

## PHOENIX SKY HARBOR EASES CONGESTION WITH NEW AIRPORT APM

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### ABSTRACT

Phoenix Sky Harbor International Airport is designing an Automated People Mover (APM) system that will connect parking, terminals, rental car facilities and a proposed light rail system that is scheduled to be in service within the next five years. The purpose of the APM is to relieve surface transportation congestion and allow the airport to grow from its current 36 million passengers to a capacity of 60 million. This paper outlines the APM features and describes solutions to the project's greatest challenges which include: maintaining airport operations, construction and passenger safety, coordination of multiple work groups, project security, and traffic control. The airport has chosen a collaborative team approach for this project involving many key consultants including: DMJM Aviation/HDR Engineering (Project Management), Lea+Elliott (APM System Design), Gannett Fleming (APM Facilities Design), and Shughart Thompson & Kilroy (Legal Consultant).



## INTRODUCTION

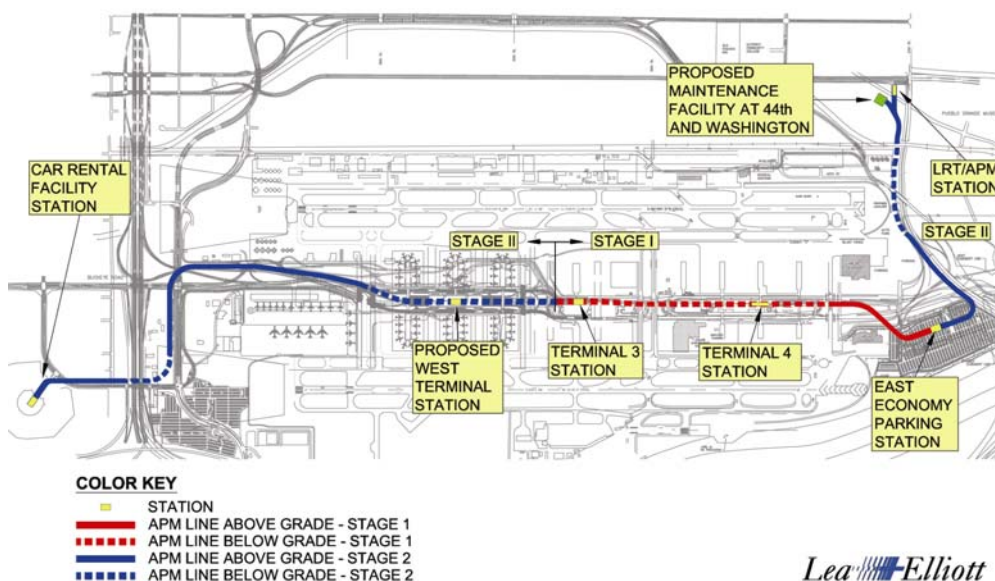
Approximately 192,000 passengers and guests pass through Sky Harbor International Airport each day. As population growth in the valley has increased, so has the demand for airport services. Sky Harbor has experienced a 32 percent increase in passengers since 1990. In 2001, the airport ranked as the 6th busiest in the country for passenger volume (35.4 million passengers).

The number of aircraft landing and departing the airport has also increased. With over 550,000 operations per year, Sky Harbor currently ranks as the 5th busiest airport in the United States for takeoffs and landings. Cargo volume has increased 44 percent since 1990, with 312,389 tons of cargo shipped from the airport in 2001.

The dramatic increases in demand have caused the airport to outgrow its facilities and have made it more difficult to provide quality customer service. In an effort to improve customer service, the City of Phoenix Aviation Department has undertaken an aggressive expansion program. One facet of the program is the new automated people mover system.

The City of Phoenix Aviation Department initiated studies and the development of conceptual design for a Phoenix Sky Harbor International Airport transit system in 1985. The development of the schematic design for Terminal 4 included the evaluation of alternative alignments and locations for a future transit system.

More recently, plans have been developed for an APM serving the Terminals, Car Rental Facility, Light Rail Station, and Economy Parking.



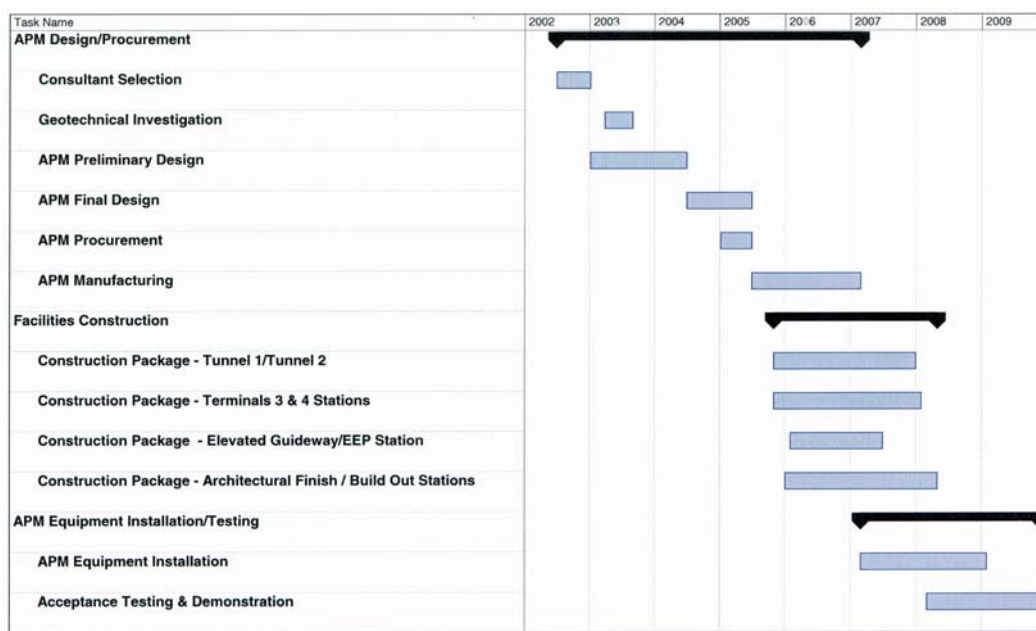
The APM project would be completed in two stages. Stage I, a total of 7,768 dual-lane feet, will provide APM service from the East Economy Parking (EEP) Station to the west side of Terminal 3. The system alignment generally follows the airport access roadway through the terminal area and is partially routed below grade.

The Stage I APM system will be a linear configuration starting at an elevated station and guideway at the EEP Station. The APM exits the EEP Station to the west and remains elevated for 550 feet to a point east of Taxiway R, where a grade change drops the elevation of the guideway to the at-grade tunnel portals. The guideway will then continue a grade transition to an approximate elevation of 59 feet below the baggage claim level at Terminal 4 and continue approximately 49 feet below street level at Terminal 3. The system will move westerly, underground, through Terminal 4 and Terminal 3 Station areas. The western limit of Stage I will terminate beneath the roadway on the north side of Terminal 3. Three passenger stations will be located along the alignment. Completion of the first stage is scheduled for 2009 with an estimated construction cost of \$300 million, contingent upon financing and Phoenix City Council approval.

Stage II will provide a continuation of the tunnel for 1.5 miles below Terminal 2 and the West Economy Parking Lot and is planned to connect with the Car Rental Facility. In addition, an extension on the east end of the alignment is planned to connect an Light Rail Transit (LRT) station to the system. The combined length of guideway added to the system is 16,842 dual-lane feet. The second stage will cost approximately \$400 million. Comple

tion of Stage II is dependent upon the results of an environmental impact study. Since that report will not be completed until 2004, this paper will focus primarily upon the attributes and issues surrounding Stage I.

The Stage I project will generally adhere to the following timeline:



## SYSTEM REQUIREMENTS

The APM will provide fully automated service with direct service (no transfers) among terminals and between each terminal and the remote destinations. The APM operation plan will include shuttle and run-around routes to maintain service to destinations in the event of a partial system or component failure. Failure modes of operation will also enable continued service among destinations.

Wayside and onboard automatic train control equipment will provide all functions necessary for safe and efficient operation, including train movements and protection, door operations, and central control and supervision.

Power systems will supply all train electrical needs, including traction power, onboard auxiliaries, track equipment, and related station equipment. A power distribution system will provide transformers, rectifiers, switchgear, cabling, trackside power rails, and other equipment as needed to ensure proper voltages for all trains at ultimate train lengths and headways even during single-point failure conditions. Separate traction power substations will be located at various facilities along the alignments.

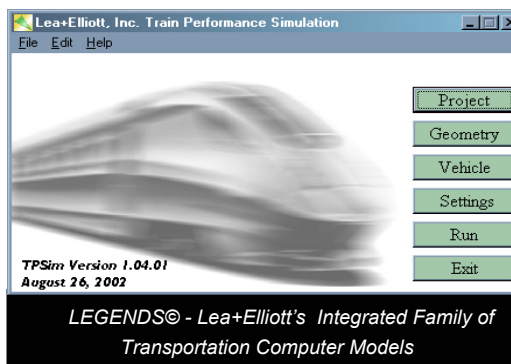
The April 2001 *APM Planning Study Report*, prepared by Lea+Elliott, Inc., included a typical single-line diagram for a DC distribution system for the Stage I system. Typically, each traction power substation will be designed to utilize two redundant sets of transformers/rectifiers with either set capable of supplying the entire load indefinitely. The typical DC distribution technology will provide for each substation to be connected by two redundant feeders independent of the other substations. These same two feeders may be utilized to supply power to each APM passenger station, parking station and to the Maintenance & Storage Facility. A stand-by generator will be used as a backup to the normal utility power source.

The electrical demand for the overall APM system, exclusive of fixed facilities requirements, is projected to be less than 7MW RMS. Several of the APM suppliers that could potentially submit proposals for Phoenix Sky Harbor International Airport can regenerate power when they decelerate or go down significant grades. Depending on the relative timing of trains starting and stopping and methods of absorbing the regenerative energy, this could reduce external power demands by 5-15 percent.

## OPERATIONS MODELING

Lea+Elliott's LEGENDS<sup>®</sup> model was used to determine the operational characteristics of the APM system. A generic, large APM technology was used for this analysis. This assumes the vehicle runs at a maximum cruise speed of at least 38 mph and has a nominal length of 40 feet.

LEGENDS<sup>®</sup> is an integrated group of transportation computer models used to analyze and evaluate all aspects of transportation systems performance, including passenger travel times, system headways, energy consumption, failure management, capital cost, operational cost, vertical circulation and passenger station population/queuing. The LEGENDS<sup>®</sup> Train Performance Simulator was used to assess the performance of the APM trains operating on each stage of the recommended alignment. It calculated individual train performance and power demand characteristics on a per-second and guideway-location basis throughout a single round trip. The Train Performance Simulator, along with the Ridership Model and the Operations Model, allowed the team to model passenger demand and round trip time of the APM system to define appropriate and optimal system headways.



Another tool used is the Power Demand Analysis Model that accumulates the total simultaneous power demand for each substation as a function of the positional and per-second KiloVoltAmpere (KVA) requirements of each train consist. The train consist positional data was used to determine the particular substation(s) that will supply power to the train. The per-second KVA data determined the amount of power on the substation(s). The substation load calculation output provided per-second power demand, Root-Means-Square (RMS) KVA and peak power demand for each substation and for a single feeder supplying all substations.

Since the per-second power demand of APM systems varies significantly over a headway period, the RMS KVA was calculated from the per-second power demand data for each substation. Using the RMS function on the per-second KVA data, instead of an averaging function, imposed a design margin that weights the peak values.

Initially, train performance was for a typical AC technology APM vehicle and train model operating on the recommended guideway and station layouts. A set of simulations was run for each system phase to generate appropriate data to develop system substation capacity requirements data and assumed maximum passenger loading. The Stage I fleet assumed three, one-car trains and the Stage 2 fleet assumed eight, three-car trains.

The train performance prediction data was applied to the Power Demand Analysis using an Automatic Train Control (ATC) design headway of approximately 90 seconds for the on-airport service that was derived from an estimation of the minimum non-interference headway and was used to generate conservative design requirements for the power distribution system. Model estimates of the operational electric power demands are performed using operations schedules to predict annual energy consumption.

The number of trains needed to meet the demand of Stage I and II was determined by comparing the required capacity with the provided capacity. The analysis considered operational alternatives as either a dual-lane shuttle or as a pinched-loop. The results indicated that the dual-lane option would not provide a better frequency of service to passengers than the current bus operation. Therefore, the pinched-loop configuration was determined to be the optimum choice.

## RIDERSHIP CONSIDERATIONS

Ridership estimates have been developed from the passenger forecasts in the *Aviation Demand Forecasts West Terminal EIS Phoenix Sky Harbor International Airport* by Leigh Fisher Associates, dated November 2002. Estimates through 2015 have been used to help size the APM requirements and the associated facilities.

Ridership will grow over the years, but by 2015 the demands are expected to require capacities that average about 2,600 people per hour/per direction (pphd). The split in demand by terminals will vary over the years, with Terminal 4 having the major share in the near term. The ridership projections are based on current business models and likely future growth scenarios. They consider distribution of airlines among the three terminals and other limiting factors such as ultimate number of gates, baggage system capacity, etc. Ridership projections directly affect programmatic requirements, particularly platform size, vertical circulation, and emergency exiting. The ultimate demands served during Stage I are expected to be about 900 pphpd, but could be higher depending on the timing of the opening of Stage II.

### ESTIMATED CAPACITY AND TRIP TIME

The technologies available and those most likely to be implemented would produce typical round trip times of nine minutes or less for Stage I. Three, one-car trains with typical APM car lengths of about 40 feet, holding about 50 people, would provide line capacities of about 1,000 passengers per hour/per round trip. This would also provide a desirable 3.0-minute headway (or less) between trains. Dual shuttles, each with two-car trains, could be used in the event of a crossover malfunction. This would also provide a capacity of about 1,300 people per hour/per round trip, but headways of about 4.5 minutes.

### FLEET SIZE

With one spare car, the total Stage I fleet would be five vehicles, depending on the final ridership to be handled prior to the start of Stage II. Additional fleet are required for Stage II to create eight, three-car trains to operate at approximately 3.4 minute headways to provide about 2,600 pphpd. The total fleet for Stage II to accommodate demand up to 2015 is 29 vehicles. Additional vehicles may be required beyond 2015, either by making longer trains or adding trains to the fleet.

	Stage I	Stage II	Stage I & II
<b>Guideway dual lane ft</b>	7,768	16,842	24,610
<b>Number of switches</b>	12	28	40
<b>Number of stations</b>	3	3	6
<b>Max. station length</b>	1-car trains	3-car trains	3-car trains
<b>Estimated fleet</b>	5	24	29

### RELIABILITY AND AVAILABILITY CONSIDERATIONS

Reliability and availability will be key factors in the technology selection. Reliability refers to the lack of system failures that can disrupt operations of the APM trains, normally referenced in terms of "mean time between failures." Availability is a combination of the system reliability and the required time to restore the system to operation after a failure. Availability is then expressed in terms of the percentage of the scheduled operations time that the system is actually operating.

While reliability is best with the simple systems, with fewer parts to fail, overall availability is best with the greater complexities of highly redundant systems that can continue operations even after some failures.

For this application it is critical that the APM system have high availability. To reach most of the airport destinations served by the alignment, walking is not a realistic alternative because the distances are too great. Maintaining a backup bus system with adequate capacity would be cumbersome to operate and very non-responsive due to the time required to initiate service. Based on their operating history, the APM technologies will be capable of achieving availability in excess of 99 percent in this application.

## PASSENGER COMFORT

Many factors affect passenger comfort, including at least the following: smoothness of ride during acceleration and braking; noise and vibration levels; light levels; heating/ventilation/air conditioning characteristics; seating and stanchion arrangement; boarding and alighting door configurations; size of gaps between vehicle floors and station platforms; and availability of communications systems. Most of these are governed by industry standards, such as the *Automated People Mover Standards* (ASCE 21-96) published by the American Society of Civil Engineers.

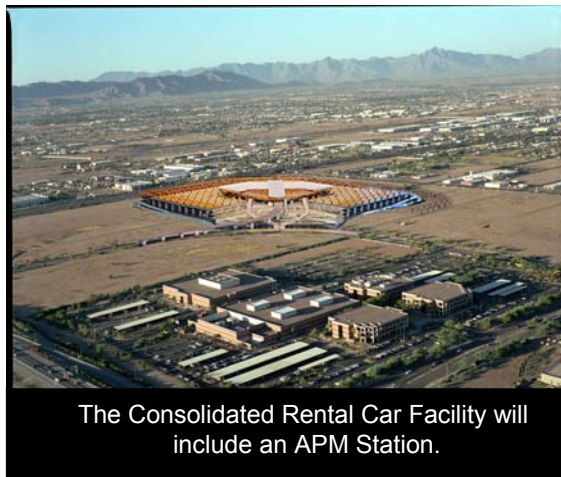
The key variable among the technologies is the door configuration, including the door-open width and the number of doors per side of each train. Wider doors allow better flow of passengers with baggage. Greater numbers of doors per side (closer spacing between doors) will encourage better distribution of passengers. These dimensions are important to the analysis of congestion on the boarding platforms as well as internal vehicle circulation congestion.

## STATION CONFIGURATIONS

A significant design consideration involves the quality of the passengers' experience and is directly related to the character and quality of the built environment. Form, materials, light, color, and sound influence the experience. The challenge is to design a public passage that is clear, well lit, safe, convenient, and inviting.

The approach to underground station design is exactly opposite of how one usually goes about designing a building. After analyzing the functions, one usually masses the outside to relate to the context; but an underground structure has no exterior architectural expression (with the exception of the entrance), so one carves away the earth to create a sequence of interior spaces.

Design issues and systems that are commonplace above-ground need special focus and solutions below grade. In a typical above-ground building, natural light is a given, while underground, opportunities for introducing natural light must be created. All of the typical building components are required— structural, mechanical, electrical, and plumbing— but underground they take on a heightened importance. The structure is holding back the weight of the earth and groundwater; the mechanical systems provide all the air and electrical systems that replace daylight. To counteract the natural human reaction to going underground, visual and audible clues can be provided through signage, art, lighting, and sound. Glass elevators and the elimination of blind corners, combined with visible CCTV cameras, provide increased security. It is important to think the station through and explore its passenger potential and its long-term impact.



The Consolidated Rental Car Facility will include an APM Station.

## TUNNEL CHARACTERISTICS

Stage I includes two tunnels of 21-foot outside diameter each and an approximate total length of 8,000 lineal feet. Two stations, one each at Terminals 3 and 4, will provide access to the tunnels. The tunnels will be bored using an earth pressure balance type of Tunnel Boring Machine (TBM).

Accommodating the range of APM technologies under consideration requires a tunnel with an inside diameter of 18 feet and an outside diameter of 21 feet. The minimum separation between the tunnels is 11 feet, or one-half the tunnel diameter. The minimum outside dimension of the two-tunnel cross section is 53 feet. If the center-to-center track dimension of the minimum cross section were maintained in the station area, then the width of the passenger platform would be 21 feet. The usable platform area would be less to account for the thickness of the train screen doors that are required by the driverless APM technology. The station platforms are planned to be approximately 170 feet in length. If the platforms are staggered, then the length will be about 340 feet.

At Terminal 4, the station structure will be directly beneath the terminal structure, under baggage claim areas and car rental facilities. At Terminal 3, the station will be outside the terminal footprint. The tunnels east of the station will run under the northern edge of the Terminal 3 garage and the north-south aircraft taxi lines and aprons. At Terminal 4, the existing structure is supported on piers with intermediate caissons. The approximate diameters of the caissons are 4 feet 6 inches and 7 feet. The maximum depth of the caisson is 80 feet below the ground surface. The existing terminal structure provides for a tunnel to be built under the terminal via a passage 60-feet wide. The clear width of this passageway is 52 feet.

A structural grade beam is provided for the tunnel roof. Originally, two 18-foot (inside diameter) tunnels were considered, based on available APM technology. Based on available subsoil data and the fact that the tunnel(s) would be constructed under an active terminal, it was decided to use two small diameter tunnels over one large diameter tunnel. This decision was based on reasons of safety, cost and control of settlements. The tunnels will be bored through subsoils consisting of dense to very dense sand, gravel, and cobbles with occasional silt or clay binder.

## PROGRAM IMPLEMENTATION

The implementation and execution of the Stage I APM construction will be a multi-phased process. This implementation strategy takes into account the many disruptions to airport operations that must be minimized. Since the APM will be constructed within congested and operating surroundings, the following needs are receiving particular consideration:

- Preserve the convenient circulation and safety of passengers and vehicles during construction.
- Maintain roadways and vehicle circulation routes during construction.
- Minimize the need for temporary facilities, roadways and other temporary construction.
- Consider factors related to cost, climate, and seasonal construction variables that could impact completion.
- Maintain airfield operations during implementation and construction.
- Design and plan for construction to be sensitive to traffic, land use and other "edge" impacts on the surrounding community.
- Design for incremental, phased construction.
- Minimize interruptions to the airport operational functions.
- Design to be flexible for changes.



The APM will be implemented with minimal disruption to existing roadways.

## CONCLUSION

The APM system would improve the level of service from the LRT/APM connection to Terminals 3 and 4 and accommodates passengers through the 2015 planning period. Improving passenger convenience, connecting to the upcoming city light rail and reducing roadway congestion will help enhance the overall performance of one of America's fastest-growing airports. Without this APM, significant delay would result to the passengers, adversely impacting the airlines.

## REFERENCES

- DMJM Aviation/HDR, 2001. Automated People Mover Program Technical Report.  
DMJM Aviation/HDR, 2002. Analysis of an East APM Extension to LRT Airport Station.  
Lea+Elliott, Inc., 2001. Phoenix Sky Harbor International Airport APM Planning Study.  
Lea+Elliott, Inc., 2001. Phoenix Sky Harbor International Airport APM Planning Study Addendum.  
Lea+Elliott, 2002. APM Alternative Alignment: LRT Station.  
Nicols, Judy. Sky Harbor to Build People Mover. *The Arizona Republic*, January 30, 2003: Page 1.