



# Automated People Mover "Crystal Mover" for Singapore Changi International Airport

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*Mitsubishi Heavy Industries, Ltd. (MHI) received an order for its Crystal Mover for Changi International Airport of the Civil Aviation Authority of Singapore (CAAS), to serve as the transportation system connecting its terminals where the newly constructed Terminal 3 is a symbol of the New Singapore Changi Airport. The new transportation system is characterized by its innovative and futuristic vehicle design, by a unique design for connecting to a new guideway through the retrofitting of the structure of the existing system, and by realization of the request for a seamless transition service from the existing system to the new system, thus providing a complete system which connects all the terminals, Terminals 1 to 3. This paper reports on the new Crystal Mover and its construction process.*

## 1. Introduction

During recent years in South East Asia and East Asia, new airports have been established and existing airports have been expanded. These include, for example, Bangkok New Airport and Chubu (Nagoya) Airport. The economic development of these regions has enhanced their network with Asian countries and also with Europe, Oceania and North America. These airports continue to grow through the expansion of their existing functions or the addition of new functions, and are more comfortable and convenient air transit hubs. They are also regional bases for efficiently connecting active traffic in Asian countries.

In 2002, the Civil Aviation Authority of Singapore (CAAS) planned to expand its airport function by constructing Terminal 3, and they selected MHI's Crystal Mover as the transportation system between terminals. CAAS requested at the time of adoption that the new system should feature innovative vehicle design, retrofitting the structures of the existing system which has been in revenue service since 1990, and a seamless transition to the new system, which MHI has endeavored to do. Concerning the transition from the existing system to the new one, the construction started with the retrofitting of a part of the existing system for the Interim Operation which was then followed by further expansion to Terminal 3 for the Overall Operation. This undertaking was the first experience of its type for MHI. The "interim revenue service" section was started on March 16, 2006, and entered commercial operation. The entire system is now in the process of test runs preparatory for the expansion and handover of the complete system in June 2007.

## 2. Automated People Mover (APM) System Configuration

The Singapore Changi International Airport APM System consists of 6,400 m of single-lane track. This includes about 1,300 m of the retrofitted existing system. The system configuration is composed of two independent guideway segments, PMS/North (4,100 m in total length) and PMS/South (2,300 m in total length), each having an independent maintenance area. The PMS/South provides services between Terminal 2 and Terminal 3, Terminal 3 main building and South Pier for transit passengers moving between the terminals and passengers after immigration clearance. The PMS/North provides services between Terminal 1, Terminal 2, and Terminal 3 for public passengers. This system also links up the different airport public transport facilities, taxi stands, subways and car parks, allowing more convenient access to the city.

This system consists of seven stations (A-South, A, B, C, D, E, and F), each giving the name of the nearest boarding gate for easy recognition for passengers (**Figs. 1 and 2**).

The APM Main Operation Control Center is located inside the maintenance office near A-South Station and the Standby Satellite Control Center is located in the center of the Terminal 3 building. Either of the control centers can be used to control the entire system (**Fig. 3**).

In the contract of this project, MHI supplies the concrete running plinths, guideways, station equipment, power distribution system, signaling system, communication system, maintenance facilities, and designing, manufacturing, installing and testing and commissioning of the vehicles.

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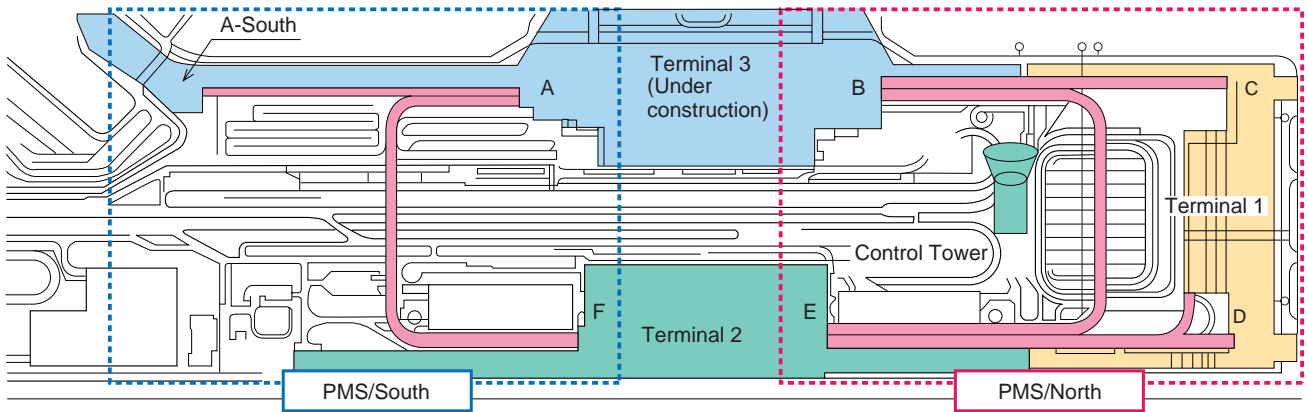


Fig. 1 Overall layout of airport



Fig. 2 APM platform



Fig. 4 Original Crystal Mover and rendering image for Changi Airport



Fig. 3 Main operation control center

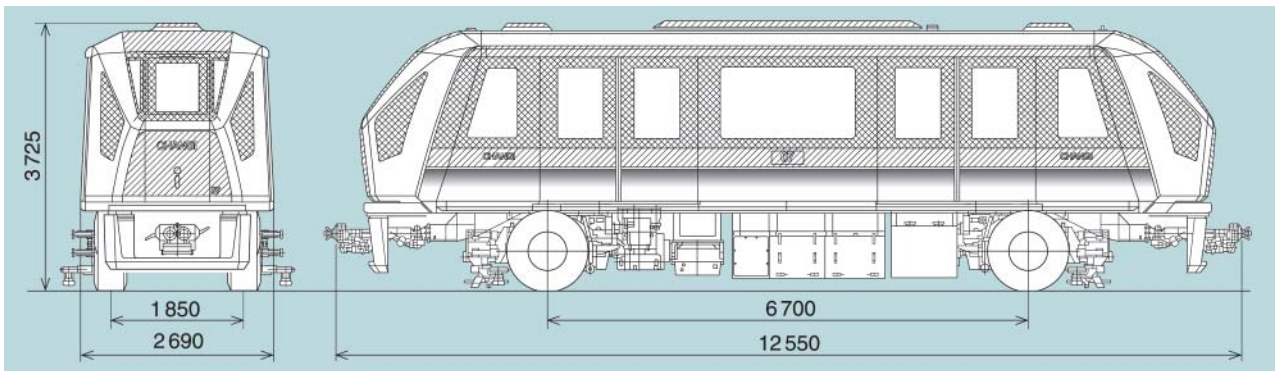


Fig. 5 Vehicle configuration



### 3. Crystal Mover vehicles

MHI has delivered 16 Crystal Mover vehicles to Singapore Changi Airport, ten of which are allocated to PMS/North and six to PMS/South. Five different designs with innovative external face images derived from the original Crystal Mover design were proposed to the client, who finally selected the vehicle model shown in **Fig. 4**. MHI has developed the vehicle shown in **Figs. 5, 6, and 7** through a design process focused on faithfully realizing the innovative and leading-edge rendering of the original design. This vehicle was awarded the Good Design Award 2006, instituted by the Ministry of Economy, Trade and Industry of Japan since 1957.

MHI can flexibly respond to a variety of operations, from a one car operation to multiple coupled-car operations, depending upon the system requirements. Actually, a two coupled-car operation is in operation between Terminals 1 and 2, with the intention of expanding it to a three coupled-car operation in the future.

### 4. Signaling/communication systems

#### 4.1 Signaling system

In the Changi Airport APM system, the signaling sys-



Fig. 6 Vehicle for Changi Airport



Fig. 7 Vehicle interior

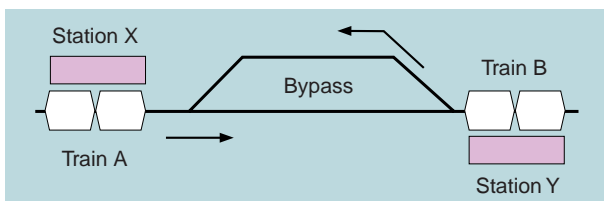


Fig. 9 Bypass shuttle

tem complies with the Signaling and Safety Standard, while the automatic operation system complies with the standards of the Urban Transportation System, utilizing a train detection system based on the check-in/check-out principle and the well proven automatic train control system.

In this APM system, as the overrun protection distance from the stopping position for the vehicle to the track end is short due to architectural restrictions, the system adopted an ORP (overrun protection system) by on-board ATP (automatic train protection) (**Fig. 8**). When a train enters the ORP signal aspect section, the on-board ATP device creates the ORP control pattern in a manner which protects the fixed-point stop control pattern by the on-board ATO (automatic train operation) device. If the train speed overshoots the ORP control pattern, the emergency brake is activated, safely bringing the train to an emergency stop.

#### 4.2 Operation control system

As the line currently in commercial operation is used to supply and withdraw vehicles, this must be taken into account when marshaling vehicles and operation becomes more complicated. To realize efficient operability, a programmed route control based on selection of the start and end points has reduced the operators' burden.

Another characteristic feature regarding the operation of this system is the by-pass operation used between Terminals 2 and 3 as shown in **Figs. 9 and 10**, where trains are placed under synchronous control so that they

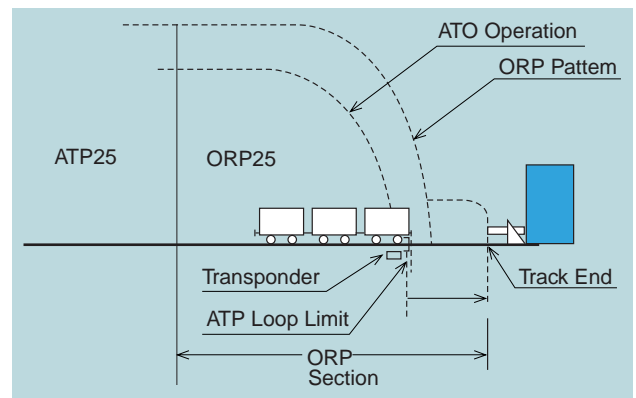


Fig. 8 Overrun protection system



Fig. 10 Bypass shuttle (photo)

depart and arrive at each corresponding station at the same time. Specifically, the station departing times are synchronized by the count of the station dwell time which is automatically adjusted based on the stoppage state at the station. Also, the train speed is adjusted by ATO which recognizes signals which are sent from the way-side control devices to the on-board control device at the time of departure from a station so that the crossing times in the bypass section are optimized and their arrival times are synchronized.

### 4.3 Communication system

A radio space wave system using three channels (voice, voice control and data transmission) on the 400 MHz frequency band in accordance with application and approval

has been adopted for voice communication and data transmission between vehicles and control which are especially important for train operation. The PMS North area and the PMS South area each have two antennas to cover the entire area. By using the 2.4 GHz band for the on-board CCTV system for on-board supervision (Fig. 11) and the 5.2 GHz band for the on-board information display system, flight information, advertisements etc. (Fig. 12), the radio communication system sends and receives image data and information data between vehicles and control. For transmission of critical control data, an optical fibre transmission device equipped with the redundancy configuration of an optical transmission line is located at each station, helping ensure reliability.



Fig. 11 On-board CCTV camera



Fig. 12 Flight information

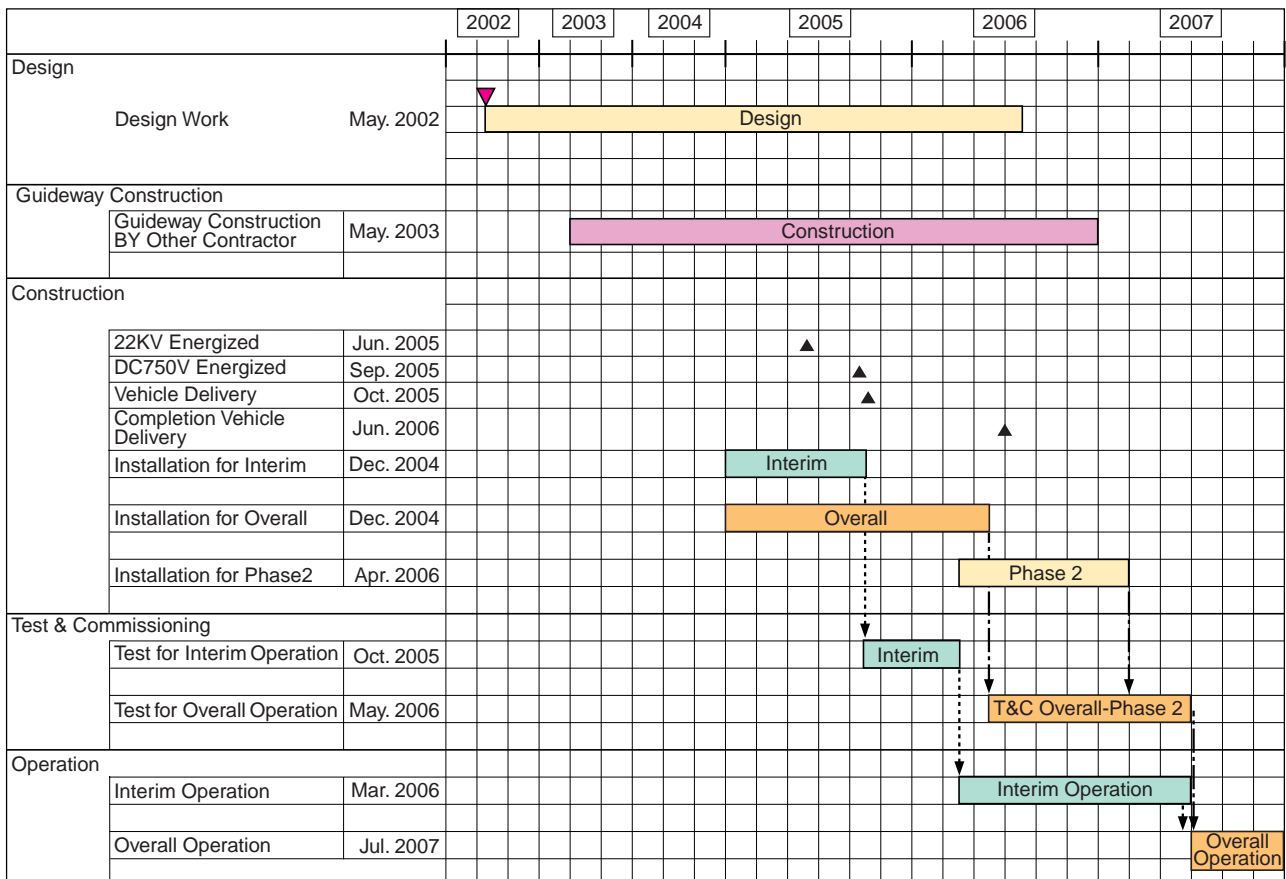


Fig. 13 Project schedule

## 5. Construction

The construction schedule has two different phases (Figs. 13 and 14). The first phase consisted of the construction work of the Interim Operation in which retrofitting of the existing guideway was performed for commercial operation starting at an early date and the Overall Operation (accounting for 70% of the total work) in which Terminal 3 is connected to Terminals 1 and 2 after the new guideways are built. They are referred to as Interim and Overall respectively.

The second phase consists of the construction work (accounting for 30% of the total work) utilizing the existing system structure, which we perform by stopping the existing system after commercial operation in the Interim Operation is started. We call this construction "Phase 2".

Two challenging missions were requested in Phase 2, moving to the new system by utilizing the existing system structure and speedily changing over from the existing system to the new system without any long shutdown of commercial operations. The project has progressed in accordance with the construction sequence and is now in Step 3 below.

### (1) Step 1

After operation on one side (inside the red frame) of the existing double tracks was stopped, the guideways

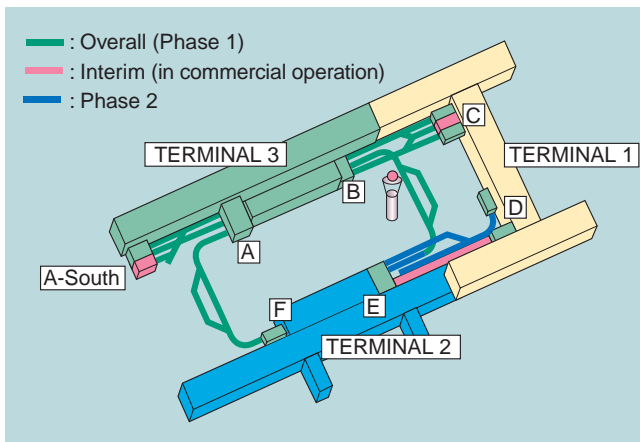


Fig. 14 Entire guideway

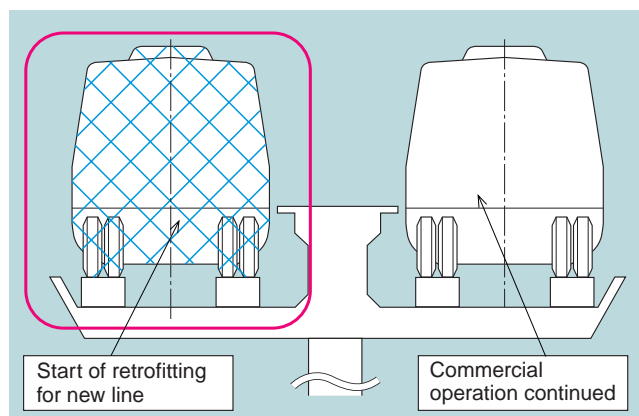


Fig. 15 Retrofitting existing system (Step 1)

and running plinths were removed by the client's contractor, and retrofitting including adding a parapet wall along our guideways and alignment (side guide system) and construction of the station were carried out. On the other side of the tracks, commercial operation continued up to the commencement of operation of the new system. The retrofitting work for which the client was responsible started in October 2004, immediately followed by start of the installation work of the new system in December 2004 (Fig. 15).

### (2) Step 2

In about nine months from December 2004 to September 2005, system construction including the running plinths, guideways, and cabling work was completed for a section of about 550 m in length. In October 2005, two Crystal Mover vehicles were lifted up and test runs were started. After test runs which lasted to the middle of March 2006, the interim revenue service operation was started officially on March 16, 2006 (Fig. 16). Simultaneously with the start of this interim revenue service operation, the existing system stopped and the new retrofitting work was started.

In parallel with this work, the construction of systems for the new guideway, the Overall (accounting for 70% of the total work), was carried out in the beginning of 2005, including construction of the running plinths, guideways, power distribution system, signaling system, communication system, station facilities, and maintenance facilities. After completion in July 2006, these systems are now undergoing testing and commissioning.

### (3) Step 3

Following commencement of the Interim Operation, construction work for the rest of the existing guideway section and the new guideway section connected to the existing guideway section were started. As of March 2007, almost all the construction has been completed and test runs are under way. The double tracks were expanded to four tracks which were arranged in parallel. Test runs are now under way toward the expected handover in July 2007 (Figs. 17 and 18).

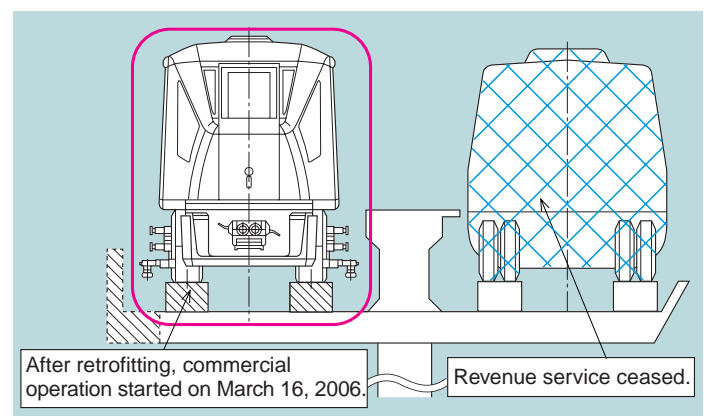


Fig. 16 Retrofitting existing system (Step 2)



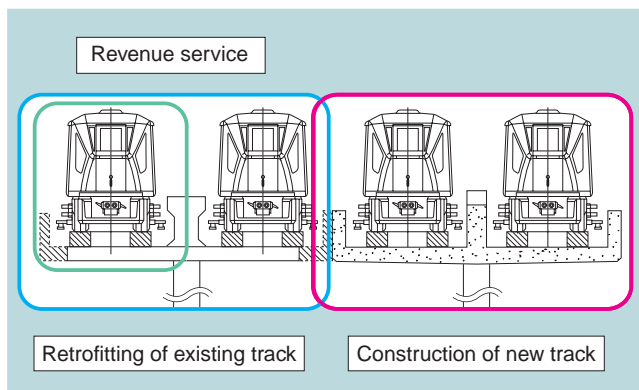


Fig. 17 Retrofitting existing system (Step 3)

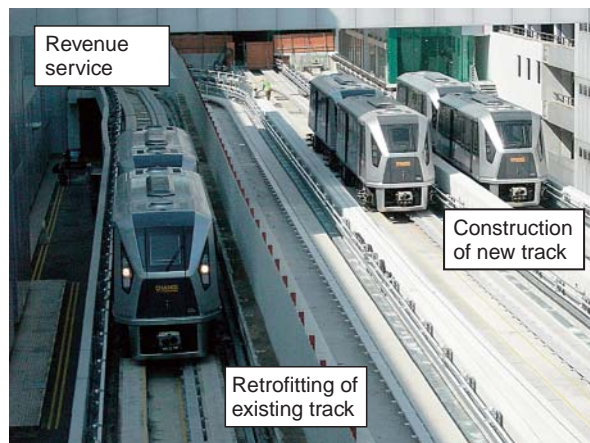


Fig. 18 Retrofitting existing system (Step 3 photo)



Fig. 19 Interim revenue service



Fig. 20 Airport passengers

## 6. Interim Operation

The Interim Commercial Operation in the advanced revenue operation section (between Terminals 1 and 2) was started on March 16, 2006 and 14 months have passed since then.

Currently, the system is operated in a two-vehicle configuration using one vehicle for transit passengers and the other for public passengers (Fig. 19).

Each day 19.5 hours of service is available from 6:00 am to 1:30 am at intervals of about 5 minutes. In these 14 months, approximately 114,000 km has been traveled over about 8,000 hours and the average availability has been 99.8%. This commercial operation has achieved high availability despite there being no spare vehicle available for replacement during the interim revenue service and time for maintenance is limited to nighttime hours. This Interim Operation will be continued up to the commencement of the overall revenue service, where it is intended that the interim system will be speedily replaced by the overall system without affecting the revenue service.

## 7. Commencement of overall revenue service

Currently, the Interim Operation is continuing and, on completion of the newly constructed Terminal 3, full-scale commercial operation will commence. When the overall revenue service starts, each station will be connected by a shuttle service operated for 24 hours in three different patterns, Peak mode, Off-peak mode, and On-call mode, according to the number of passengers using the airport.

## 8. Conclusion

Through its flexible response to the client's requirements and careful planning and implementation, MHI has successfully overcome restrictive conditions caused by use of the existing systems, and has accomplished the changeover of the systems without adversely affecting the existing system or creating a long downtime. Also with regard to the commercial operation, it has gained trust because of its high availability.

Now our project has reached the final stage prior to handover of the overall system and we are endeavoring to safely complete the work for commencement of the overall revenue service.

It is our strong determination to continuously provide a safe and pleasant APM system so that passengers can move enjoyably and comfortably inside the airport (Fig. 20).

Lastly, but by no means least, we would like to express our sincere gratitude to all the parties concerned for their guidance and the cooperation extended to us in the course of implementation of this APM System Project.



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