Development of a Simulator Based on Train Performance Simulation

Hyun-Kyu Jun[1], Dong-Hyung Lee[2] and Doh-Chul Yang[3]

[1]Korea Railroad Research Institute, hkjun@krri.re.kr
[2]Korea Railroad Research Institute, dhlee@krri.re.kr
[3]Korea Railroad Research Institute, dcyang@krri.re.kr

ABSTRACT

Virtual reality technology has been regarded as an useful tool owing to the visualization capability of objects even before they are manufactured or constructed. In this research, we developed a simulator for rubber-tired automated guide-way transit based on train performance simulation. Immersive driving scenery of the Korea rubber tired automated guide-way transit, called the K-AGT, was generated with 4 workstations, 3 PDPs and a head mounted display device with motion tracking system. By using the simulator, train performance characteristics of 3 urban transit systems, K-AGT, VAL208 and meglev system were analyzed to select the most appropriate system on the railway, which is scheduled to construct in Korea. The result showed that it could help a designer to have a more accurate design at an early stage of system development, and to understand their design intuitively. The simulator could help engineers who have various specialties to cooperate in distance area.

Keywords: Virtual Reality, Train Performance Simulation, Train Simulator, Urban Transit System

1. INTRODUCTION

Light rail transit system has been regarded as a proper transportation system for an urban transit system owing to the pollution-free, low construction and operation cost and low energy consumption rate, compared to the subway and bus transportation system. But it requires a lot of revenue to set up infrastructure. Generally, the light rail transit system is designed to operate automatically. Therefore time scheduling, operating condition controlling and security of safety in emergency condition to prevent from unexpected accidents, are considered as the most important things. Time scheduling depends on the radius of curves and gradients in railway, train performance, number of stations and distance between stations et al. And it can be calculated based on the results of train performance simulation. The train performance simulation can be performed manually or by the help of simulation software. But the simulation results can't fully represent the physical behavior of train operation because there always unknown variables exist. Therefore it needs to develop a method to design the train operating condition accurately before we apply the design to build a newly scheduled railway line.

Virtual prototyping in manufacturing and constructing is understood as the application of virtual reality for prototyping physical mock-up using product and process data. The VR system simulates and renders all characteristics as precisely and realistically as possible in an immersive environment. Initially, virtual prototyping technology has been applied in the field of manufacturing [1], but currently it is also understood as an important tool in the field of constructing [2].

Recently, in railroad industry, virtual reality technology has a great advance in designing, training and simulating fields. SNCF (French National Railway Company)[3] developed a simulator to study the evolution of driving rules need to take advantage of maximum speed limits allowed by the infrastructures. They made scenarios to simulate and determine the maximum cant deficiency and minimum length of speed transition. They realized ergonomic observations and recordings of driver's actions in TGV cabin during a dozen travels on conventional line based on the scenarios. With the simulator, they could find more optimal driving condition. Chung [4] developed a multi-discipline simulator to analyze the different technical disciplines, such as number of passenger at station and influence of dwell time variation at station on traveling time, at the same time. All trains are traveling on given scenario, as long as there are no interferences. But if there occurs malfunctions or accidents then train automatically recalculate their traveling schedule considering the distance from the precedence train. Through the simulator, they could analyze the behavior of train system while other disciplines are varying. Australia's state-rail [5] developed a secure, immersive virtual environment to make their driver to learn advanced accident avoidance procedure, intuitively. They built a simulator with 8 channel, 160-degree fields of view and 100dB sound system. With the simulator, they could train their drivers on various scenarios like that what driver had to do when he suddenly found a worker on the track or what an officer had to do when there occurred a fire accident et al. Even though the driver failed to stop train, no one injured.

We [5] have been researching on the development of an integrated system to support design work at the concept design stage. Because a train system is consisted of trains, railway, signals, stations et al., a design work of train system is very complicate. So we have been developed a system to support the design work at an early design stage. In this paper, we are going to introducing a development strategy of a simulator for rubber-tired automated guide-way transit based on train performance simulation. Immersive driving scenery of K-AGT was generated with 4 workstations, 3 PDPs and a head mounted display device with motion tracking system. By using the simulator, train performance characteristics of 3 urban transit systems, K-AGT, VAL208 and meglev system were analyzed on the railway, scheduled to construct in Korea. The result showed that it could help a designer to have relatively accurate design at an early stage, and to understand their design intuitively.

2. TRAIN PERFORMANCE SIMULATION

2.1 Theory

Derailment is one of critical train accidents that we want to avoid if possible. Because it can cause following accidents like a rollover or a rear-end collision. For this reason, there always have speed limits on railways. The speed limits on railway are determined as the conditions of railway (radius of curve, gradient, distance from stations or precedence train). It is highly recommended to drive slightly below, but never above the speed limits to fulfill the economic requirements, by doing powering, coasting and braking operation as shown in Fig. 1. For this reason, even though a train has high performance, it is difficult to expect high performance when we consider the railway conditions and number of stations to stop. Therefore it is highly recommended to find proper train performance to check the feasibility of train operation to prevent from over designing of train.

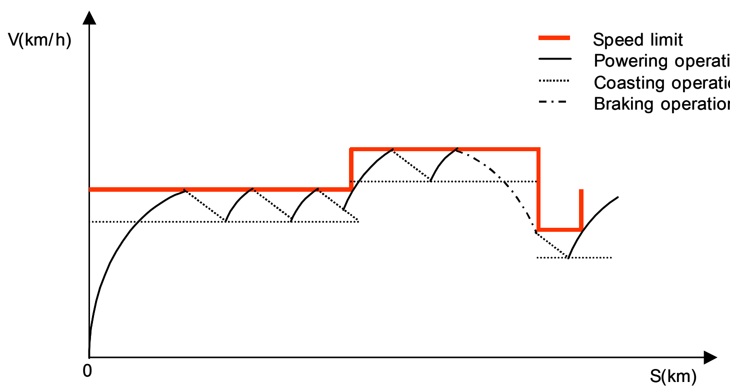


Fig. 1. Typical train operation curve.

Train performance characteristics could be calculated based on Newton's second law of motion as following.

$$m \cdot \alpha = T - (B + R) \tag{1}$$

where,

m=Mass of train-set
α =Acceleration
T=Traction force of train-set
B=Braking force of train-set
R=Total resistance force

From the relation between driving distance, S and velocity, v, equation (1) can be transformed as following.

$$\frac{W}{g} \cdot \frac{v_2^2 - v_1^2}{2S} = T - (B + R) \tag{2}$$

where,

W=Weight of train-set

g =The acceleration of gravity

Total resistance force is defined as the summation of train driving resistance, R_r, gradient resistance, R_g and curve resistance R_c.

$$R = R_r \pm R_g + R_c \tag{3}$$

where,

$R_r = 114W + (0.2 + 0.3n)v^2$

n = numbers of car per train-set

Fig. 2 shows the procedure for calculating the train operation curve. Tractive effort, $T_{m,}$ which is produced by the traction motor and braking effort, B, which is produced by braking unit, are inputted from train driver. According to the operation mode, the tractive effort or braking effort can be calculated from the characteristic curve, which is shown in Fig. 8. And total resistance force is calculated based on the railway condition. Acceleration and deceleration speed can be calculated from eqn. (1) or (2) and the velocity and driving speed at current step can be calculated. Then these results should be checked with the speed limits of railway and it should be checked whether the distance from the precedence train is enough to stop in an emergency condition. If the train velocity at step i is larger than the speed limit then it has to be recalculated after changing the tractive effort or braking effort until the condition is fulfilled.

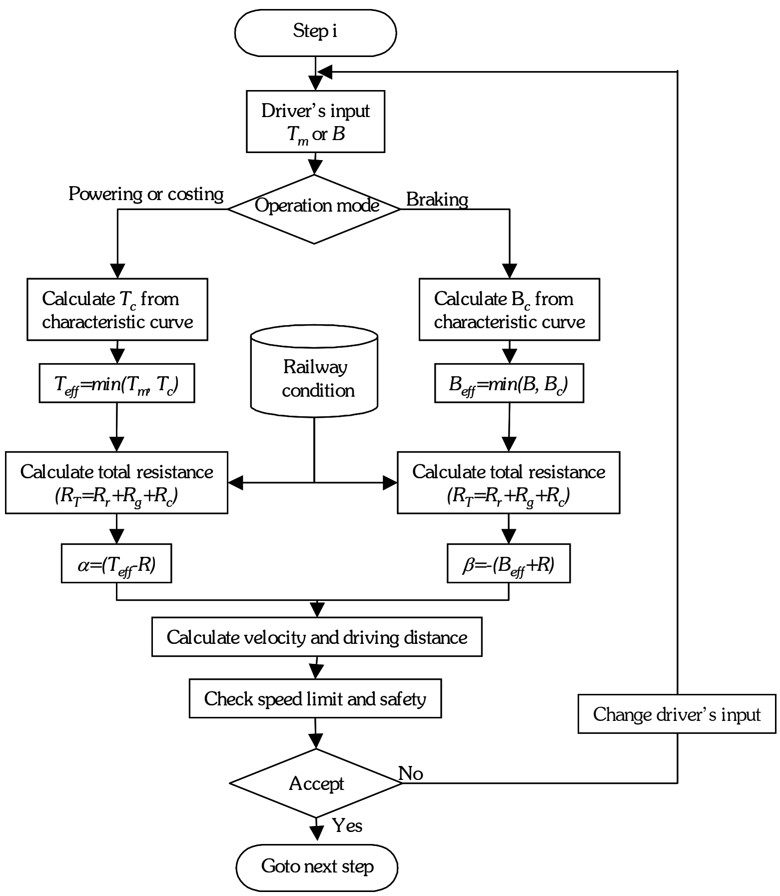


Fig. 2. Procedure for train performance simulation.

2.2 Train Operation Simulator

To validate the results from train performance simulation, a simulator applying virtual reality technology was developed as shown in Fig. 3. It is consisted of one main control computer, three image generation computers, a head mounted display device with a motion tracking device and three 42" PDPs. Train performance simulation is performed in main computer and simulation results of each train-set are sent to image generation computers. The image generation computers are consisted of one master and two slaves. The master loads the virtual reality geometry database and sends it to two slaves and synchronizes frames at every step, generated by the master and the slaves respectively. Although, three 42" PDP systems do not give fully immersive environment, they give 135° FOV(field of view) and it is enough to check the simulation results 2 or 3 persons together. An engineer, wearing the head mounted display with motion tracking device, which give stereoscopic and fully immersive vision, can check the interior or exterior of train and station. User can see what he wants by simply turning his neck, because the user interface is connected with the motion-tracking device. They are all connected with 100Mbps network cable to support corporation among engineers in distance area.

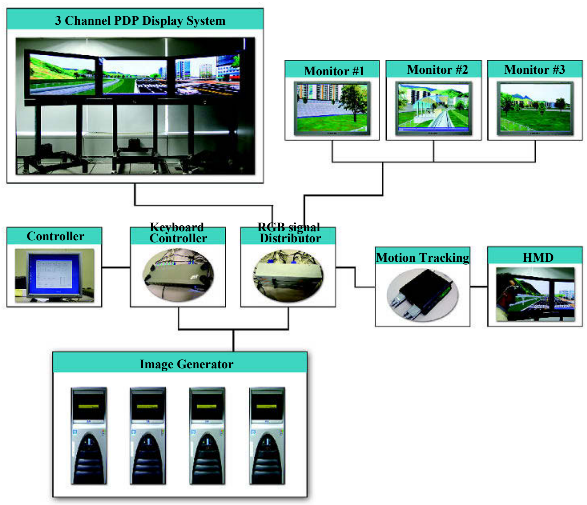


Fig. 3. Structure of the train performance simulator.

To visualize realistic urban environment, we built a virtual city using the 3D computer graphic technology. The virtual reality model database is consisted of an urban area, a railway, number of train-sets determined by user input, and 4 train stations. We built a virtual city in 2.5km×2.5km area and put roads, cars, buildings, sea, trees et al to generate realistic city visualization. And then we put a virtual railway to simulate train performance as shown in Fig. 4. It is consisted of 4 virtual stations, 1 tunnel and 1 downward and 1 upward gradients. Total length of virtual railway is 7.63 km and the distance from station A to B is 1.75 km, B to C is 2.21 km, C to D is 1.57 km and D to A is 2.09 km. There are two gradients in the line, one for 48.2 ‰ downward gradient between the station A and B, one for 20.2 ‰ upward gradient between the station C to D. Although, we could not fully model the scheduled line, because of the limit in computer power, we could verify the train performance simulation routine by comparing the simulation results with those of visualization in immersive driving environment.

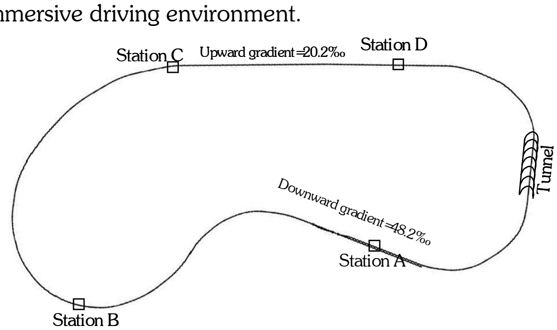
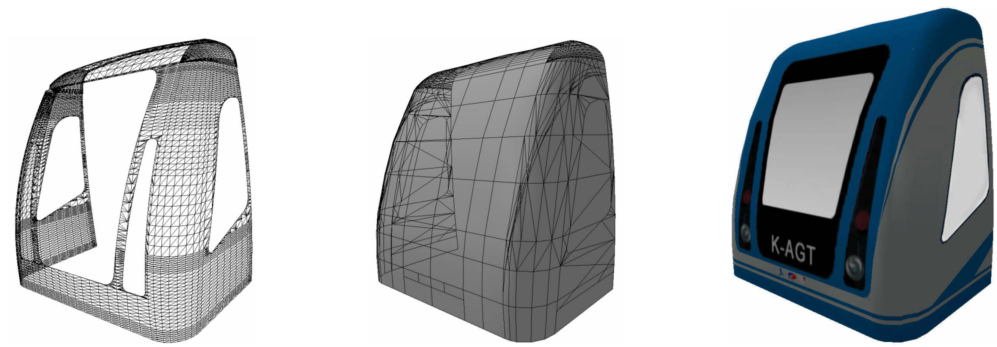


Fig. 4. Virtual railway for train performance simulation.

We built a virtual model of K-AGT based on the 3D CAD model. We could get a raw polygon model by converting 3D CAD model to neutral file format (IGES) directly, and reduced the number of polygons based on Okino's [6] algorithm until the number of polygons met the performance of the image generation computers. Fig. 5 shows the polygon model of driver's cab. Fig. 5(a) is the model directly converted from 3D CAD model, Fig. 5(b) is the optimized model and Fig. 5(c) is the rendered polygon model, mapped with true picture. The number of polygons of original model is 8771 and that of optimized model is only 1076, but it can still render the driver's cab of K-AGT, realistically.



(a) 3D CAD model (b) optimized polygon model (b) rendered polygon model

Fig. 5. Polygon optimization on the driver's cab of K-AGT.

Fig. 6 shows the driving scenery of K-AGT in the virtual city. It drives following the scenario, which is produced based on the results of train performance simulation. The train starts from station A and drives through station B, C and D and finally arrives at station A. The train stops at each station for 20 seconds, 5 seconds for door open, 10 seconds for passenger boarding, 5 seconds for door close. The numbers of passenger who are waiting at station could change the durations at each station. We can check directly the operation of a train-set and determine whether it operates properly following the schedules.

(a) Start from station A (b) Arrive at station B

Fig. 6. Driving scenery of K-AGT following the scenario.

Fig. 10 shows the picture that an engineer checks the design of K-AGT in front of simulator with wearing a head mounted display device. The engineer can control the direction of view by simply turning his neck. Motion tracking device automatically calculate location (x, y, z) and direction (heading, pitching, rolling) of eye point view and send the data to main computer. Then the main computer controls three image generation computers to generate the scene properly. By doing this, the engineer can evaluate the design just like that he rides a newly developing train even before it is built.

Fig. 7. Stereoscopic vision with wearing a head mounted display device.

3. PRACTICAL APPLICATIN

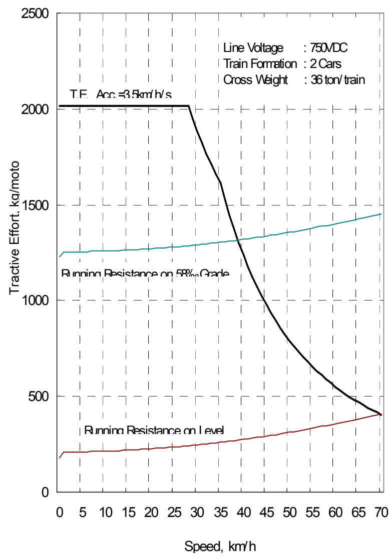
3.1 Simulation Conditions

By using the simulator developed in this research, we performed a train performance simulation to find a proper system on the railway, scheduled to construct in Korea. We evaluated scheduled speed, energy consumption rate and travel time of three urban transit systems. Scheduled speed is defined as the mean speed, which is divide the total travel distance into elapsed time from the first station to the last station. Energy consumption rate is defined as the ratio of energy used for traveling. Tab.1 shows the specifications of three urban transit systems, considered to evaluate in this research. The K-AGT is a rubber-tired train, designed by the maximum commercial operating speed of 60 km/h. It is medium sized transit, bigger than bus and smaller than subway. Its carrying capacity, 5,000~30,000 people per hour, is lower than that of subway system. Subway system generally carries 30,000~80,000 people per hour. The Val208 is the system, developed by Siemans. It is operated automatically with the maximum commercial operating speed of 70 km/h. The maglev system is a recently manufactured magnetic levitation train system by ROTEM, one of well-known train manufacturers in Korea. It is designed as an urban transit system with maximum commercial operating speed of 80 km/h. We supposed all train-sets were consisted of 2 controlling cars and they reached full carrying capacity. Because of the lack in information about the VAL208 system, we supposed the driving resistance force was the same as that of K-AGT and tractive effort increased proportionally as the increase of acceleration speed as shown in Fig. 8.

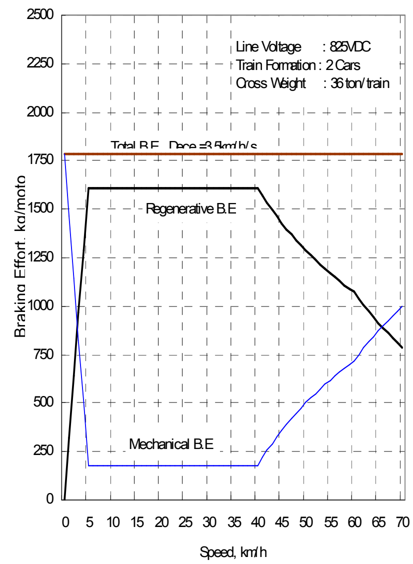
	K-AGT	VAL208	Maglev
Operation unit	2 units per train-set	2 units per train-set	2 units per train-set.
Mass of train-set	18 ton	23.5 ton	30 ton
Inertia factor	1.065	1.065	1.060
Maximum commercial operating speed	60 km/h	70 km/h	80 km/h
Acceleration speed	0.972 m/s^2	1.300 m/s^2	1.000 m/s^2
Deceleration speed	0.972 m/ s^2	0.650 m/ s^2	1.000 m/ s^2
Length of operation unit	19,280 mm	25,400 mm	27,500 mm
Driving resistance force	$114M+(0.2+0.3N)V^2$	-	$0.730V^2$

Tab. 1. Specification of urban transit systems.

Tractive effort and braking effort can be calculated from the characteristic curves, measured by physical train driving as shown in Fig. 8. Fig. 8(a) shows the characteristics of tractive effort of K-AGT. The vertical axis represents tractive effort produced by a traction motor and the horizontal axis represents driving speed. Tractive effort remains constantly at the range from 0 to around 30 km/h, but it drops rapidly as the driving speed increase at the range over 30 km/h. On the other hand, running resistance is slightly increased as driving speed increase. Fig. 2(b) shows the characteristics of braking effort of K-AGT. Braking effort is defined the summation of regenerative braking effort and mechanical braking effort. Regenerative braking effort means the resistance force from motor to generate electricity by using the inertia force of train.



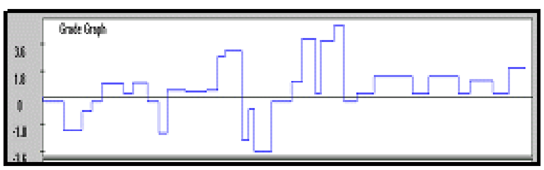
(a) Tractive effort vs. driving speed



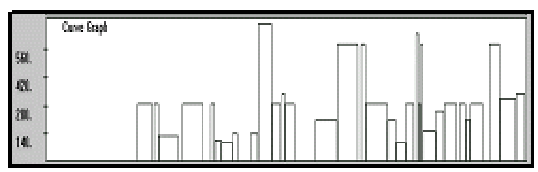
(b) Braking effort vs. driving speed

Fig. 8. Performance characteristic curves of K-AGT [7].

The railway line used for simulation in this research is consisted of gradients and curves as shown in Fig. 9. Mean distance between stations is 850m and total traveling distance is 12km and the numbers of station are 15. We suppose the dwell time as 20 seconds in each station. The simulation results could be different by the condition of railway because the train performance simulation depends on the railway conditions.



(a) Gradient condition



(b) Curve condition

Fig. 9. Railway condition used in the simulation.

The speed limits of K-AGT are as shown in Tab. 2. It decreases in proportion to the decrease in radius of curves. On the other hand, it increases in proportion to the decrease in downward gradient. Although, Tab. 2 is the speed limit for K-AGT, it is used to calculate the train performance characteristics of VAL208 and meglev system because of the lack in information.

		Speed limit (km/h)
Radius of curve (m)	Over 350	70
	250~350	60
	200~250	50
	150~200	40
	100~150	30
Downward gradient ($^0/_{00}$)	Below 20	70
	20~25	65
	25~30	60
	30~35	55

Tab. 2. The speed limits of K-AGT

To evaluate train performance characteristics according to the variation of distance between stations, we changed the mean distances between stations as 750m, 1,000m, 1,250m and 1,500m maintaining the total distance constant as 12km. Also, to evaluate train performance characteristics according to the variation of radius of curve, we changed the ratio of curve, below 250 m, as 0%, 20%, 40% and 50%, maintaining the distance between stations constant as 1,500m.

3.2 Simulation Results

The scheduled speeds of 3 urban transit systems were analyzed as shown in Fig. 10. The scheduled speeds of K-AGT, VAL208 and maglev system were calculated as 31.9 km/h, 32.0 km/h and 32.2 km/h, respectively. The traveling times of each system were calculated as 22.60 min, 22.55 min and 22.40 min, respectively. Even though the maximum commercial driving speeds of meglev and VAL208 are higher than that of K-AGT, the scheduled speed and total driving time are almost same. From the results, we can find the reason from the number of curves, which prevent from driving in maximum speed of train. Also the mean distance between stations is as short as 850 m. It means that we have to reduce the speed before it reached the maximum commercial operating speed.

The maglev system shows the highest energy consumption rate and the K-AGT shows the lowest energy consumption rate, which is only 66%, that of maglev system. From the simulation results, we can conclude that the scheduled speed and travel time does not depend on the train characteristics when it runs in a railway, which is consisted of many small curves. The scheduled speed increased linearly to the increase of mean distance among stations, as shown in Fig. 11. But the differences of three systems are small.

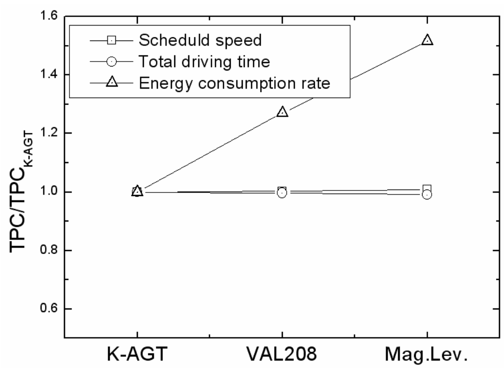


Fig. 10. Results of train simulation results.

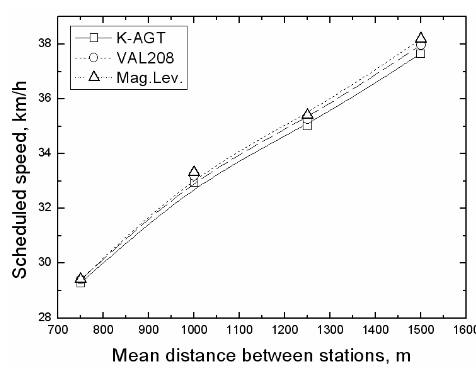


Fig. 11. Scheduled speed according to the variation of mean distance between stations.

The maglev system shows the highest scheduled speed in straight railway. And the difference are reduced as the ratio of curves below 250m increase. Generally, there are a lot of curves in urban railway because the railway for urban transit usually built after the city was constructed. Therefore, the number of curves below certain radius could be an important factor to select train performance.

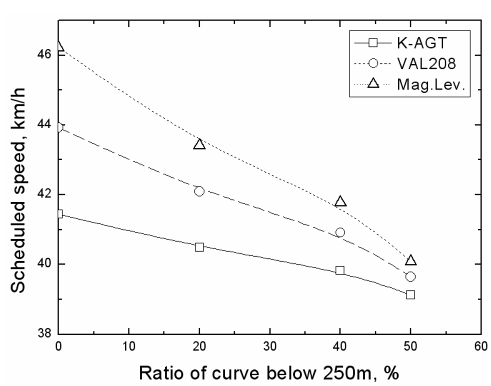


Fig. 12. Scheduled speed according to the variation of curve ratio.

We can conclude that the energy consumption rate of K-AGT is the lowest among three urban transit systems that are compared in this research, even though the scheduled speed and travel time are almost the same. Therefore, the K-AGT system is regarded as a proper transit system for the railway line. Based on the simulation results, we can conclude that the K-AGT system shows good advantage as an urban transit system on the railway, which is consisted of many small radiuses of curves.

4. CONCLUSION

In this paper, we introduced a development strategy of a simulator for rubber-tired automated guide-way transit based on train performance simulation. Immersive driving scenery of K-AGT, was generated with 4 workstations, 3 PDPs and a head mounted display device with motion tracking system. With the simulator, train performance characteristics of 3 urban transit systems, K-AGT, VAL208 and meglev system were analyzed on the railway, which is scheduled to construct in Korea. By using the simulator, it is possible an engineer to get a more accurate design at an early stage of system development, and to understand their design intuitively. Based on the simulation results, we can conclude that the K-AGT system shows good advantage as an urban transit system on the railway, which is consisted of many small radiuses of curves.

5. ACKNOWLEDGEMENT

This research was supported by the Korean Research Council of Korea Science and Technology (Development of virtual engineering technology for rolling stock) research program. We are grateful for the support.

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