of doors and departure of vehicles. Decomposing the above requirement to lower level functional requirements are as follows:

If the train stops in a correct position, stop braking is operated, and it reports a stop completion signal to the ground signal device. The train opens its doors after deciding which direction to open (left side or right side) and closes the doors after stopping time passes. The Door Control Unit manipulates the doors according to signal of the cab ATO. The Door Control Unit can detect stumbling blocks of more than 10 millimeters. If stumbling is detected between doors, the Door Control Unit does not send a 'closed' signal to ATO. ATO never departs the train without a 'closed' signal. In the meantime, if stopping is over, the ground signal device removes the door- opening signal and sends admission for departure (AD). After receiving admission for departure, and the status of all doors is "closed", the train can remove stop braking and depart from the station. Signal systems in the car and ground supposedly interact through a wireless LAN.

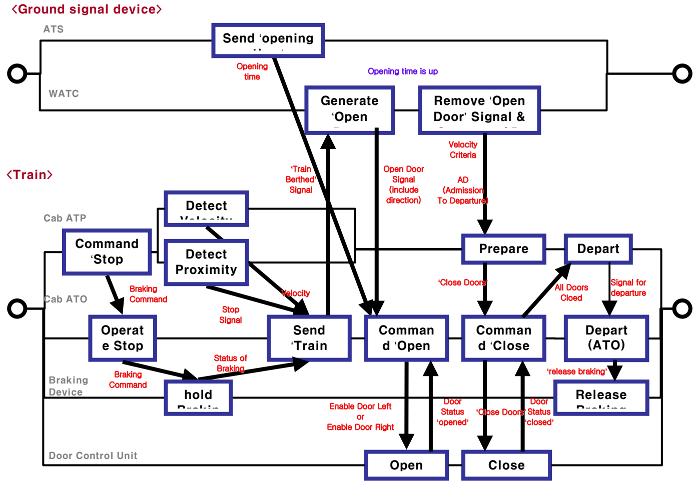
Functional requirements and specifications explained in this clause are summarized in Table 3.

Table 3. Functional Requirements and Specifications of "Doors Control and Depart" Function

| Functional Requirements | | Specification |
|---|---|---|
| Level 3 | Level 4 | |
| System shall enable passenger to board and alight by manipulating doors and shall depart safely. | System shall confirm a perfect stop | Check velocity of train as '0km/h' |
| | According to the station, the opening direction of doors should be confirmed. | Signal equipment of the station controls the opening direction of doors and opening time |
| | Train doors shall open according to a predetermined time. | |
| | Before leaving the station, the safety of passengers should be confirmed. | Departure is possible when the status of doors is 'closed'. |

Enhanced Functional Flow Block Diagram about "Door Control and Departure" function is shown in Figure 5.

Figure 4. EFFBD of “Decelerate and Stop” Function




# 4 RESULTS OF FUNCTIONAL ANALYSIS

## *4.1 Finding a Missed Specification*

Functional analysis can find omitted items in the logical procedure of function or input/output relation because we examined the logic of each item, given its specifications.

Table 4. Relationship between Requirements and Specifications (with Missed Items)

| Requirements | Specifications | | |
|---|---|---|---|
| | Vehicle | Rail track | Ground Signal Device |
| o Train shall decelerate and stop exactly as it approaches the station.<br>- Train shall obtain the velocity.<br>- Train shall decide the deceleration amount by position.<br>1.3 Train shall be able to stop correctly in a specified position. | Radar Doppler system | ***Counterpart for Radar Doppler sensor**** | Installation of TAG<br><br>Installation of proximity plate |
| o System shall enable passenger to board and alight by manipulating doors, and shall depart safely<br>- System shall confirm a perfect stop.<br>- According to the station, opening direction of doors should be confirmed.<br>- Train doors shall open according to a predetermined time.<br>- Before departure, the safety of passengers should be confirmed. | Check velocity of train is ‘0km/h’<br>&<br>***Check ‘stop braking’****<br><br>Departure is possible when status of doors is ‘closed’. | | Signal equipment of the station controls the opening direction of doors and opening time |

* Missed Specification

The train uses a Radio Doppler sensor in Chapter 3.4.1’s case study to measure velocity of the vehicle, but there is no specification connected with this in the track. We can find the function that does "velocity information gathering" in the rail track side through functional analysis, and know that the "Counterpart for Radar Doppler sensor of vehicles" is needed by designing an item that corresponds to the Radar Doppler system at the train.

Engineers who develop vehicles should embody a function that measures velocity. However, in the case of a maglev train, because there is no wheel, velocity measurement is impossible detecting its wheel-spin. Therefore, we chose the velocity measurement method through the Radio Doppler sensor. This sensor projects electromagnetic waves in the girder part of the rail and measures the velocity through spectrum change of reflected waves in reply. Because this method does not require special mounting to the track like the Proximity Plate for stopping point and TAG for position detection, no contents correspond to the Radio Doppler sensor of vehicles in early rail track specifications. However, if such contents are not reflected on rail track specification, rail track designers who have not considered the item for Radio Doppler sensor can see that the Radio Doppler sensor does not operate properly. There is actually an example being designed to show that the girder of some sections of the rail track may not transmit properly to the Radio Doppler sensor of vehicles in the rolling stock base.

There is an example for "stopping confirmation in station" requirement by a similar instance. The train must open doors after it stops perfectly in place for safety reasons. If the velocity is '0 km/h' at the wheelbase of the train, the stopping state is easily confirmed because '0 km/h' means that the wheel is not rolling. However, in the case of maglev trains, where measurement of velocity is not through the wheel, if velocity measurement method produces an error and the velocity of vehicles is below its extent, then we cannot confirm a perfect stop. Therefore, it should be confirmed whether "stop braking" is operated before the doors open. There is also a part where specification is omitted regarding the reflection to the design of a cab signal device.

### *4.2 Identify Interface Items*

We can distinguish various interface items between functions through the diagram obtained throughout the function analysis. Such obtained interface items are examined with each field specialist and should be managed over the system development stage after choosing the item of administration. Important interface items drawn by functional analysis in this paper is introduced below.

Table 5. Major Interface Items Derived from Functional Analysis

| Interface Item | Contents |
|---|---|
| Interface with TAG signal and vehicles' TAG antenna | - Establishment position and Space of TAGs<br>- Establishment of TAG's height (space between TAG antenna of TAG and vehicles)<br>- Awareness rate of TAG<br>- Electromagnetic characteristic with TAG and vehicles' TAG antenna |
| Interface with proximity plate and vehicles | - Establishment of space between the position of proximity plate and counterpart of vehicles<br>- Awareness rate of proximity plate |
| Counterpart for Radar Doppler sensor | - Position and angle of Radar Doppler sensor<br>- Reflection characteristic on surface |
| Interface between signal systems | - Radio frequency and modulation-demodulation<br>- Communication protocol<br>- Logical functional procedure and interface |

## 5 CONCLUSION

Functional analysis is an examination of a defined function to identify all the sub functions necessary to the accomplishment of that function.

In this paper, we presented an application study on the vehicle-oriented functional analysis focused on the case of a commercial application project of an urban maglev train in Korea. This research represented a logical verification of specifications and discernment of system interfaces through functional analysis. And we presented examples that distinguish omitted specifications.

Because this functional analysis involves the process where time and manpower are required, it may not be as effective in executing a detailed functional analysis overall in the extent of the system involved in the project due to restrictions in schedule and cost.

However, highly satisfactory results are expected in the meticulous functional analysis that converge an important part of the system. For example, it can become an alternative to have better achieved results by laying stress on vehicles in the case of maglev train.

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