The use of automated people mover (APM) technology is one of many ways that passenger flows inside large airport terminals can be improved. Without adequate airport terminal transit technologies, passengers would probably incur intolerable walking distances and large aircraft-to-aircraft transfer times at major hub airports. Airport terminal expansion continues a growing trend to accommodate passenger demands for air travel that in the United States alone reached 643 million enplanements in 1998. The number of enplanements is expected to grow to 991 million by the year 2010 (1).

APM systems are fully automated and driverless vehicles that operate on a fixed guideway through an exclusive right-of-way. The first installation of an APM system at a major U.S. airport was at Tampa International Airport in 1971 (2). Today, 15 U.S. airports have APM technology. Several more are planned to enter service shortly.

The integration of transit technologies at airport terminals requires careful planning and a good understanding of the interactions between passenger and transit flows. This integration process can be expedited with the use of computer models to quickly estimate measures of effectiveness (MOE) for various terminal configurations under various passenger demand load conditions. The computer models used in the planning of airport terminals must be easy to use and reconfigure. This increases the opportunity to study multiple airport terminal configurations, including the execution of a sensitivity analysis for each configuration, in short periods of time. Odoni and de Neufville (3) provide an in-depth analysis of airport terminal design practices and their relation to computer models. The authors suggest, among other things, the need for better integration between preliminary and detailed models for airport terminal design.

The objective of this paper is to describe a flexible APM computer simulation model (APMSIM) that can be used to analyze the operational characteristics of APM systems at airport terminals. The model simulates an APM system by using both discrete-event and continuous simulation language constructs that allow airport planners and designers to

1. Model passenger flows and APM vehicle movements at airports;
2. Determine the sensitivity of system performance for a range of APM design parameters, such as capacity, station dwell time, safe headway, and speed;
3. Estimate APM vehicle energy consumption on the basis of network constraints and system characteristics; and
4. Examine the flexibility of an APM system under given service policies, demand functions, and network configurations.

The main thrust in the development of APMSIM has been the lack of easy-to-use models that can be used to provide an understanding of the interactions between airport passenger terminal and APM vehicle flows. Several computer simulation models developed to study airport passenger terminal flows are documented in the literature (4). Most of these models do not have an explicit logic that can be used to model APM systems. Sproule (5) and Elliot and Norton (6) have presented descriptions of airport terminal APM systems. The literature has many good examples of APM design practices, including numerous references devoted to airport applications (7–14). Some models have focused on the economic aspects of APM design (15), whereas others concentrate on the operational aspects of the APM design (16, 17). Unfortunately, the models in the latter category are proprietary in nature and not publicly available.

**METHODOLOGY**

A hybrid computer simulation model was developed with EXTEND, a general-purpose simulation software developed by Imagine That, Inc. (18). EXTEND provides a convenient graphical simulation language that represents complex queueing and transportation processes such as those that represent flows of passengers, baggage, and vehicles inside an airport terminal. An EXTEND simulation model consists of interconnected blocks that represent different parts of simulation processes. EXTEND uses a series of libraries to store all blocks. These blocks can be either blocks that are available in the language and that are loaned from existing libraries or user-defined blocks created from scratch (which is the case for the models presented here). Plenty of simulation languages with which one can model airport terminal passenger flows are available. Some representative languages are GPSS, Simscript II.5, SLAM, Arena, and STELLA (19). EXTEND was chosen because it represents one of the most user-friendly environments available in personal computers today. It is also one of the few simulation languages available for use with both Microsoft Windows and Apple Macintosh.
operating systems. This last point was an important consideration in the simulation model development process.

The specifications for any simulation model require basic definitions of entities (system components), activities, attributes, events, and their relationships. The concepts of event, process, and activity are important in the construction of a model of a system. An event signifies a change in the state of an entity. A process is a sequence of events ordered in time. An activity is a collection of operations that transform the state of an entity. An event is the occurrence of an activity at a particular instant of time. These definitions are consistent with those found in the general simulation literature.

The model considers only entities (system components) of the real system environment that could cause significant effects in the decision-making process. Each type of entity has a distinct set of attributes associated with it. APMSIM contains several major entities that fall into two categories: (a) the station model and (b) the guideway model. The station model is defined in terms of seven entities: (a) circulation area or passageway, (b) elevator, (c) entrance or exit, (d) escalator, (e) platform, (f) sidewalk, and (g) stairway. The guideway model is defined in terms of five entities: (a) two-way switch facility, (b) merge or diverge guideway, (c) pinched-loop guideway, (d) single-lane guideway, and (e) turnaround facility. These components are represented as blocks in EXTEND and are shown graphically for the two models in Figures 1 and 2, respectively.

Two additional essential components of the APM model are passenger and transit unit (TU) flows processed through the airport system. In the APM simulation model, most entities are built as an individual block or hierarchical blocks in which an event, an activity, or a process occurs. Attribute data are input directly into EXTEND block structures through simple data fields.

In APMSIM arriving and departing passengers are treated as scheduled events. Like scheduled events for arriving and departing passengers, the arrival activities (mostly at the beginning of the simulation) of TUs are also treated as scheduled events that generate new TUs in the system. In most cases, the simulation does not delete TUs from the system; that is, the TU departures are not only activities but are also events. A detailed discussion of the events and their associated activities is given in the simulation model logic section.

**FIGURE 1** Basic APM system model blocks.
Model Assumptions

To create a flexible and reliable simulation model, the following basic assumptions that characterize the APM system are made:

1. The user specifies the duration of the simulation for a particular system.
2. The simulation requires the passenger origin-destination linkages to be identified and known by using passenger schedule blocks (denoted Pax-schedule blocks in the APMSIM software) for a specified time period.
3. Boarding and alighting passenger flows are mixed and are simulated together with vehicular flow.
4. New passengers added in the model are only from stations that use Pax-schedule blocks. The new TUs added in the model can be generated at stations or on the guideways by using vehicle schedule blocks (denoted Veh-schedule blocks in the APMSIM software).
5. Passengers on escalators and sidewalks do not walk on these facilities.
6. Passengers alight first and then board when TUs arrive at stations.
7. The boarding time per passenger is currently deterministic. However, it can be modeled by using any 1 of 27 built-in distributions available in the original EXTEND package.
8. The simulation model accounts for transfers as an exogenous variable.
9. The TU safety headway strategies are controlled by vehicle schedule by using Veh-schedule blocks.
10. The descriptions of the characteristics of all TUs are the same. For example, the mass and performance properties of all TUs are the same.

11. Station dwell time is modeled as a constant. However, it can easily be converted into a stochastic variable if known data exist.

12. A station can be located only at the end point of a guideway section.

13. Up to 10 TUs can be simulated at one time. If more than 10 TUs enter the simulation, they are handled without the creation of energy consumption files.

14. The interstation distance and the performance parameters of the TU dictate the cruise speed of a TU.

15. The acceleration rate of a TU is not constant and is derived from equations of motion by consideration of TU tractive effort and resistance.

16. The braking deceleration of a TU is constant.

17. The total resistance of a TU considers only aerodynamic, rolling, and gradient resistances and is calculated on the basis of a modified Davis equation (see Equation 3).

Simulation Model Logic

The APM simulation model, based on a graphical user interface, reflects the real system environment through a block diagram that represents an APM network (Figures 3 and 4). The simulation model logic is based on the estimation of two distinct flows: (a) passenger flows and (b) TU vehicle flows. Thus, all the blocks set in the model represent the actual flow patterns of the system environment. The boarding and alighting passenger flows are mixed as a biflow and are simulated in the model. By using the same passenger biflow paradigm, the inbound and outbound TU flows are simulated together. In addition, the flow patterns of passengers leaving and arriving at each station are simulated simultaneously with the modeling of the TUs’ progress through the guideway network. A process-oriented approach is applied to describe the simulation model logic, in which passengers and TUs are treated as entities that form flows through the system. During the development of a particular model, it is important to determine what characteristics of the system are to be simulated in great detail. Others can be simplified to make the model more flexible and easier to manage. APMSIM is intended to study the levels of service (LOSs) of facilities, passenger queuing and delay, and TU speed and energy requirements. Therefore, the operations of each station and the performance of each TU on the guideway are simulated in great detail.

In operational terms, the APMSIM simulation model components are stored as user-defined libraries in EXTEND. To construct a new model the analyst uses these libraries to build a model graphically. Each block available in the model libraries is dragged and dropped into the EXTEND simulation environment. Connections between blocks are established, and the simulation model is ready to run. In some cases it is necessary to initialize some APM parameters if default values are not consistent with those of the system being analyzed.

APM Station Model

The identification of the station system is the first step in the development of the APM station model. The model suggests that a station is modeled as a series of system component blocks in which events occur, and each block represents a basic type of functional activity. Two sample station models are shown in Figure 4. The second step is to identify the system components (entities), attributes, activities, and events that occur in each system component. There are two basic entities within the station system: (a) passengers and (b) TUs. The dynamic feature of the model is that activities occur within each system component block. That is, the activity within the

![Diagram of Atlanta Hartsfield International Airport APM guideway model.](image)
block performed by passengers or TUs. The genesis of an activity is an event that may start or stop that activity. The possible activities and their associated events are listed in Table 1.

The demand estimation for APM users was defined by consideration of airline schedules, the size of the terminal facilities, and the number of stations passed. The best indication for general peaking effects in these systems at airports is the airplane arrival and departure schedule data. Passenger data by hour are just one of three types of data that can be entered into demand schedules in APMSIM. For quick analyses or for prediction of APM system performance in a horizon year (future scenario), a simpler block generator can represent aggregate demand flows as a function of time. Other potential ridership sources include

1. The number of individual transferring passengers who move directly from the arrival gate to the departure gate without baggage claims or ticketing.
2. The percentage of visitors, crews, and workers, which is considered to be known.
3. The number of passengers who travel between terminals and remote facilities, such as parking areas, rental car areas, city transit stations, and hotels.

Passengers arrive at their origin station at the time defined in Pax-schedule blocks and enter a boarding queue through station system components such as the escalator, stairway, and passageway facilities. When the simulated TU arrives, passengers alight if the particular station is their destination and then board if the TU has sufficient space and is headed toward their destination stations. Figure 4 illustrates the passenger flow patterns at two stations and includes system components such as entrance or exit, passageway, stairway, elevator, escalator, and one shared platform facility with guideway lines.

Three kinds of Pax-schedule blocks generate the arrival of passengers. Passengers arrive independently of each other on the basis of arrival rates, specific times, or distributed interarrival times that can be specified in the different Pax-schedule blocks. The Pax-schedule (Method 1) block is a hierarchical block that schedules a number of passengers into a facility at discrete intervals of time selected by the user. The input data for passenger demands are based on the exact arrival time and the number of passengers. In addition, the destination (station number) of each passenger should be assigned. The Pax-schedule (Method 2) block provides the number of passengers to the facilities at discrete intervals chosen by the user. The input data for passenger demands are based on the passenger arrival flow (passengers per second) and corresponding time vector (in seconds). This method provides a simple linear, piecewise approximation of demand curves. The Pax-schedule (Method 3) block provides the number of passengers to the facilities as a random probability distribution selected by the user. If necessary, these three blocks can also be combined or reused in the same model. Once the passenger arrival times have been defined, the destination stations of arriving passengers are specified on the basis of a general distribution. The total number of passengers arriving at a station is computed by using standard accumulator blocks provided in EXTEND. Several queue-server system blocks are provided to model various queuing elements that interface with the APM such as security-check processes.

Before entering a platform, passengers may pass through several system components. In the model each system component is built

FIGURE 4 Atlanta Hartsfield International Airport station submodels: (a) Baggage Station model and (b) Concourse A, B, C, and D Station model.
as a queue-server function. The maximum number of passengers allowed to enter a facility at one time is defined in terms of the number of servers at that facility. The processing times at each facility are defined by user-defined random distributions and their corresponding parameters.

The use of the platform and the TU blocks models the interactions that occur as passengers alight and board. They also model TU arrivals and departures. The alighting event removes passengers arriving at their destinations from TUs. The boarding event places passengers from the boarding queue, in particular, TUs that head to their destinations and have sufficient capacity. The door opening and closing times and the alighting and boarding times for each passenger control the number of passengers who alight or board during the station dwell time. The arriving and departing events are used to determine the time that the TU is dispatched as a function of the arrival time and the station dwell time. In addition, the activities of a shared platform with two guideway lanes and those of a separate platform with a single lane can also be simulated in the model. After alighting, passengers leaving a station may or may not use the same station facilities, depending on the system configuration.

**APM Guideway Model**

The APM guideway model represents the movement of the TUs on the guideway. The model contains all information about the physical guideway layout of the APM system to be simulated (see Figure 3 for a sample dual pinched-loop system model). The information contained in the APM guideway blocks provides a sense of the guideway configuration, the location of guideway interlocking, the locations of switches and crossovers, station locations, and control strategies. The simulation selects those locations where interactions and interferences between TUs and between TUs and passengers occur. These locations are simulated in greater detail than other portions of the system. Most interactions and interferences occur on station platforms and interlocking points such as switching, merging, and diverging points. These are therefore referred to as control points.
and have been selected to receive the most attention in the simulation. Between control points the TU movement is simulated only for energy consumption calculations.

Figure 2 lists the functional blocks used to build the APM guideway model. The network configurations that can be constructed with APMSIM include (a) single-lane shuttle, (b) single-lane shuttle with bypass, (c) double-lane shuttle, (d) single-lane loop, (e) double-lane loop, and (f) pinched loop with turnbacks. Safe headway separation is maintained according to a user-defined vehicle control strategy in the Veh-schedule blocks. TUs travel along predefined routes. The model keeps track of the current occupancy and the time integral of occupancy for all vehicles at each station, on each guideway section, and on each route of the network. At the control point of a station platform, passengers arrive at a station and wait in a queue until they can board a TU moving toward their desired destinations.

The network is modeled by dividing each route into blocks of one guideway section from one interlocking to another. An initial TU speed of zero is assigned to each TU at a station. After departing from a station, TUs move from one guideway section of a route to another one until a new station is detected. Attributes of each guideway section include the section capacity, cruise speed, breaking acceleration rate, and section length. At each section, the running speed, acceleration, travel distance, power requirements, energy consumption, occupancy, and load factors are calculated by the energy consumption model. This model uses a second-order numerical integration algorithm (the step size is within the user’s control) to estimate state variables forward in time.

The two-way switch blocks simulate the activity of a TU switched to another guideway. This block is useful to simulate single-shuttles with a bypass section. The merge-diverge blocks are analogous to the two-way switch except that one merge-diverge section allows TUs to stop and to wait for overtaking. Two-pinched-loop blocks are used to model pinched-loop guideway networks. The application of these blocks is illustrated in Figure 3, in which the Atlanta Hartsfield International Airport has been modeled in APMSIM.

**Energy Consumption Model**

This section describes how APMSIM includes a dynamic model of each TU to estimate train operation profiles. Variables computed in this model are TU speed, acceleration, travel time, travel distance, power requirements, energy consumption, occupancy, load factors, and the LOS along the guideway route. All these state variables are determined by using EXTEND’s MODL language simulation capabilities. Multiple integration of the TU acceleration profile provides speed and distance histories. The acceleration function of every TU is related to three profile phases. In the first phase, the TU moves at a prescribed acceleration rate calculated from the combination of tractive effort and resistance, as the traditional train simulations do. In the second phase (cruise), the TU moves at a cruising speed; thus, the acceleration is zero. The cruising speed is dependent on interstation distance. In the third and final phase (deceleration), the TU approaches a stop with a constant breaking acceleration rate. The distance traveled is derived from the numerical integration of the speed profile.

The energy consumption algorithm is encapsulated in the energy consumption block. This block considers various forces acting on the vehicle including (a) inherent rolling, (b) aerodynamic, and (c) gradient resistances. To calculate the inherent resistance a Davis equation is applied. In the model, the guideway route is described in terms of sections between stations. A grade and a nominal cruise speed characterize each section. The gradient resistance is considered only as a TU goes uphill. It is assumed that no power is required when a TU moves with a braking acceleration. The total energy consumption over the route is calculated as the integral of the power required over time. Some of the fundamental equations used to calculate TU resistances, power, and energy consumption are presented below.

The power required to move the vehicle at speed $V$ is calculated by:

$$ P = \frac{T(V)}{\eta} \tag{1} $$

where

- $P = \text{power developed by the engine(s) (in W)}$,
- $T = \text{the tractive force required to overcome the resistance forces (in N)}$,
- $V = \text{speed (in m/s)}$, and
- $\eta = \text{an efficiency factor}$.

The power is the time rate of doing work, which has units of energy consumption. Therefore, the energy consumed can be calculated by:

$$ E = 3.6 \times 10^{-4} \int P \text{d}t \tag{2} $$

where

- $E = \text{energy consumed in kilowatt-hours (in kWh)}$,
- $P = \text{power (in W)}$, and
- $t = \text{the operating time (in s)}$.

The major contributors of total energy consumption per APM TU between two stations are (a) aerodynamic drag, (b) rolling resistance, (c) guideway resistance (flanges, joints), and (d) alignment resistance (gradient, curvature). For a TU traveling on a straight and level track, the resistance is usually estimated using the Davis equation:

$$ R_{(a+c)} = K_0 + \frac{K_1}{w} + B(V) + \frac{C A V^2}{w n} \tag{3} $$

where

- $R_{(a+c)} = \text{inherent resistance (aerodynamic + rolling resistances) (in lb/ton)}$,
- $w = \text{average load per axle (in tons)}$,
- $A = \text{cross-sectional area (in ft}^2\text{)}$,
- $B = \text{an experimental coefficient due to guideway conditions}$,
- $C = \text{drag coefficient or shape factor}$,
- $V = \text{velocity of vehicle (in mph)}$, and
- $n = \text{number of axles}$.

$K_0$ and $K_1$ are constant coefficients with magnitudes of 1.3 and 29, respectively. If the Davis equation is expressed in Standard International units, in which inherent resistance $[R_{(a+c)}]$ is in newtons/ newtons, average load per axle ($w$) is in newtons, cross-sectional area ($A$) is in meters squared, and velocity ($V$) is in meters per second, the following relationship applies:

$$ R_{(a+c)} = 5 \times 10^{-4} K_0 + 4.4480 \frac{K_1}{w} + 1.1187 \times 10^{-3} B(V) + 239.6904 \frac{C A V^2}{w n} \tag{4} $$

This equation does not include the resistance caused by alignment. $B$ and $C$ are coefficients applicable to different types of equipment. In addition, the gradient resistance is computed by using Equation 5:
Figure 3. Vehicular flow is counterclockwise from the south Ticketing Station to south Concourses A, B, C, D, and E. The TUs leaving Concourse E stop behind the switch, reverse direction, and cross over to the north guideway. The TU then travels to Concourses D, C, B, and A, followed by the Ticketing Station and the Baggage Station. The TUs then switch back to the south guideway and repeat the cycle.

**Model Assumptions**

The following data inputs are assumed in the development of this model application:

1. Vehicle characteristics.
   - Seven separate TUs of three vehicles each operate in the system during the simulation time.
   - Each vehicle has two doors opened at each station stop. The door opening or closing time is 1.5 s. The average passenger loading or unloading rate is 1 s/passenger.
   - Each vehicle can hold 65 passengers. The floor area of each vehicle is 25 m².
   - The weight of vehicle is 70 000 N. Each vehicle has two axles, and its cross-sectional area is 9 m².
   - The power efficiency is 0.85. The experimental coefficient is 0.03, and the drag coefficient is 0.00034.

2. Network
   - The average cruise speed on the guideway is 10 m/s, and the breaking acceleration is 1 m/s.
   - The guideway gradient is +0.2 percent from the Baggage Station to Concourse E.
   - The station dwell times are nominally 35 s for all stations.
   - The minimum safety headway is 120 s.

3. Station characteristics
   - The Baggage Station has a shared platform, two escalators up, one escalator down, one elevator, and one stairway.
   - The Ticketing Station has one shared platform, two escalators down and one escalator up, one elevator, and one stairway.
   - At the stations at each of Concourses A, B, C, and D there are two separate platforms, two pairs of escalators, one elevator, and one stairway for boarding and alighting passengers.
   - At the Concourse E Station there is a shared platform, two escalators up, one escalator down, one elevator, and one stairway (Figure 4).
   - The area of each station platform is 355 m². The escalator dimensions are as follows: width, 1.2 m; length, 30 m. The escalator speed is 0.5 m/s. The trip time in the elevator is 20 s, and the area is 6 m². The area for each stairway is 90 m².
   - The probability that passengers will enter platforms by taking escalators is 95 percent, the probability that passengers will enter platforms by taking elevators is 2 percent, and the probability that passengers will enter platforms by taking stairways is 3 percent.
   - It is assumed that 100 percent of all passengers will use the APM system facility when they enter or leave terminals and concourses.

4. Network
   - The average cruise speed on the guideway is 10 m/s, and the breaking acceleration is 1 m/s.
   - The guideway gradient is +0.2 percent from the Baggage Station to Concourse E.
   - The station dwell times are nominally 35 s for all stations.
   - The minimum safety headway is 120 s.

5. Station characteristics
   - The Baggage Station has a shared platform, two escalators up, one escalator down, one elevator, and one stairway.
   - The Ticketing Station has one shared platform, two escalators down and one escalator up, one elevator, and one stairway.
   - At the stations at each of Concourses A, B, C, and D there are two separate platforms, two pairs of escalators, one elevator, and one stairway for boarding and alighting passengers.
   - At the Concourse E Station there is a shared platform, two escalators up, one escalator down, one elevator, and one stairway (Figure 4).
   - The area of each station platform is 355 m². The escalator dimensions are as follows: width, 1.2 m; length, 30 m. The escalator speed is 0.5 m/s. The trip time in the elevator is 20 s, and the area is 6 m². The area for each stairway is 90 m².
   - The probability that passengers will enter platforms by taking escalators is 95 percent, the probability that passengers will enter platforms by taking elevators is 2 percent, and the probability that passengers will enter platforms by taking stairways is 3 percent.
   - It is assumed that 100 percent of all passengers will use the APM system facility when they enter or leave terminals and concourses.

6. Scenario Analysis
   - The following data inputs are assumed in the development of this model application:
     - Vehicle characteristics.
     - Seven separate TUs of three vehicles each operate in the system during the simulation time.
     - Each vehicle has two doors opened at each station stop. The door opening or closing time is 1.5 s. The average passenger loading or unloading rate is 1 s/passenger.
     - Each vehicle can hold 65 passengers. The floor area of each vehicle is 25 m².
     - The weight of vehicle is 70 000 N. Each vehicle has two axles, and its cross-sectional area is 9 m².
     - The power efficiency is 0.85. The experimental coefficient is 0.03, and the drag coefficient is 0.00034.

   - Network
     - The average cruise speed on the guideway is 10 m/s, and the breaking acceleration is 1 m/s.
     - The guideway gradient is +0.2 percent from the Baggage Station to Concourse E.
     - The station dwell times are nominally 35 s for all stations.
     - The minimum safety headway is 120 s.

   - Station characteristics
     - The Baggage Station has a shared platform, two escalators up, one escalator down, one elevator, and one stairway.
     - The Ticketing Station has one shared platform, two escalators down and one escalator up, one elevator, and one stairway.
     - At the stations at each of Concourses A, B, C, and D there are two separate platforms, two pairs of escalators, one elevator, and one stairway for boarding and alighting passengers.
     - At the Concourse E Station there is a shared platform, two escalators up, one escalator down, one elevator, and one stairway (Figure 4).
     - The area of each station platform is 355 m². The escalator dimensions are as follows: width, 1.2 m; length, 30 m. The escalator speed is 0.5 m/s. The trip time in the elevator is 20 s, and the area is 6 m². The area for each stairway is 90 m².
     - The probability that passengers will enter platforms by taking escalators is 95 percent, the probability that passengers will enter platforms by taking elevators is 2 percent, and the probability that passengers will enter platforms by taking stairways is 3 percent.
     - It is assumed that 100 percent of all passengers will use the APM system facility when they enter or leave terminals and concourses.
contributed to Atlanta's increase in passenger traffic were Delta, ValuJet, Continental, and Kiwi International. Today, 50 percent of the airport's passenger trips originate or end in Atlanta. For the model, the typical weekday peak-hour arrivals are extracted from the *Official Airline Guide* (21). It is assumed that half of the arriving passengers are transfers and that the connecting concourse of each passenger is based on a random distribution. All enplaning passengers start arriving at the APM station between 30 and 20 min before the departure time. The busy hours occur from 11:30 a.m. to 1 p.m., with a total of about 88 flights arriving, and the simulation time was set from 12:00 p.m. to 1:00 p.m. The demand in the horizon year (2010) is assumed to reflect a 30 percent increase from that of the base year. The service facilities are assumed to remain the same as in the scenario for the base year.

**Model Results**

Some representative results of the APM simulation model are shown in Figures 5 through 8. Figure 5 illustrates basic kinematic

![Travel Distance](image)

**FIGURE 5** Travel distance (a) and vehicle acceleration (b) versus simulation time profiles for TU 4 traveling from Ticketing Station to Concourse A Station.
relationships for a sample TU. Figure 5 shows travel distance and acceleration versus simulation time for one TU (labeled TU 4). Figure 6 illustrates the time histories of the power required and the energy consumed as the TU travels between two stations. Since the model uses continuous simulation, it is possible to assess variables related to the TU state in great detail. Figure 7 shows the time histories for the average passenger waiting times and passenger queuing at a typical APM platform. Figure 8 illustrates the time histories of two LOS metrics: area per passenger and the cumulative number of passengers entering and leaving the APM station. Note that LOS is measured as the area per passenger at the platform. Since the model presents dynamic variations over time for each MOE, running averages can be computed to estimate "static" measures of effectiveness and can be compared with traditional airport terminal LOS indicators.

FIGURE 6  Power required (a) and energy consumption (b) for TU 4 traveling from Ticketing Station to Concourse A Station.
CONCLUSIONS AND RECOMMENDATIONS

The APM simulation model described in this paper represents a prototype designed to provide planners and designers with a flexible computer model that they can use to analyze APM systems. The output information provided by APMSIM includes various APM measures of effectiveness such as waiting times and passenger space allocations at various airport terminal areas. Other measures of effectiveness computed in the model are passenger queuing, travel times for individual TUs, the number of passengers traversing the system, vehicular load factors, vehicular speed, power requirements, and energy consumption. This information could be useful to airport planners and designers in the evaluation of candidate APM systems.

The following conclusions are derived from the development of this prototype hybrid simulation model:

1. One of the major benefits of APMSIM is its ability to model various types of APM system configurations quickly.
2. The model developed is useful for estimation of the effects of policy changes in existing or new systems. Important variables such as the number of vehicles per TU, the number of TUs, cruising
speed, safety headway, station dwell times, and passenger demand functions can easily be changed.

3. The guideway model blocks provide the capability to easily model alternative service concepts such as shuttles, loops, and single or double routes.

The main recommendations as a result of the experience gained during the development of APMSIM are as follows:

1. It is necessary to increase the capability of the APM simulation model so that it can accommodate more sophisticated system control strategies, such as flexible station dwell times affected by variations in passenger demand and loading-unloading rates and the possibility of nonstop service at some stations for particular TUs.

2. The APM system developed in the present study should be integrated with airport landside simulation to produce more accurate results. This effort is necessary as APMs are just one integral part of the airport system. The same simulation framework used is extensible to accomplish this.

3. It is necessary to validate a model like the one described in this paper. The resources to do this went beyond the scope of this 8-month development effort.
REFERENCES


Publication of this paper sponsored by Committee on Airport Terminals and Ground Access.