The World’s Largest Airport People Mover Project

David G. Nicholas, PE¹
Perfecto M. Solis, PE²
Dwain K. Brown, PE³

Abstract

Dallas / Fort Worth (DFW) International Airport has experienced significant increases in air traffic demand that supports the need for an overall airport expansion program. Recent expansion of existing terminals has caused the current Airports Train network to operate at nearly maximum practical capacity. Therefore, the addition of a secure Automated People Mover (APM) System to transfer passengers between all Airport Terminals is critical to the expansion and future operation of DFW International Airport. The new APM will enable secure connecting passengers to travel between all gates within the Airport’s Central Terminal Area (CTA).

The APM Project involves the construction of new facilities and the purchase of a train system that will completely replace the existing system. The system design is driven by schedule constraints, airline operational restrictions, physical site constraints, and the performance requirements of the selected train system. Construction on the active airside apron presents numerous challenges. Through the use of relatively unusual precast concrete columns and bent caps, construction time is reduced from 7 days to 2 days, significantly minimizing impacts on airline operations and saving 6 months on the schedule.

Meeting the overall completion schedule of the Airport’s Capital Development Program dictates an aggressive “Design – Build / Fast – Track” strategy, unique structural design solutions, and design and construction resources co-located on-site at the Airport’s new CDP Satellite Office Complex. The APM Program schedule is an eighteen (18) month design schedule, an overlapping thirty (30) month construction schedule, and an overall sixty (60) month Program schedule for completion. The Program Team is a multifaceted organization made up of the Owner, Designers, Contractors, Train Consultant, and the Train Supplier.

¹ DFW APM Project Manager, Brown & Root Services, CDP Satellite Office, 3003 South Service Road, DFW Airport Texas 75261: PH 972-576-5711; dnicholas@dfwairport.com
² DFW APM Program Manager, DFW International Airport Board, CDP Satellite Office, 3003 South Service Road, DFW Airport Texas 75261: PH 972-574-6259; psolis@dfwairport.com
³ DFW Deputy APM Program Manager, Freese and Nichols, CDP Satellite Office, 3003 South Service Road, DFW Airport Texas 75261: PH 972-586-5752; dkbrown@dfwairport.com
Introduction

DFW is undergoing a five year $2.6 billion Capital Development Program (CDP) that includes 3 runway extensions, an automated people mover system, a new international terminal, as well as several other projects. DFW has experienced significant increases in air traffic demand that support the need for a new automated people mover system to meet the FAA’s 30-minute transfer criteria. The existing Inter-Terminal train system, which is currently running near maximum capacity, is unable to meet the forecasted demand. A secure APM System that can move passengers quickly between terminals is needed to support future terminal expansions.

The new DFW APM will have the ability to move 5,000 passengers per hour per direction at each station on opening day. The “Ultimate System” will handle the higher passenger load forecasted for the future of 8,500 passengers per hour per direction. Passengers will have to wait no longer than two minutes between trains, and will be able to reach the farthest points of the airport in less than nine minutes.

The APM Program consists of six major elements:

- Guideway Structure
- Stations
- Maintenance and Storage Facility
- Integration with existing Terminals on the concourse level.
- Apron / Jet Bridge Modifications
- Train System

The design solutions for these elements are driven by schedule constraints, airline operational restrictions, physical site constraints, and the performance requirements of the selected train system.

Program Strategy

The APM Program requires a sixty (60) month completion schedule from start of design until initiation of public service. The General Contractor must complete the last section of guideway and the propulsion power substations within thirty-three (33) months to meet the availability dates contained in the Train System Suppliers contract. The consolidated design / construction
schedule was coordinated to meet this contractual obligation and required very aggressive design and construction sequences.

The design team identified 23 pricing packages and 96 Construction Document packages to support the “Fast-Track” construction schedule. Schematic design began in May 2000, and the first foundations were under construction three months later. Construction will be complete by the middle of 2003, and installation and testing of the train system will end by the first quarter of 2005.

The General Contractor will field almost two thousand (2,000) workers daily at the peak of construction. The Contractor will also have to manage multiple work zones at each of the five terminal locations and along the landside segments.

To accelerate the design-build process as much as possible, the General Contractor hired a steel-detailing firm to work directly with the steel design engineers even as the schematic designs were being developed. By working with the steel detailer directly from the earliest stages of design, the design drawings and shop drawings were created simultaneously. As soon as plate sizes were determined, these long-lead time items were immediately ordered from the steel mill well before final design details were developed.

**Consolidated Organization**

The combination of a highly accelerated schedule, a technically complex project, and a large design team dictates that the entire APM Program Team works in harmony. The APM Program Team is a multifaceted organization made up of the Owner (DFW International Airport), Facilities Designer (Brown and Root Services), Contractor (Hensel Phelps Construction Company), Train Consultant (Lea+Elliott), Maintenance & Storage Facility (MSF) Designer (Halff and Associates), Train Supplier (Bombardier Transportation, formerly Daimler Chrysler Rail Systems – Adtranz) and the tenant airlines (Figure 1).

All management, design, and construction resources are primarily co-located at the Airport’s Capital Development Program (CDP) Satellite Office Complex. The complex consists of a 40,000 square foot office building and 102 construction trailers that house the owner’s personnel, design consultants, train manufacturer’s personnel, and contractor’s personnel. Co-locating all
parties together under “one-roof” has greatly improved coordination and communications over the more typical approach of work performed in individual consultant offices.

The Facilities Designer, Brown and Root Services (BRS), is responsible for designing the Guideway and Stations. BRS is also responsible for the Quality Assurance (QA) of the construction component of the Program. The BRS design team is composed of engineers, architects, construction inspectors, and support personnel from BRS and 17 other consulting firms. Relocating these individuals to the new satellite office complex equates to creating a new 180-person consulting firm overnight. All the necessities of an established design office environment had to be created from computer systems, software, plotters, reference materials, and catalogs to calculation pads and business cards.

Team building efforts were critical during the start-up of the Program in order to form one productive design and construction group. All of the major organizations in the APM Program are participating in a formal partnering program in order to facilitate a closer working relationship and a sense of common cause. An experienced partnering facilitator is on staff and helping to guide the Program. A partnering charter was created at the initial session that clearly defines the common goals of the APM Program.

**APM Overview**

The Program cost of $849 million makes the DFW APM Project the largest airport people mover system constructed to date. In addition to meeting the passenger transport functional goals, the project also presents an opportunity for the APM guideway to provide a homogenous and sleek look coordinated with the DFW airport CTA environment that was designed during different timeframes, thus establishing a new image for the airport.

The 25,400 linear foot guideway structure has two independent bi-directional lanes that will allow the trains to run in both directions at speeds up to 37 mph. The guideway is a continuous loop that extends along the “airside” face of existing Terminals A/ B/ C/ E, through the interior space of the new Terminal D, and is freestanding through the future Terminal F site (Figure 2). Construction of the guideway is equivalent to building a five-mile elevated bridge structure while having aircraft operate and function underneath. The guideway alignment between terminals follows the Airports existing public and service roadway system, adding to the
construction challenges. The north and south ends of the guideway alignment also span across the existing public/service roadways, all of which had to remain operational.

The guideway superstructure consists of either concrete U-beams or steel trapezoidal box beams, topped with an 8-inch thick concrete deck, supported by post-tensioned concrete columns. The columns have an elliptical shape with strong vertical/horizontal reveals (Figure 3). The columns have a nominal dimension of 5 foot x 7 foot, and range in height from 50 to 70 feet.

The space between the beams is used for structural bracing, installation of multiple electrical conduits, communication ducts, and drainage lines. A metal soffit panel is installed between the beams to conceal the utilities (Figure 4). The metal panels also prevent any potential bird roost, which could have a detrimental effect on airline ramp operations.

Each of the Terminals incorporates two “center-platform” APM Stations (Figure 2). The Stations provide passengers access into the secure concourse side of the Terminal.

A Maintenance and Storage Facility (MSF) is located at a remote location outside of the Airport’s CTA (Figure 2). The 100,000 square foot MSF and the 50,000 square foot train storage yard are designed to accommodate the maintenance and testing of the entire initial APM Train fleet (64 cars). The MSF will house all the command, control, communication, and maintenance functions needed to operate the new System.

APM Guideway Structure
The APM Guideway structure is the visual link and unifying element for the terminal complex. To achieve DFW’s goal for a strong architectural cohesiveness, DFW specified that the guideway superstructure provide a “ribbon-like” appearance with a smooth (clean) underside, similar to precast segmental post-tensioned concrete bridges. Segmental post-tensioned construction, however, was estimated to cost about 15% more and take one year longer than common prestressed concrete beam construction. U-beams were dapped at the ends to fit into inverted-tee bent caps to give as sleek a finish as possible (Figure 5). The beams are topped with a cast-in-place bridge deck and parapet walls. The result is an economical bridge structure that has the beam soffits flush with the bottom of the bent caps. The metal soffit panels between the beams also help provide the clean monolithic appearance that is desired (Figure 6).
The basic guideway structure was originally concepted to use Precast concrete beams that span approximately 100 feet between columns. Design development determined that the landside Inter-terminal loops and the north/south gateways required steel trapezoidal box beams. Spans of up to 254 feet, and radii as tight as 280 feet, were necessitated due to restrictions on column placements by buildings, utilities, and roads (Figure 7).

Three hundred and seventy two (372) columns nominally spaced every 100 to 125 feet, support the guideway superstructure. A single drilled shaft ranging from 8 to 10 feet in diameter typically supports each guideway column. The drilled shafts extend about 25 feet through clay soils and then penetrate approximately 16 feet into shale.

Airside / Landside Strategies

Different strategies were required for the airside and landside construction due to natural site constraints. Progression of the work on the airside presented numerous challenges to minimize impacts on existing airline operations. As a prerequisite to the airside construction sequences, modifications to the existing aircraft parking positions were required to generate additional space between the terminal face and the aircraft for the APM alignment. Approximately 83% of the gates required modifications that included some mix of re-striping, fixed walkway modification / extension, passenger boarding bridge (PBB) replacement, and/or fuel pit extensions.

Construction of the airside guideway structure required close coordination with the airlines, support services, and DFW Operations. Airline operations and passenger level of service will not allow gates to be closed for an extended period of time. Gate closure restrictions and operational dependencies dictated a complicated sequence for the modifications.

In areas outside of airport air operations area, where 118 of the 372 columns are located, cast-in-place concrete columns are used. This method of construction takes about 7 days per column for reinforcing steel and column form erection, concrete placement and curing, and form striping.

The airside guideway columns consist of pre-cast, post-tensioned concrete segments joined together with a pre-cast concrete bent. The use of precast concrete beams is commonplace, but the use of precast concrete columns and bent caps is relatively unusual. This technology, while
approximately twice as expensive as traditional cast-in-place construction, allows for savings in reduced construction time and minimized disruption to airport operations, which outweighs the added costs.

Precast erection does not need the sizable amounts of airfield space that guyed cast-in-place concrete formwork requires. A column can be completely erected in 2 days without closing a gate or impacting adjacent gate operations. Pre-cast construction results in a timesaving of approximately 6 months and will keep the construction process within the 33-month construction window required by the Program.

A precasting yard was assembled on site, adjacent to the concrete batching facilities. The column segments and bent caps are fabricated well in advance, stored at the yard, then shipped during night operations and erected. Almost all of the major material delivery and hauling efforts are required to be performed at night to reduce traffic on the ramp during the day and because stockpiling materials at the work zone is rarely feasibly.

The precast column segments are cast in ten-foot tall hollow sections, each weighing about 38 kips (Figure 8). Each segment is match cast against the adjacent segment with post-tensioning ducts, drainage lines, and electrical conduits cast into the segments. There are four post-tensioning bars and eight post-tensioning ducts in each column.

The transition between the drilled shaft and the precast column is a critical juncture. There are three important things happening at this point. First, the post-tensioning force in the column (which is around 4,200 kips) must be transferred to the mild reinforcing in the drilled shaft. Second, at this juncture the first precast segment is placed; any misalignment here will cause the entire column to be out of plumb. Finally, this area must be able to endure traffic impacts (estimated to be 200 kips) from the tug vehicles and baggage trucks moving constantly around the airfield.

The solution was a five-foot tall pier cap cast above the airfield paving and jacketed with 3/8-inch thick steel plate. This pier cap anchors both the post-tensioned reinforcing from the column and the mild reinforcing from the drilled shaft. The column post-tensioning ducts extend through the pier cap and end in a loop in the top 5 foot-3 inches of the drilled shaft. The top of
the pier cap has three adjustable leveling bolts to plumb the first column segment. A flowable grout is placed in the 2-inch gap between the first column segment and the pier cap. Finally, the steel plate encasing the pier cap provides impact resistance to the airfield traffic (Figure 8).

After the first column segment is placed, successive segments can rapidly be added, followed by the bent cap. When the bent cap is in place, the four post-tensioning rods are stressed and the multistrand tendons are run through the ducts. After stressing the tendons, the ducts for both the bars and tendons are fully grouted.

The bent caps are inverted-tee members to support the dapped ends of the precast beams. A typical bent cap is 25 foot-7 inches long and weighs 109 kips. The ends of the bent caps are sloped to match the sloping sides of the prestressed U-beams. The bent cap design presented a formidable challenge to the precaster. The bent caps are quite congested with the typical mild reinforcing, drain piping, electrical conduits, sleeves for future utilities, prestressing ducts, and bursting reinforcement (spirals) (Figure 9).

**APM Stations**

The APM system will have twelve stations, 2 at each of the four existing and two future terminals. The stations at future terminals D and F are totally integrated into the design of the stations. At the four existing terminals, each of the eight stations is a substantial structure in itself: 76 feet tall, 454 feet long, but only 30 feet wide (Figure 10). The objective of the station design process was to introduce a world-class image that is visually high-tech in appearance and architecturally strong. This dictated that the architecture should define a sense of arrival with a strong visual connection when the passenger is approaching the station. This is achieved through soaring interior spaces tied together with large expanses of glass supported by a lightweight truss system (Figures 11 and 12).

The APM platform, which is approximately 13 feet above the rooftop elevation of the existing terminals, is 180 feet long, 30 feet wide, and features 3 escalators, one elevator, and one stair tower at each end. The escalators and elevators take the passengers “to and from” the platform level down to the Terminal concourse level. The stair tower is intended to provide egress down to the ramp level in the event of an emergency.
The structural design of the stations is unique. There are 10 main support columns, which are 6-foot x 10-foot precast post-tensioned hollow segmental concrete spaced 90 feet on center. Long steel trusses span between the columns, supporting composite steel floor beams. By spacing the columns at 90 feet on center, valuable airfield space was conserved and disruptions to airport operations were minimized. At the train platform level, the long spans allowed for variations in train door configurations.

The APM guideway runs on the front and backside of the station and is supported by the station framing. Twin steel plate girders, each 62 feet long, rest on the precast columns and cantilever 16 feet beyond each column to support the precast prestressed guideway beams (Figure 13).

Each station has multiple construction phases that are determined by the configuration of the gates in the vicinity of the station, type of ramp and baggage operations that occur in the area, and configuration of the steel frame, to name a few. A detailed phasing plan for each station is prepared by the design team in collaboration with the General Contractor and coordinated with all stakeholders by the APM Program Management.

**Conclusion**

The design of the DFW APM system has been underway since May 2000. The guideway construction began in September 2000 and is progressing on schedule. The visual impact the guideway will have on the airport CTA is just beginning to reveal itself as the columns are coming out of the ground all around the airport. The solutions to meet the schedule-driven project and minimize disruption to operations have resulted in creative design achievements. The DFW APM conserves valuable airfield space, and uses relatively unusual precast concrete columns and bent caps to significantly reduce construction time. These structural design innovations also contribute to the clean monolithic appearance of the guideway and the floating, soaring feel of the stations.

The decision by DFW to locate the entire APM Team on site has proved to be invaluable. The complexity of precast post-tensioned structure has proven to be a very complicated fabrication process. The efforts of the designers and contractors to resolve issues and minimize impacts to the production schedule have proven that a team approach to solving problems really works.