# A Traffic Wave based Transport Simulation of Maglev using Discrete Event System Modeling

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ABSTRACT: Korea's Urban Maglev system is essentially controlled by unmanned automatic operation on the 6.1km demonstration line at Incheon International Airport. Therefore, it is necessary to carefully establish and validate the train operation plans and strategies in advance. This paper describes a method to simulate the maglev's passenger transport considering continuous demand changes that are mainly caused by traffic waves. For this purpose, we employed the discrete event system model, which is suitable for modeling the behavior of railway passenger transportation. Through an implementation and experiment, we tested the feasibility of the proposed model and also verified that our demand-driven simulation technology could be used for prior review of the train operation plans and strategies.

## 1 INTRODUCTION

Korea's Urban Maglev program is aimed mainly at developing a low-to-medium speed maglev transit system and operating the system on the 6.1km demonstration line at Incheon International Airport[1]. This maglev system is essentially controlled by unmanned automatic operation. Therefore, it is necessary to carefully establish and validate the train operation plans and strategies in advance. In general, when making a train operation plan, the statistically predicted traffic data are used in order to develop schedules of trains considering the transport capability. A traffic wave, however, can occur when real train service is operated, due to various factors such as season, day of the week, and occasional events around the service area. For this reason, demand-driven simulation technology is required to review train operation plans and service qualities considering such traffic waves.

This paper describes a method to simulate passenger transport on the maglev considering continuous demand changes. For this purpose, we employed the discrete event system model, which is suitable for modeling the behavior of railway passenger transportation[2-3]. The system was modeled using DEVS (Discrete Event System Specification)[4], which describes the complex system behavior as a hierarchical structure using mathematical formalism based on set theory. In addition, we developed a maglev driving simulation program that simulates the aforementioned discrete event model using the DEVSim++[5] simulation environment. Through the implementation and experiments, we tested the feasibility of the proposed model and also verified that our demand-driven simulation technology could be used for prior review of train operation plans and strategies.

## 2 SYSTEM ARCHITECTURE

This system is designed to undertake a train operation simulation with six stations (northbound and southbound) and four trains. Basic boarding/alighting and train movements can be conceptually expressed as in Figure 1, with the train, stations, and passengers being the crucial models for the system. A train is run on the designated tracks based on signal control, experiencing such discrete events as arrival at and departure from the station. When the train arrives, the doors are open and passengers get on or off the train, and the train departs after a predefined standby time. This boarding/alighting process may also be modeled as a discrete event. The entrance of passengers into each station and the process of keeping the train standby can be modeled using a random process and queuing; the discrete event model provides an appropriate modeling method, encompassing train operation and passenger boarding/alighting [2-3].

Figure 2 diagrammatically illustrates the structure of the entire simulation system. Passengers are generated based on the demand forecast results, and train operation, dwell time at the station, and passenger boarding/alighting are simulated on the basis of train operation information (DIA), and the results are collected and turned into statistics.

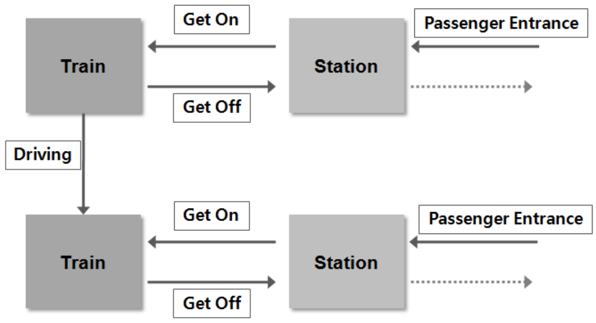


Figure 1. The concept model of boarding/alighting with train movements

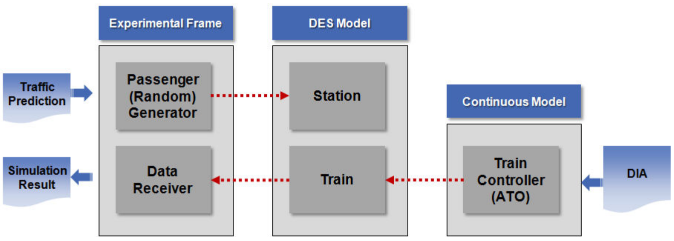


Figure 2. Simulation system structure

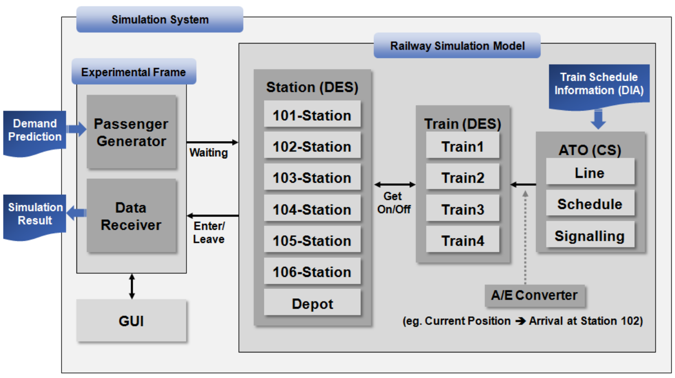


Figure 3. Detailed structure of the entire simulation system

Figure 3 describes the detailed structure of the entire simulation system. First, unmanned automatic operation is carried out on the basis of predefined operation information, and the model that simulates passenger boarding/alighting per station is defined as a railway simulation model. This model includes automatic train operation (ATO), which is responsible for scheduling and signal control as well as trains and stations transmitting or receiving messages related to passenger boarding/alighting. The behaviors of trains and stations may be expressed as changes in the internal status due to discrete event inputs/outputs, and as such the discrete event system (DES) model is suitable here. ATO is modeled using the continuous system (CS); the analog-to-event (A/E) converter is used to generate station arrival events on the basis of information on the current train location.

A passenger generator is needed to model passenger generation, which is carried out as a random process on the basis of demand forecast; a data receiver to collect and statically process all the data related to train operation and passenger boarding/alighting is also required. These two tools can be abstracted into an experimental frame model that generates various inputs and analyzes outputs for the aforementioned railway simulation model. The experimental frame model may also be linked to the GUI system, which is capable of monitoring the entire simulation process and data involved.

## 3 SYSTEM MODELING USING DEVS

Suggested by Zeigler [6], the discrete event system specification (DEVS) formalism provides a mathematical framework to divide a discrete event system by module and model it hierarchically. DEVS formalism expresses the dynamic equations of the system on the basis of set theory; it uses atomic and composition models to enable structured modeling. The system's behaviors are expressed as state transition processes over time with individual atomic models sharing events with each other. Composition models are responsible for the delivery of events between individual component models. In line with DEVS formalism, atomic models are expressed into three sets and four functions, describing the behaviors of the discrete event system whose internal condition changes or is altered by external input over time. See [6] for in-depth descriptions of DEVS formalism and modeling/application on this basis.

$M = < S, X, Y, \delta_{int}, \delta_{ext}, \lambda, ta>$

S : sequential states set

X : input event set

Y : output event set

$\delta_{int}$ : internal transition function ( $S \rightarrow S$ )

$\delta_{ext}$: external transition function ( $Q \times X \rightarrow Q$ )

$\lambda$ : output function ( $Q \rightarrow Y$ )

ta : time advance function ( $S \rightarrow Real$ )

$Q = \{ (s,e) \mid s \in S, \text{ and } 0 \leq e \leq ta(s) \}$ : state of M

This paper seeks to utilize DEVS formalism to model the maglev operation and boarding/alighting system, which is expressed as a discrete event system. First, an atomic model expressing the maglev, CAtmMaglev, may be expressed as six system states: operation underway (Driving), doors open (Open), passengers alighting (GetOff), passengers boarding (GetOn), standby (Idle), and doors closing (Close). In the Driving state, the current location of the train is updated by ATO, which is renewed each cycle; upon arrival in the station, the arrival output (Arr) is generated, and the system state is switched to "Open." When the doors are open, a passenger alighting output (Out) is generated, and the input on new passengers (In) is fed after all passengers disembark. Once all passengers have exited the train, the standby process is carried out before door closing, departure, and subsequent generation of the departure output (Dep). When all passengers have disembarked, a signal that passenger boarding can initiate (Ready) is sent to the station, which then releases the passengers. Based on these system behaviors, we described the DEVS formalism as follows:

**CAtmMaglev = <S, X, Y, $\delta_{int}$, $\delta_{ext}$, λ, ta >**

X = {stop, in}

Y = {arr, dep, out, ready}

S = {DRIVING, OPEN, GETOFF, GETON, IDLE, CLOSE, STOP}

**$\delta_{ext}$ : Q x X → Q, Q = { (s,e) | s ∈ S and 0≤e≤ta(s) }**

$\delta_{ext}$ ((DRIVING, t), stop) = (STOP, 0)

$\delta_{ext}$ ((OPEN, t), stop) = (STOP, 0)

$\delta_{ext}$ ((GETOFF, t), stop) = (STOP, 0)

$\delta_{ext}$ ((GETON, t), stop) = (STOP, 0)

$\delta_{ext}$ ((IDLE, t), stop) = (STOP, 0)

$\delta_{ext}$ ((CLOSE, t), stop) = (STOP, 0)

$\delta_{ext}$ ((GETON, t), in) = (GETON, 0) (if not last passenger of station)

$\delta_{ext}$ ((GETON, t), in) = (IDLE, 0) (if last passenger of station)

**$\delta_{int}$ : Q → Q**

$\delta_{int}$ (DRIVING, Ts) = (DRIVING, 0) (Ts : time-step of updating continuous system)

$\delta_{int}$ (DRIVING, Ts) = (OPEN, 0) (if maglev arrived at a station)

$\delta_{int}$ (OPEN, Td) = (GETOFF, 0) (Td : door-operation time)

$\delta_{int}$ (GETOFF, Tf) = (GETOFF, 0) (Tf : get-off time of a passenger)

$\delta_{int}$ (GETOFF, Tf) = (GETON, 0) (if last passenger of maglev)

$\delta_{int}$ (IDLE, Ti) = (CLOSE, 0) (Ti : idle-time if dwell-time remained)

$\delta_{int}$ (CLOSE, Td) = (DRIVING, 0) (Td : door-operation time)

**λ : Q → Y**

λ (DRIVING, Ts) = arr (if arrived)

λ (GETOFF, Tf) = out (if passengers in maglev)

λ (GETOFF, Tf) = ready (if no more passengers in maglev)

λ (CLOSE, Td) = dep

**ta : S → R**

ta(S) = ∞, S={GETON, STOP}

ta(S) = Td, S={OPEN, CLOSE}

ta(GETOFF) = Tf

ta(IDLE) = Ti

In addition, an atomic model, CAtmStation, may be expressed as a typical queuing model, which involves the entrance of passengers and waiting condition on the station platform. In other words, the station acts as a buffer between a passenger generator and trains, and can be implemented by a FIFO(First In First Out) queuing model. When "Ready" input is received from the train, the station changes its state to passengers boarding (Board) from waiting condition (Wait), and subsequently generates boarding signal (Out). Once all passengers have boarded on the train, the station returns its state to waiting condition (Wait). The passenger entrance input (In) can be processed in both "Wait" and "Board" state. The DEVS formalism related to such boarding/alighting process in a station is described as follows:

**CAtmStation = <S, X, Y, $\delta_{int}$, $\delta_{ext}$, λ, ta >**

X = {in, ready}

Y = {out}

S = {WAIT, BOARD}

**$\delta_{ext}$ : Q x X → Q, Q = { (s,e) | s ∈ S and 0≤e≤ta(s) }**

$\delta_{ext}$ ((WAIT, t), in) = (WAIT, 0)

$\delta_{ext}$ ((WAIT, t), ready) = (BOARD, 0)

$\delta_{ext}$ ((BOARD, t), in) = (BOARD, 0) (continue existing internal transition)

**$\delta_{int}$ : Q → Q**

$\delta_{int}$ (BOARD, Tb) = (BOARD, 0) (Tb : boarding time of a passenger)

$\delta_{int}$ (BOARD, Tb) = (WAIT, 0) (if no more passengers in station)

**λ : Q → Y**

λ (BOARD, Tb) = out

**ta : S → R**

ta(WAIT) = ∞

ta(BOARD) = Tb

## 4 IMPLEMENTATION

We utilized the DEVSim++ simulation environment to implement a system modeled with DEVS formalism. The object-oriented programming language of C++, DEVSim++ is used to develop an implementation environment/engine that updates system information (i.e. state information) by order of event occurrence and carries out the simulation as a whole in line with the hierarchical scheduling algorithm. We also used Visual C++ 2008 as a compiler. Figure 4 shows the GUI of the simulation program implemented in this paper; the program presents a wide array of information—monitored in the analyzing interface with MFC—either in graphics or in text. Data are graphically expressed at the top of the display to help users intuitively identify changes to the maglev train operation and passenger boarding/alighting; the box on the left list displays messages and log information related to boarding/alighting simulation, and the box on the right list provides log information for the DEVSim++ engine. Also, a "Command" button was created to perform simulation control such as simulation ratio setting and simulation beginning and ending.

To generate traffic waves, we utilized daily average demand forecast data obtained from the maglev commercialization project. On the basis of time slots set by the level of crowdedness, we arrived at the loading rates, as indicated in Table 1, and calculated the passenger generation speed on this basis. The passenger generation speed is usually in line with a Poisson's distribution and the per-passenger generation time has an exponential distribution, and hence we applied the random process against this backdrop.

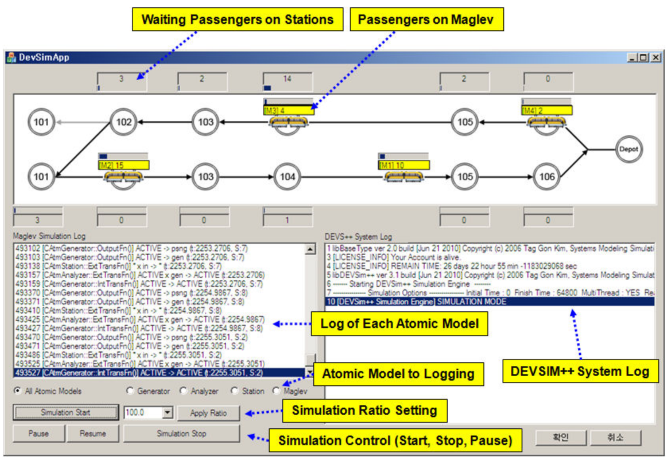


Figure 4. GUI of Simulation Program

| Station ID | On Quiet | | On Peak | | Normal |
|---|---|---|---|---|---|
| | Boarding Rate (person/day) | Gen Time (sec/person) | Boarding Rate (person/hour) | GenTime (sec/person) | GenTime (sec/person) |
| Down Line | | | | | |
| 101 | 11,906 | 5.44 | 1,869 | 1.92 | 3.68 |
| 102D | 2,940 | 22.04 | 462 | 7.79 | 14.91 |
| 103D | 1,914 | 33.85 | 300 | 12.00 | 22.92 |
| 104D | 644 | 100.62 | 101 | 35.64 | 68.13 |
| 105D | 423 | 153.19 | 66 | 54.54 | 103.86 |
| Up Line | | | | | |
| 106U | 1,461 | 44.35 | 229 | 15.72 | 30.03 |
| 105U | 1,492 | 43.43 | 234 | 15.38 | 29.40 |
| 104U | 8,953 | 7.23 | 1,406 | 2.56 | 4.89 |
| 103U | 1,557 | 41.61 | 244 | 14.75 | 28.18 |
| 102U | 3,866 | 16.76 | 607 | 5.93 | 11.34 |
| Sum | 35,156 | | 5,518 | | |

Table 1. Time-based Passenger Generation Rate

## 5 RESULT

In order to evaluate normal train operation and examine the service quality of the applicable line through a simulation considering a traffic wave, we measured the headway (i.e. the interval at which trains are operated), dwell time, and passenger standby time from the simulation results. The headway is calculated based on arrival/departure information by station and may be compared with the headway in the operation plan. Dwell time and passenger standby time may be adjusted by signal control when the number of passengers is too high or when the preceding train is delayed; they are compared with the original schedule in the operation plan to quantify inconveniences suffered by onboard passengers or standby passengers.

Simulation results show that headway stood at 5.45 minutes, constituting a slight delay relative to the time stated (i.e. 5 minutes) in the initial operation plan. This is presumably because the operation strategy specifies that the dwell time should be longer than the standard dwell time when there are many passengers and that the standard dwell time (20 seconds) must be observed when the number of passengers is small. Average dwell time was simulated at 25.6 seconds, as average passenger boarding/alighting time exceeded the average dwell time owing to the aforementioned operation strategy. Passenger standby time per station was estimated at 3.9 minutes on average, with southbound tracks having longer standby time than northbound ones overall. This is essentially because the 101 Station (Transportation Center where northbound and southbound tracks cross each other) involves considerable traffic demands and often experiences delays, as passengers for both northbound and southbound trains board/disembark at the same time.

## 6 CONCLUSION

This study developed a train operation simulation system to reflect the dynamic changes of passengers in the maglev transit system whose commercial application as a new means of transport is actively underway. We utilized the predesigned train operation plan and demand forecast data for each train station to suggest a discrete event-based modeling and simulation method for examining the train operation plan and strategy prior to actual train operation. We also implemented and tested the system using DEVS formalism and the DEVSim++ simulation environment to verify its feasibility and usability.

## 7 ACKNNOWLEDGEMENT

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