Singapore Changi People Mover System
APM Replacement and Expansion – A Success Story With Lessons to be Learned

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Abstract

This system and the evolution of this project were described in papers presented by the authors at the 2001 ASCE APM Conference in San Francisco and the 2003 APM Conference in Singapore. This paper closes the loop of the previous papers on this system, which described first the planning process and results and then the procurement process and implementation strategies. It does this by discussing the process to design, construct, install and test the new APM shuttle systems. This paper also provides "lessons learned" with respect to the complexities of installing an APM within an operational airport and in conjunction with other major construction projects.

Another paper presented at this conference: "Singapore Changi Airport PMS – The Progress of Project" by M. Kashiwa of Mitsubishi Heavy Industries (MHI), provides a detailed description of the Changi APM (also called People Mover System – PMS) with regard to the configuration and progress of the project to date. It also provides details of the transition from the previous system by Bombardier to the new one by Mitsubishi.

Introduction

Singapore Changi International Airport, managed by the Civil Aviation Authority of Singapore (CAAS), was the first airport in Asia to have an APM system designed to be fully integrated with its terminal buildings. In 1990 the airport opened a dual lane shuttle system that connected Terminal 1 and Terminal 2 (T1 and T2) buildings with both an airside (riders not in-country) shuttle and a landside (riders in-country) shuttle system. This APM system was designed and installed by AEG Westinghouse (now Bombardier) and operated with four C-100 vehicles. It was called the Skytrain System and contributed significantly to Changi's reputation as a world class airport. For the new system, CAAS has decided to keep the name "Skytrain".

In the mid-1990s, CAAS embarked on a major terminal expansion program that focused on building a new Terminal 3 (T3). The APM system was made a priority for connecting the new T3 with the other two terminals. A program schedule was developed for the new APM system and adjusted to coincide with the commencement of T3 operations.

CAAS, assisted by Lea+Elliott, developed the plan for the APM system consisting of seven shuttles connecting seven terminal stations and two storage and maintenance facilities. The overall system configuration is shown in Figure 1. This configuration was designed to ensure seamless and comfortable connection for airside and landside passengers between all three terminal buildings.

CAAS called for an open tender for the new APM system that resulted in three firms proposing: Bombardier, Mitsubishi, and IHI/Niigata. A consortium of Mitsubishi Heavy Industries (MHI) and Mitsubishi Corporation was selected to design and build the new APM using the MHI Crystal Mover technology that was then being installed in an urban circulator application connecting to the Mass Rapid Transit (MRT) NorthEast Line at Seng Kang–Punggol. This selection meant that the original center-guided C-100 APM would be replaced with a side-guided technology. The side guided technology has similar sized vehicles but a very different power distribution and train control system configuration (see Figure 2).

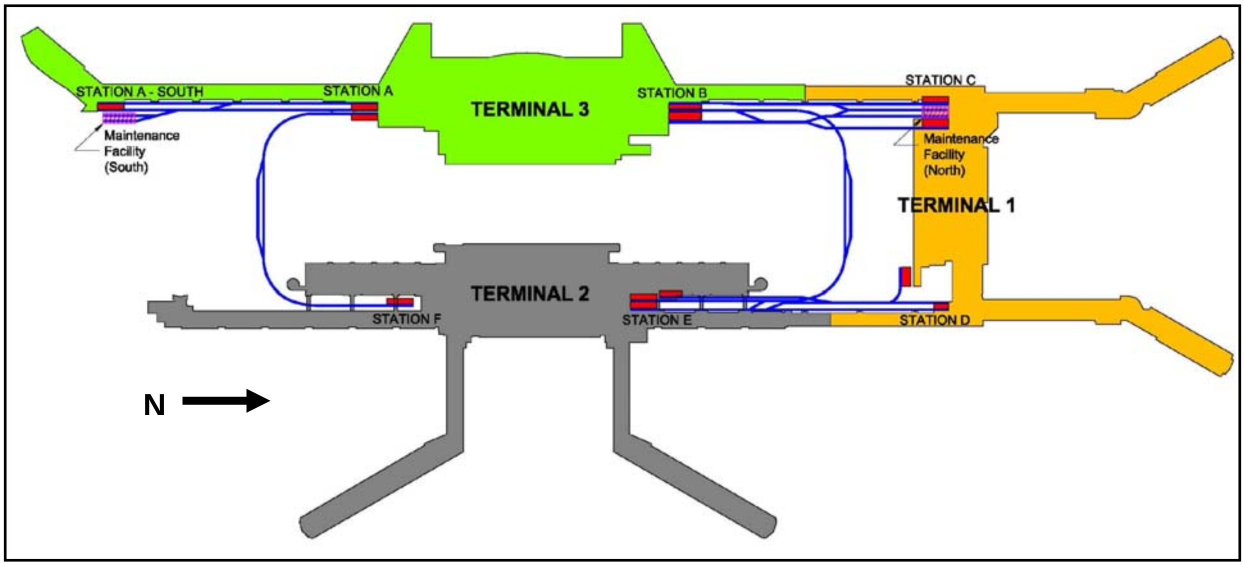

Figure 1. Changi International Airport People Mover System Configuration

Figure 2. Original Bombardier C-100 Vehicle and Replacement MHI Crystal Mover Vehicle

Planning versus Reality

The final system is, in most respects, the same as that which was originally planned. Several changes were made during the course of the procurement process to reduce the cost. These “value engineering” changes were implemented after the tendered prices for the three original proposals exceeded the budget. The changes included: a smaller fleet (16 vehicles instead of 24); a smaller storage and maintenance facility for the south system (one less lane); and a single lane with a bypass on the south system between T2 and T3 instead of a dual lane shuttle. The dual lane configuration could have ultimately employed a 3-train pinched-loop system (compare Figures 1 and 3). These changes resulted in a reduction in the ultimate capacity of the system between Stations A and A-South and a slightly slower operation on the system between Stations A and F. This latter effect is due to enforced speed restrictions for operation of the switches on the bypass. These changes are not expected to change the initial planned service and capacity significantly, but could limit the ultimate system capabilities. Still, these changes allowed the project to go forward while meeting the CAAS’ project goals and budget. The results of the re-proposals were: the relative positions of the three finalists did not change, and the project was within budget.

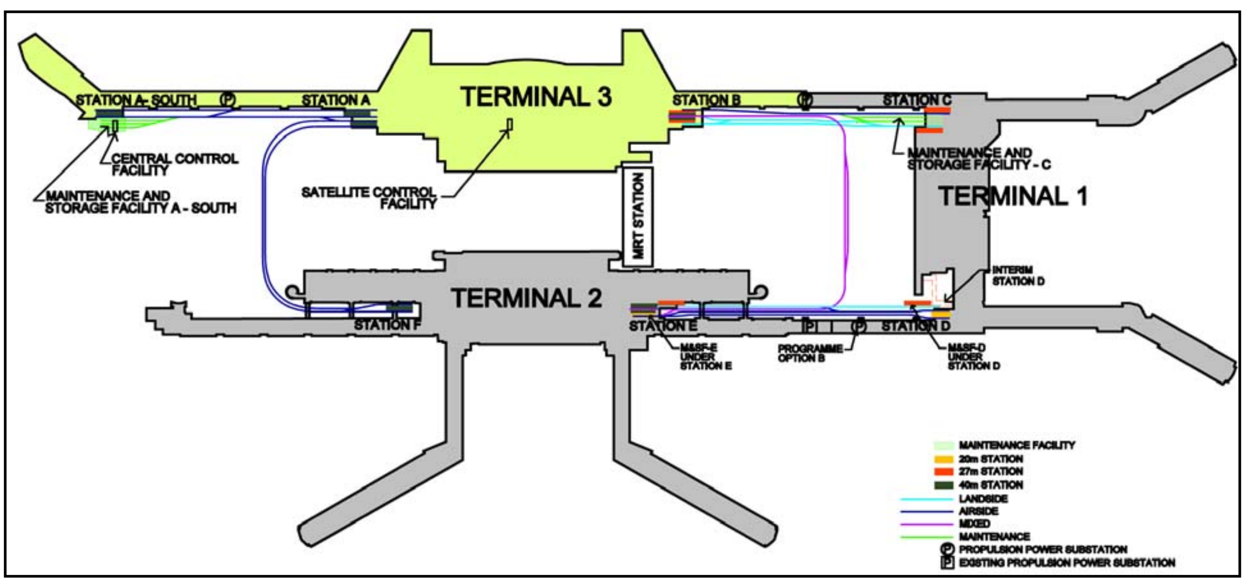

Figure 3. Original Three-Terminal PMS Configuration

Replacing an Operating APM System at an Airport

The original T1-T2 AEG Westinghouse C-100 system was replaced by the MHI Crystal Mover system. All other shuttles are new: T1-T3 and T2-T3. This was one of the few times one proprietary APM technology replaced another. The Jacksonville Automated Skyway Express had its original MATRA VAL 258 technology replaced by a Bombardier Type III monorail. Although these were very different systems, the replacement monorail was much smaller and lighter, thus it could fit structurally on the old guideway with major modifications to the running/guidance beam. In Taipei, the original Mucha Line was a Siemens/MATRA VAL 258, but the extension/expansion is being built by Bombardier, which has designed a vehicle to fit on the original guideway. The original Hong Kong airport APM was built by MHI, but the extension is being built by IHI-Niigata; both have "Japanese Standard" vehicles that can be tailored to fit on each other's guideways. At Changi, the MHI Crystal Mover replaced the original AEG Westinghouse C-100 system with vehicles that are of similar size and weight, but have different guidance, power collection and train control subsystems.

One of the CAAS project requirements was to replace the original operating APM with a new one while minimizing disruptions to service and using as much of the existing facilities as possible. To minimize disruptions, all engineering and design were done in detail, and the new vehicles and other equipment were manufactured and brought to the site while the old system continued to operate.

Special station facilities were temporarily constructed and hoarding (fencing) was put in place to allow the airside lane between T1 and T2 to be demolished to the original structural deck level and then re-built for the new system while the landside lane continued to operate. It was not necessary to demolish or replace the entire guideway structure, since the operating loads of the both the old and new vehicles are similar. The running surfaces were rebuilt because of the different vehicle floor heights to use the existing stations, and to accommodate the change from center guidance to side guidance vehicles. New guide and power rails were added to the side and the new train control system (with a temporary central control center) was installed. During this period, the APM service was shut down intermittently for a few days each time to allow modification works on the new lane. Buses were deployed during the shut down periods. (See Figure 4)

The airside and landside stations in T2 and the airside station in T1 were modified for the new system, including new platform walls and doors. A temporary airside station was built in T2. Once the modification works was complete, two new vehicles were put on the airside guideway and tested. The landside lane C-100 system continued to operate as two, one-car trains (one for landside and one for airside) in a synchronized shuttle until the new leg opened. When the new system was being tested, servicing and maintenance of the Bombardier and the Crystal Mover vehicles were carried out at the existing maintenance facility, which was in-situ with the existing stations. When the initial testing showed the new single-lane shuttle system to be capable of reliable operation, this lane was opened, using one car for landside passengers and the other for airside passengers. The landside C-100 system was then closed and the remainder of the old equipment was removed so that the rest of the new system could be installed.

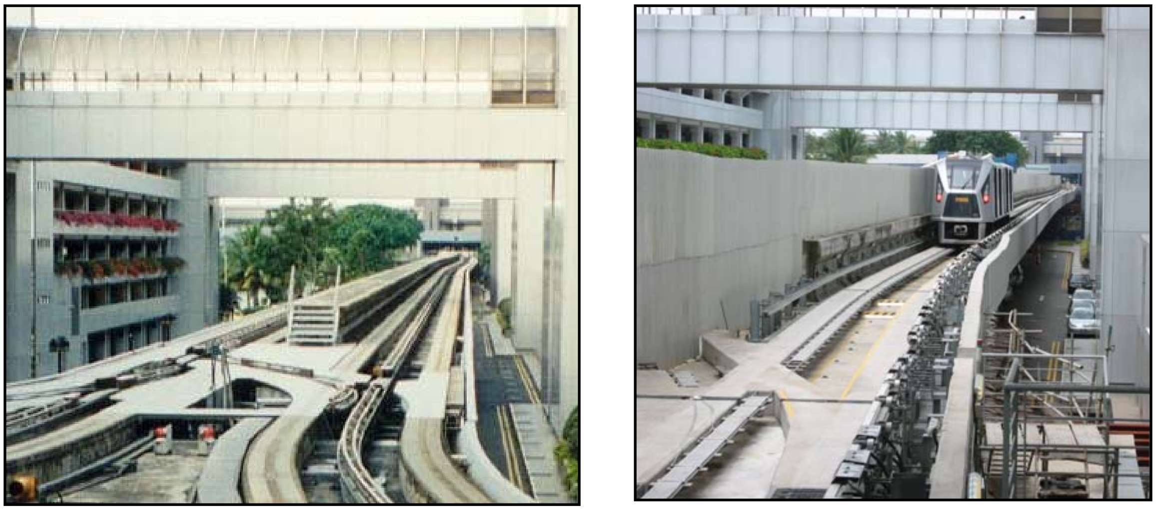

Figure 4. Original and Modified Terminal 1 – 2 Guideway Configurations along Terminal 2.

Staged Opening

As discussed in the previous section, one leg of the T1-T2 dual lane guideway was opened early to maintain APM service on the existing system. This was known as Interim Operation. The rest of the system is nearly completed and is known as the Initial System. The Initial System is really all of the facilities construction and most of the system equipment, which has been ongoing throughout the program including during the same time as the T1-T2 replacement program. Only vehicles will be added for the Ultimate System. With significantly more guideway and stations, and two new maintenance facilities, as well as the second T1-T2 guideway lane on which the original system was operating, construction continued both before and after the Interim system opened for passenger service. The south PMS (T2-T3 connections) construction was completed before the north PMS (due to the requirement to keep the T1-T2 old, then new system operating), so vehicles subsystem and operational testing began there earlier than in the remaining north area. Thus there were effectively three stages to system installation and testing: 1) T1-T2 “airside” lane, 2) South PMS, and 3) finally the North PMS, including its interface with the landside of the T1-T2 shuttle.

The Interim system operated with a Temporary Operations Control Center (TOCC) that was installed in the maintenance area of the original system. This TOCC and its associated equipment were transferred to the permanent central control facility in the south maintenance facility when it was completed. The three stages of implementation and the re-location of the TOCC added to the complexity (and cost) of the system installation, integration, and testing process, but also offered some advantages. One clear advantage was early testing of the Interim system. Although the test period was somewhat rushed to open the T1-T2 service on schedule, the system worked reasonably well and the problems discovered during this limited Interim system operating period were resolved not only for this two-station shuttle, but also for the overall system. Installing the new Crystal Mover system while keeping the Bombardier system operational required detailed planning and coordination to ensure that the work was carried out smoothly with minimal disruption to other airport operational areas. Testing and commissioning of the system had to be conducted twice – once for the Interim system and another for the Initial system.

Although the three-stage implementation and re-location of the TOCC added to the complexity of the project, CAAS decided that this approach in line with Changi’s philosophy of providing the highest level of service for its passengers and airport users. The Skytrain connection between T1 and T2 is of utmost importance especially for passengers and airport users who ride the Mass Rapid Transit (MRT –

Singapore’s heavy rail system) system to Terminal 2 and use the Skytrain to connect to Terminal 1, as well as transfer passengers who need to commute between terminals. Despite the time and cost savings that could have been derived from shutting down the Bombardier system fully for modification work, it would have resulted in a degradation of service, even if buses were provided to transport passengers between the terminals, so CAAS chose the higher level of service approach.

Partial Design-Build Project

This Changi APM project was design-build for the system but design-bid-build for the facilities. This added significant interface coordination for the system facilities: guideway, stations, and maintenance facility. The initial facility design was based on a generic APM – an amalgam of the three finalist technologies (Bombardier CX-100, IHI-Niigata NTS, and MHI Crystal Mover). The final design had to accommodate the specific requirements of the selected Crystal Mover system. Thus an early effort for MHI was coordinating with CAAS’s designer of record: CPGC. There were also several different construction contractors working on the guideway and buildings, requiring coordination among all parties, including CAAS and CPGC.

It would have been possible to appoint the APM system provider as the main contractor for this project, who would also be responsible for constructing and modifying the guideway and stations (facilities). However, there were significant cost savings derived by calling separate tenders for the system and the facilities as the work was carried out by the respective specialist contractors. Additional coordination and planning were required of CAAS and the consultants (Lea+Elliott and CPG Consultants) to facilitate and coordinate work between the different contractors.

Remote System Oversight

CAAS retained Lea+Elliott for the initial APM planning work, then for the system equipment DBOM procurement, and finally for the PMS design and installation oversight. In an attempt to be cost-effective, the contract had relatively few trips by Lea+Elliott staff to Singapore and to the design and manufacturing facilities Japan. Typically such trips have proven to useful for many reasons, including: design review meetings, document development and reviews, plant QA and progress inspections, installation inspections, test witnessing, safety certification oversight, and general coordination.

Instead of fully involving knowledgeable consultant staff, CAAS oversaw the supplier with only a few internal staff, who dealt mainly by e-mail, fax, and other correspondence, except for the daily on-site coordination. While this ultimately worked reasonably acceptably, there were misunderstandings that took time, iterative correspondence, and telephone calls to resolve.

After the procurement process was complete, Lea+Elliott had six one-week trips to Singapore for design review purposes, two trips to Japan for manufacturing QA and factory acceptance test oversight, three trips (five person-weeks total, but only two person-weeks were in scope) to Singapore to oversee site acceptance testing for Phase 1, one week-long trip to Miami for issues resolution (not in scope, but combined with other MHI Crystal Mover projects for which Lea+Elliott has oversight responsibility), one week-long trip to Japan for safety case and other submittal reviews (also not in scope and combined with other MHI projects), and one three-week trip to Singapore for Phase 2 commissioning testing. From this schedule, we found that oversight by correspondence can cost more in time and effort, particularly with misunderstandings and iterative e-mails, and be less effective than a more normal process with greater face-to-face presence.

On the other hand, by directly placing responsibility on its staff to engage MHI with Lea+Elliott in a remote oversight role, CAAS was able to acquire in-house technical expertise and direct and detailed experience with the new APM system. This was considered to be especially important as the APM is a critical system for Changi Airport. This expertise and experience gained during the planning, design and implementation stages of the project is essential in CAAS ensuring that the operations and maintenance efforts are kept at the highest levels possible.

Documentation

This was the first project that MHI worked on that followed ASCE APM and Lea+Elliott performance specifications. In previous APM projects, MHI followed standard practices in Japan or Hong Kong, and generally these required relatively little external documentation. The documentation requirements in the PMS Contract were different and sometimes more extensive than MHI had previously encountered. In addition, there were language issues, as all documentation had to be in English. MHI staff had not encountered, and did not fully understand, the bases and requirements of the usual submittals that pertained to design and design reviews, interface and integration issues, operations and maintenance plans and procedures, and particularly safety and security.

The submittal review process thus was slower and required more iterations than expected. The documents went through the small CAAS staff, who were also learning about the intricacies and issues of APM systems, for review and comment by Lea+Elliott staff. Our comments went back to CAAS staff who assembled, then forwarded, them to MHI. This indirect and written only communications chain, the unfamiliarity with document requirements, differences in the way projects were undertaken, and language differences all added to the time of the cycle of developing, reviewing, responding, resubmitting (often several times), which had other schedule, and some cost, impacts.

To avoid the problems associated with developing, reviewing, and approving the important document submittals, we recommend a series of meetings throughout the detailed design, manufacture, installation, and testing project phases in which the requirements, different approaches, and substantive issues can be understood directly and resolved relatively quickly and cost-effectively. This was finally done, primarily for safety and security and related testing, documentation, and process aspects of the project. Unfortunately it was undertaken relatively late in the schedule: after the Phase 1 system opened. Lea+Elliott and MHI staff met for a week in Japan and resolved many of the issues and misunderstandings, so that the review and acceptance of subsequent submittals went more smoothly. This meeting was not just for the Changi project, but also for similar (and slightly trailing in time) MHI (and Lea+Elliott) APM contracts at the Dulles, Miami, and Atlanta International Airports. We expect this will help all parties on all of these projects.

Codes and Standards

The MHI Crystal Mover system, like those of other Japanese APM suppliers, was designed mainly to meet Japanese codes and standards. The Changi contract and performance specifications included the ASCE APM Standards as well as somewhat more rigorous standards and requirements that Lea+Elliott has found to be important during our over thirty years of experience with APM projects. Throughout this project there has been much discussion of the correspondence of Japanese and ASCE standards. The acceptance of each set of standards by the other party has, at times, been a significant issue. Changes, particularly those that affect equipment design, can be expensive. Yet, once a contract has been signed, the system owner expects the contractor to meet all terms and conditions, and is often reluctant to accept change, particularly when safety is concerned. At other times this can become an issue of cost (to the supplier) or refund (to the owner).

We believe the ASCE APM Standard, and other codes and standards that it incorporates by reference, are important as a minimum requirement. They have been developed in a consensus process by a committee of suppliers, subsuppliers, owners, and engineering consultants. Yet other countries have standards that have proved acceptable in practice. As Gatwick, Lea+Elliott reviewed typically applicable British standards and a correspondence table with the ASCE and related standards, which gave all involved a better idea initially of what was or could be acceptable. Developing a correspondence between ASCE and Japanese standards is a more difficult issue, due mainly to language differences, but one that also appears to be needed in this global market.

Conclusions

There are many ways to implement an APM project. They vary considerably with the scope of the project and the Owner's requirements. For each project there is a balance of efforts by the owner, the expert consultant, and the APM supplier to make the project's implementation go smoothly and efficiently. That balance is not always easy to achieve and depends in part on the perspective of the participants.

The Changi PMS approach had minimal expert oversight of the APM supplier's work. From the Lea+Elliott perspective, this led to additional concerns, if not problems, with design, testing, and commissioning of the system. Fortunately, the small but dedicated CAAS staff, and MHI's experience and willingness to adjust helped considerably in resolving those issues. From CAAS' point of view, this built up in-house expertise and experience that is essential for the operations and maintenance phase of the project.

We have learned some lessons from this project, both from its problems and its successes. These include:

1. Examine the overall costs to and efficiencies of running a project. The lowest initial budget might not be the most effective way for implementation.
2. Have adequate contingencies for the inevitable changes and problem resolutions that occur during the project.
3. Be open to value engineering at all stages of the project.
4. You can successfully replace one proprietary APM system with another, but there are many design and implementation aspects to be dealt with.
5. You can keep the original APM operating much of the time while replacing it with another, but there are cost and schedule implications that should be carefully considered.
6. Staged opening of a system can add time and cost to the project, but under the right conditions can help discover and fix problems before they affect the whole system. Care must be taken to have sufficient testing, adequate safety certification, and sufficiently reliable service so as not to give the system, and the airport is serves, a negative reputation.
7. Remote oversight and document development and reviews by correspondence only, which tend to add problems, costs, and time to the project, should be balanced with the Owner's need to gain staff expertise. Each project should determine the optimal blend of outside expertise and internal experience.
8. Face to face meetings to discuss and resolve issues are important, and the project schedule and budget should include a reasonable number of such meetings.
9. Codes and standards vary by country and other jurisdictions. Developing a common set for APMs that can be generally acceptable world wide is a worthy goal for the ASCE APM Standards Committee.