

Featured Articles I

Daegu Urban Railway Line 3 Monorail System in South Korea —Overseas Project Satisfying Local Needs—

Nobuhiko Kimijima
Sang Jae Kim
Kazuya Furuta
Tomoyuki Sakatsume

OVERVIEW: Hitachi markets its monorail systems internationally by drawing on more than 50 years of experience with monorails in Japan, as well as with overseas projects. Daegu Urban Railway Line 3 is in South Korea, the fourth country outside Japan to which Hitachi has supplied monorails. It has made a concerted effort to include locally made products, reducing production costs by having the production-model rolling stock manufactured by a Korean company. Based on the lessons learned from a fire that occurred in a subway train in South Korea, improvements to fire-extinguishers on trains and to evacuation equipment were adopted to help dispel passenger concerns about riding in monorails, which run on elevated tracks.

INTRODUCTION

HITACHI has previously supplied monorail systems to three countries outside Japan. Each of these countries had different regulations, standards, and system scopes, so Hitachi built and supplied these systems in accordance with their needs and the

respective regulations and standards, taking account of customer requirements and local circumstances as much as possible.

The monorail for Daegu Urban Railway Line 3 (hereafter Line 3) is in Daegu Metropolitan City in South Korea, making it the fourth country outside Japan to which Hitachi has supplied a monorail (see Fig. 1).

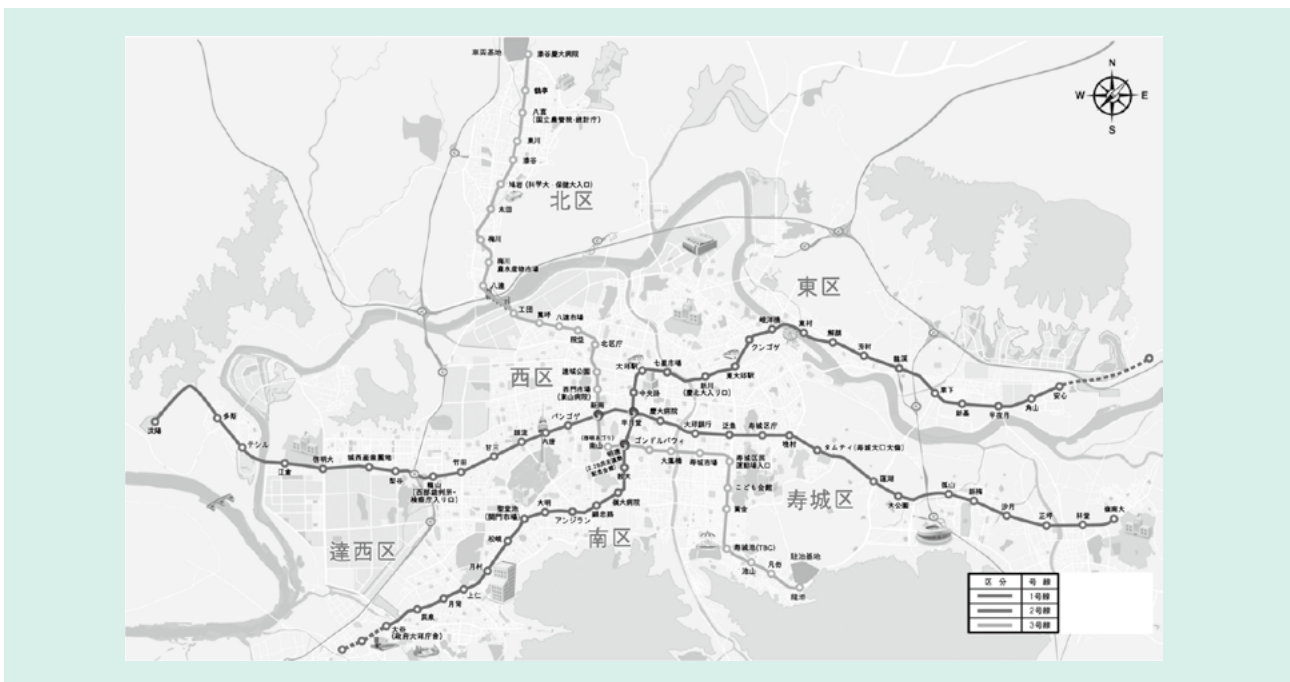


Fig. 1—Route Map of Daegu Urban Railway.

Lines 1 to 3 link major districts and provide comfortable transportation around the city.

TABLE 1. Overview of Daegu Urban Railway Lines
The existing Lines 1 and 2 are subways (including some above-ground track).

	Line 1	Line 2	Line 3
Length (of commercial service)	25.9 km (double track)	31.4 km (double track)	23.1 km (double track)
No. of stations	30	29	30
Type	Subway	Subway	Saddle monorail
Trainset configuration	6 cars	6 cars	3 cars
Operation	Automatic	Automatic	Automatic
Driver	Required	Required	Not-Required
Opened	1997	2005	2015

This article gives an overview of Line 3 and the products supplied for it, and describes Hitachi's strategy for future monorail systems for overseas.

OVERVIEW OF DAEGU URBAN RAILWAY LINE 3

Daegu is a city of about 2.5 million people (as of August 2016) located in the southeastern part of South Korea. Daegu Metropolitan Transit Corporation, the city's metro operator, has three lines in total, including the newly opened Line 3 (see Table 1).

Line 1, running from the northeast to the southwest of the city, opened in 1997, and Line 2, running from

TABLE 2. Rolling Stock Specifications

The rolling stock are saddle monorail vehicles with a rail width of 850 mm and a maximum axle load of 11 t, and are of a type that Hitachi has previously supplied for numerous lines both in Japan and elsewhere.

Item	Specification	
Vehicle type	Straddled monorail	
Trainset configuration	3-car (fixed) (Mc1-M-Mc2)	
Rated passenger capacity	265 (Mc1: 84, M: 97, Mc2: 84)	
Electrical system	DC 1,500 V	
Track beam width	850 mm	
Axle load	11 t (max.)	
Max. speed	70 km/h (max. operating speed)	
Acceleration/ deceleration	Acceleration	0.97 m/s ² (3.5 km/h/s)
	Deceleration (max. in normal operation)	1.11 m/s ² (4.0 km/h/s)
	Deceleration (emergency)	1.25 m/s ² (4.5 km/h/s)
Brake control	Electrically operated electro-pneumatic straight air brakes (regenerative braking prioritized, disk brakes with pneumatic/hydraulic conversion)	
Traction circuit control	2-level IGBT VVVF inverter	
Signalling system	Digital ATP (equivalent to digital ATC in Japan)	
Operation	ATO driverless system (onboard conductor)	

Mc: motor car with cab M: motor car DC: direct current
IGBT: insulated-gate bipolar transistor VVVF: variable voltage variable frequency
ATP: automatic train protection ATC: automatic train control
ATO: automatic train operation

east to west, opened in 2005, both as subway lines. Subsequently, there were calls from the public and

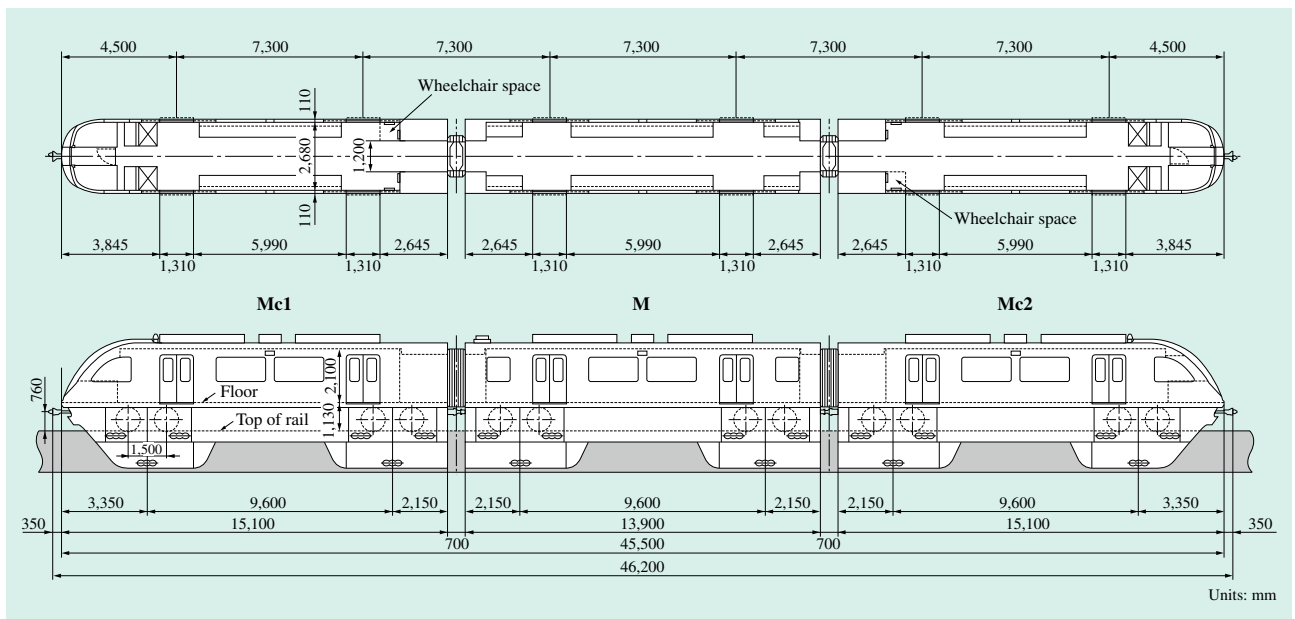


Fig. 2—Rolling Stock Dimensions.

The trainsets have a fixed three-car configuration and are 46.2 m long (including the front-end coupling). Because operation is fully automatic, the cars do not have a driver's cabin and the front-end includes viewing seats that allow passengers to enjoy the view through the windows.



Fig. 3—Monorail Cars.

A number of designs were proposed for the rolling stock under the supervision of a professor of design at Kyungpook National University in Daegu, and the final choice was made by a vote of city residents.



Fig. 4—Passenger Compartment.

The layout is based on the use of longitudinal seats. The large side windows give the compartments an airy feel.

businesses for the construction of rail-based public transportation in the northwest and southeast areas of the city, which were not served by the metro.

This led to the decision in 2007 to construct Line 3, which was to run for 23.9 km (23.1 km of which was used for services) between the northwest and southeast of the city. The decision to make the line a saddle monorail was made in 2008, and it was further decided to use a Japanese design that was already used by a number of urban transportation services. Hitachi supplied the core products and systems used by the Line 3 monorail, namely, the rolling stock, track switches, and signalling systems. The line opened in April 2015.

FEATURES OF THE ROLLING STOCK SYSTEM

The rolling stock for Line 3 are straddled monorail vehicles with a track beam width of 850 mm and maximum axle load of 11 t, and are of a type that Hitachi has previously supplied to numerous lines both in Japan and elsewhere (see Table 2).

The project involves the supply of 28 trainsets (84 vehicles) in total, with a three-car trainset configuration (see Fig. 2). The following sections describe the specific rolling stock equipment and functions supplied for Line 3, and other noteworthy aspects (see Fig. 3 and 4).

Collaboration with Local Rolling Stock Manufacturer

Rather than build all of the trainsets for Line 3 in Japan, only the prototypes were built at Hitachi's

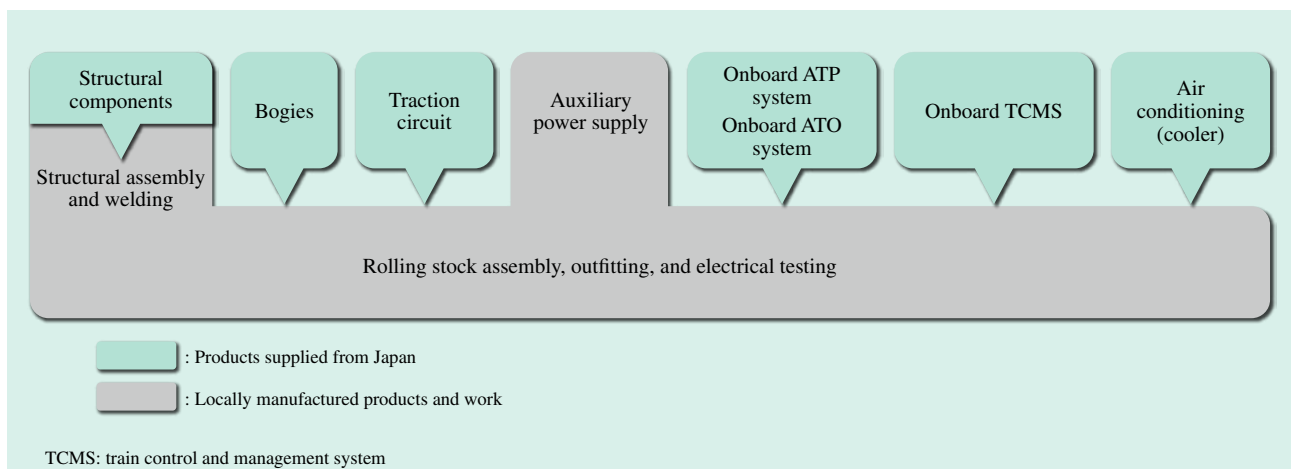


Fig. 5—Division of Responsibilities for Manufacturing Production-model Trainsets.

The production-model trainsets were built using a knock-down assembly model whereby structural components and key equipment were exported from Japan to South Korea and the rolling stock was assembled at a local rolling stock manufacturer.

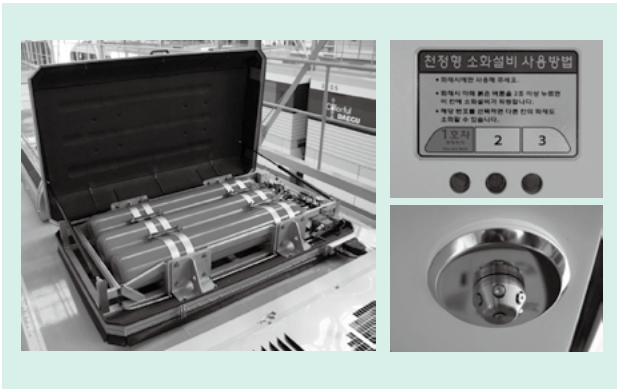


Fig. 6—Onboard Fire-extinguishing Equipment. Water and compressed air tanks are located on the roof (left). When smoke is detected by the smoke detectors in the ceiling ducts, or the manual alarm (top right) is pressed in the passenger compartment, compressed air causes water to be sprayed out at high pressure from seven nozzles in the ceiling (bottom right).

Kasado Works, and the production-model trainsets (numbers 2 to 28) were built by Woojin Industrial Systems, a local rolling stock manufacturer, with key machinery and components being supplied from Japan (see Fig. 5).

Fire-extinguishing Equipment

Learning from the experience of a major subway train fire that happened at the Jungangno Station on Daegu Urban Railway Line 1 in 2003, rolling stock

for Line 3 will be fitted with not only conventional portable fire extinguishers but also a fire-extinguishing system with highly pressurized water that sprays a mist through ceiling nozzles to ensure that any fire is quickly extinguished (see Fig. 6).

Moreover, because the fire-extinguishing system uses ordinary tap water without any special additives and is pressurized by compressed air, it poses no risk to people or the surrounding environment.

Passenger Evacuation Systems

To enable passengers to evacuate the monorail vehicles safely and speedily in an emergency, two passenger evacuation systems are located behind the viewing seats in the front and rear cars (four systems in total) (see Fig. 7).

The systems were developed jointly by Tokyo Monorail Co., Ltd. and Hitachi and feature spiral chutes. The spiral design of the chutes limits the speed at which passengers descend to 3 m/s or less, ensuring that they can reach the ground safely.

Snowfall Countermeasures

Because of the high likelihood of snowfall in Daegu during winter, Hitachi supplied snow brushes that can be fitted to front-end cars to prevent the build-up of snow on the rail. Furthermore, some trainsets have been additionally fitted with piping that can be used to apply a thawing agent to the running surfaces of the rails to prevent them from icing up during cold or snowy weather.

This is the first time that Daegu Metropolitan Transit Corporation will operate a monorail that runs on elevated rails for its entire length. Accordingly, to enable it to deal appropriately with snowy conditions, operational and other measures based on how this is handled in Japan have been collated into an operating manual.

Compliance with South Korea Regulations and Standards

Article 36 of South Korea’s railroad safety act and its associated ordinances, along with the country’s standards for performance testing of urban rolling stock, include detailed stipulations for the production inspections and performance tests to be carried out when rolling stock are manufactured (see Table 3).

The inspections and tests must be attended by inspection and testing staff from government-designated agencies, who bear witness that these criteria have been met.



Fig. 7—Passenger Evacuation Equipment. Spiral chutes are located in boxes (top left) behind the viewing seats in the front and rear cars, and are used by opening the lid of the box, taking off the cover, and removing them (bottom left). The frame is fixed to a side door and the chute is lowered to the ground (right) to allow passengers to evacuate the train.

TABLE 3. Inspections and Tests Required for Rolling Stock in South Korea

Before rolling stock is allowed to be tested on the actual line, it must first undergo unit testing of materials, parts, equipment, and key components, testing of the completed vehicle, and then preliminary on-track testing to confirm that the rolling stock is ready to run on the actual line without problems.

Inspection / Test		Description	Inspector
Production inspection	Delivery inspection	Inspection of the materials, visual appearance, and functions of designated parts and equipment in the rolling stock (78 checks)	ROTECO
	Process inspection	Inspection of visual appearance and functions at each process, including carbody production, bogie production, painting, outfitting, piping, and wiring	
Performance testing	Component testing	Individual testing of the visual appearance, functions, and performance of key components (carbodies, bogies, traction circuit, auxiliary power supply, signalling system, and TCMS)	KRRI
	Completed vehicle testing	Testing of functions and performance of completed rolling stock at the factory (Kasado Works for trainset 1 and Woojin Industrial Systems for trainsets 2 to 28), including both static testing and on-track testing at the maximum speed possible at the factory (up to 15 km/h) Note: Some tests are conducted at the depot or on the actual line	
	Preliminary on-track testing	Testing to confirm that rolling stock that has passed completed vehicle testing is ready to run without problems on the actual track Run trainsets 1 (the prototype) and 2 (first trainset built by Woojin Industrial Systems) for 5,000 km, and trainsets 3 to 28 for 1,000 km	
	Testing on actual track	Testing for final confirmation of function and performance by running rolling stock on the actual track	

ROTECO: Korea Rolling Stock Technical Corporation KRRI: Korea Railroad Research Institute

To satisfy these requirements, Hitachi established systems and processes for inspection and testing from an early stage in the project. Hitachi succeeded in passing all inspections and tests and delivered the rolling stock

without causing any delays by immediately revising its processes and substituting different procedures whenever there was a risk of exceeding the scheduled number of inspection and testing days.

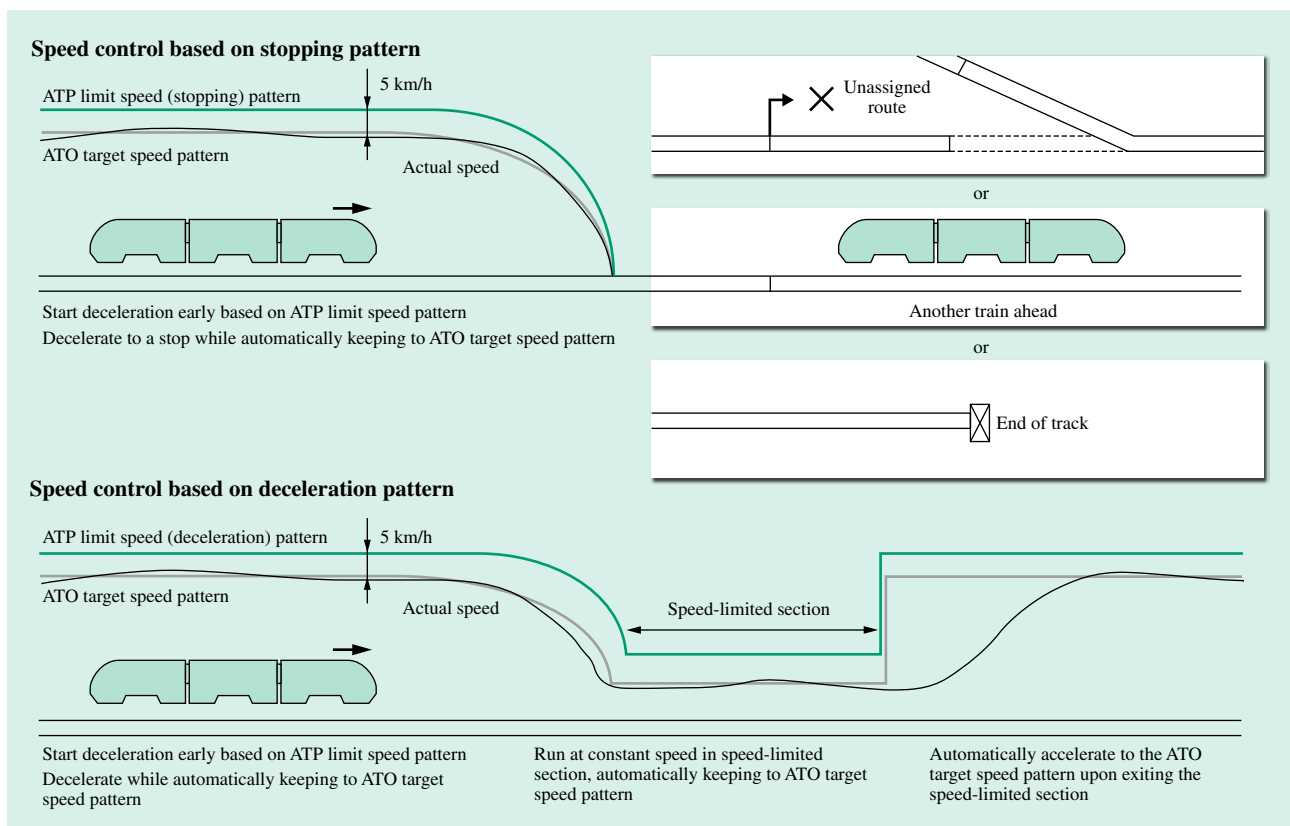


Fig. 8—Vehicle Speed Control by Digital ATP and ATO System.

The use of digital communications enables high-volume, bi-directional transmission of data between the onboard and wayside systems to achieve precise automatic operation while also reliably maintaining train safety.

FEATURES OF THE SIGNALLING SYSTEM

Signalling System with Digital Communications

Line 3 uses digital automatic train protection (ATP) [equivalent to the digital automatic train control (ATC) used in Japan], whereby digital communications are used to exchange control signals between onboard and wayside systems.

Digital ATP is based on the onboard system. That is, it prevents the train from advancing past the end of the track, or entering sections of track that are occupied by another train or have been blocked, by having the onboard system generate a stopping pattern based on information about its own location and information about where to stop, which is sent from the wayside system. Furthermore, in the case of sections of track with speed limits, such as curves or gradients, it keeps the train speed within the limits by providing the onboard system with a deceleration pattern prior to entering the speed-limited section. Meanwhile, the digital ATP system also interoperates with the automatic train operation (ATO) system to maintain smooth automatic operation (see Fig. 8).

Traffic Management System Capable of Fully Automatic Operation

Line 3 operates fully automatically without any need for driver intervention (see Fig. 9). A traffic management system has been adopted that is able to control operation automatically based on the train diagrams (operating schedules), including the trip to and from the depot storage track as well as on the line itself.

Information about the trains on the line and video from the train surveillance cameras (showing each car interior and the view from the front and rear cars) are sent to the control room in realtime to provide the controllers (control center staff) with up-to-date train information.

Track Switches

Track switches that have demonstrated their reliability in Japan and elsewhere were adopted for the Line 3 monorail, both on the line and in the depot (see Table 4).

To deal with weather conditions in Daegu, anti-icing heaters are installed in the lock grooves and control panel and operate when the temperature falls below a specified level to prevent operational disruptions caused by the icing up due to snowfall or low temperatures in winter.

FUTURE PROJECTS OUTSIDE JAPAN

Hitachi intends to undertake the following three development projects or organizational enhancements with the aim of utilizing past work and experience to supply further monorail systems outside Japan.

(1) Lightweight rolling stock

Making rolling stock lighter simplifies civil engineering structures because it reduces the load on the supporting rails, including in the case of monorails. Lightweight rolling stock also brings significant system-wide benefits, including requiring less energy to propel the rolling stock. Accordingly, Hitachi is engaged in ongoing work aimed at reducing weight, including that of monorail rolling stock, by

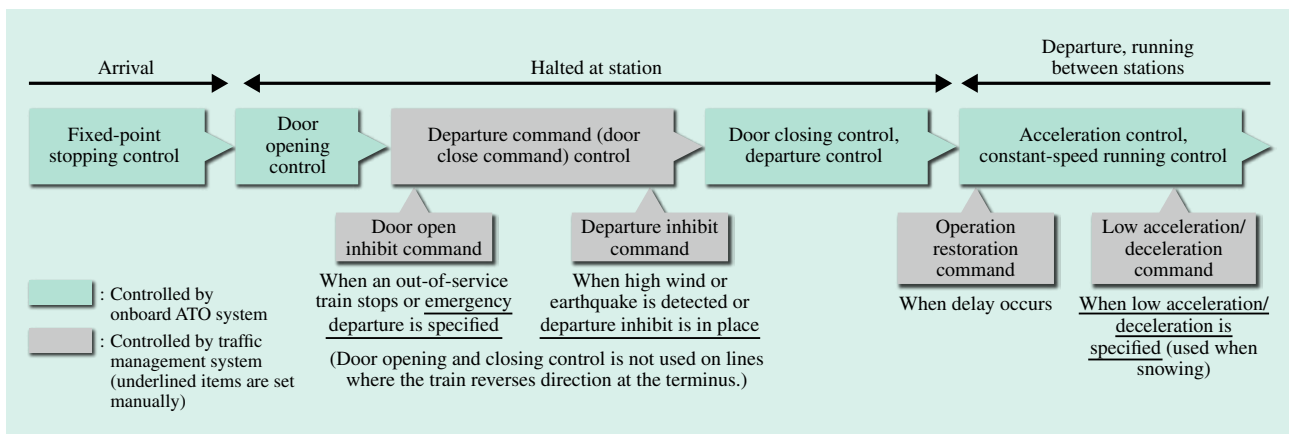


Fig. 9—Flowchart of Automatic Operation.

The system operates the trains on the line without any manual intervention, based on train diagrams (operating schedules) specified in advance. As well as on the line itself, trips to and from the depot storage track are also handled automatically, based on train diagrams.

TABLE 4. List of Track Switches

Flexible-type track switches are used in locations where there is a need to increase the opposite side passing speed (curved passing side).

Location	Track switch type and number	Purpose
Depot	5 × 5-point track switch 1 × 2-point track switch (jointed)	Depot entry and exit, reversing direction
Line (Chilgok Kyungpook National University Medical Center Station)	1 × cross over track switch (flexible)	Reversing direction at terminus
Line (between Buk-gu Office and Dalseong Park Stations)	1 × cross over track switch (jointed)	Emergency direction reversing
Line (Yongji Station)	1 × cross over track switch (flexible)	Reversing direction at terminus
	1 × 2-point track switch (flexible)	Depot entry and exit
Storage depot	1 × 5-point track switch	Depot entry and exit, reversing direction

Flexible: The sides of the track switch (guide plate and stability plate) are curved (maximum passing speed on opposite side: 25 km/h)

Jointed: The sides of the track switch (guide plate and stability plate) are not curved (maximum passing speed on opposite side: 15 km/h).

simplifying equipment and revising its designs and installation practices. Particularly in the case of bogies and drive units that have designs specific to straddled monorails, Hitachi has been working on new development projects aimed at simplifying designs and reducing their weight. Because making designs simpler also makes maintenance easier, Hitachi is taking steps to achieve this soon by conducting performance assessments on prototypes.

(2) Work toward adopting communications-based train control (CBTC) systems in wayside signalling equipment

Some overseas monorails are equipped with CBTC, which uses wireless communications for detecting train locations and transmitting rolling stock control information. CBTC has many benefits because it reduces on-site installation work by eliminating the need to install equipment in the field (such as loop coil cables and impedance matching circuits), as well as achieving shorter intervals between trains through the control of movement interlocks. Hitachi intends to work toward adopting it as its standard signalling system on monorail systems outside Japan.

(3) Strengthening of collaboration with Ansaldo STS

Hitachi intends to improve its project management, system integration, and other system-wide coordination capabilities by strengthening its collaboration with Ansaldo STS S.p.A., an Italian railway engineering

company that has become part of Hitachi, to make the most of the experience of both companies.

CONCLUSIONS

As the first commuter monorail system in South Korea, Line 3 has attracted attention from national and local government as well as from companies. The line has been well received both by those living along the line and by visitors to Daegu. It has also generated significant synergies, with businesses and tourist attractions along the line enjoying growing patronage as the number of people using Line 3 has increased.

In the future, rather than marketing monorail systems on their own, Hitachi intends to offer more advanced solutions that incorporate the needs of the customer and local circumstances.

ACKNOWLEDGMENTS

In closing, the authors would like to express their gratitude for the considerable support provided by Japanese monorail operators during overseas projects.

REFERENCES

- (1) Y. Kim et al., "Overview of Monorail System for South Korea/ Daegu Urban Railway Line 3," *Monorail* **122** (May 2012) in Japanese.
- (2) K. Akiyama, "Opening of South Korea/Daegu Urban Railway Line 3 (Nickname: Sky Rail PSC) Presentation of Track Beam and Main Structure," *Monorail* **128** (May 2015) in Japanese.
- (3) Y. Ahn, "Opening of Daegu Urban Railway Line 3 Monorail," *Monorail* **129** (Dec. 2015) in Japanese.
- (4) R. Cho, "Quality Certification of South Korea's Daegu Urban Railway Line 3," *Monorail* **129** (Dec. 2015) in Japanese.
- (5) N. Kimijima et al., "Monorail Rolling Stock for South Korea's Daegu Urban Railway Line 3," *Rolling Stock Technology* **247**, pp. 124–141 (Mar. 2014) in Japanese.
- (6) T. Ohmi et al., "Development of Monorail Rolling Stock Signaling System for Daegu Urban Railway Line 3," *Proceedings of 52nd Symposium of Congress of Japan Railway Cybernetics*, (Nov. 2015) in Japanese.
- (7) Daegu Metropolitan Transit Corporation, <http://www.dtro.or.kr/>

ABOUT THE AUTHORS



Nobuhiko Kimijima

Rail Project Engineering Department, Railway Systems Business Unit, Hitachi, Ltd. He is currently engaged in the engineering and assembling of monorail systems. Mr. Kimijima is a member of The Japan Society of Mechanical Engineers (JSME).



Sang-Jae Kim

Rail Project Department, Daegu Branch, Hitachi Korea, Ltd. He is currently engaged in the engineering and assembly of monorail systems.



Kazuya Furuta

Rolling Stock Systems, Design Department, Kasado Rail Systems Product Division, Railway Systems Business Unit, Hitachi, Ltd. He is currently engaged in the design of bogies for monorail rolling stock.



Tomoyuki Sakatsume

Signaling Systems Design Department, Mito Rail Systems Product Division, Railway Systems Business Unit, Hitachi, Ltd. He is currently engaged in engineering related to wayside equipment for overseas urban traffic signalling systems.