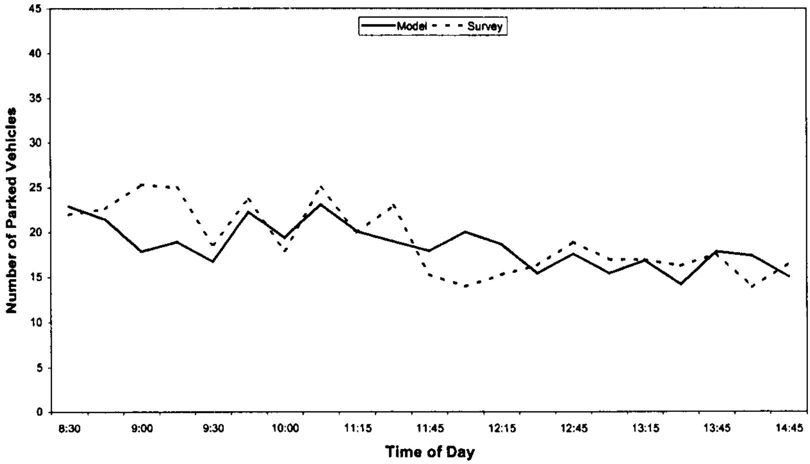
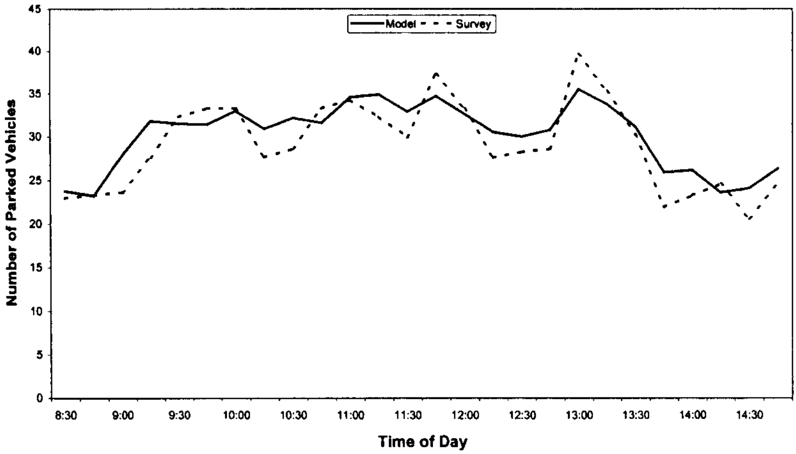
consecutive 5-minute parking counts. The number of parked vehicles from the model in a 15-minute time interval is the average number of three snap-shots in 5-minute apart. Given the data availability and quality of the data, the method for validating the exit flows is used in our parking validation.



(a) Departure Curbside



(b) Arrival Curbside

Figure 4 Vehicle Parking Comparison in 15-min Time Intervals

As it can be visually inspected from Figure 4, the simulation model's parking outputs do trace the general trend of the survey data but it fails to predict the local highs and lows. The statistical tests fail to give encouraging results to conclude that the number of predicted (model) parking is no different from the surveyed parking data.

However, based on reasons explained earlier, the comparison of the number of parked vehicles between the model outputs and the survey data by using the snapshot samples is not completely fair. Given that no better data or methods are available to conduct dependable and further analyses, we do not want to draw the conclusion that the parking logic is not valid. This part of model validation needs to be further investigated as soon as more reliable parking data become available and a fair comparison method is designed.

Model Applications

Two model applications are introduced in this paper. The first application addresses the impacts caused by the closure of a portion of the roadway and curbside. The second application analyzes the roadway and curbside operations under different traffic demand levels.

Closure of Roadway and Curbside

In this application, we presume that a 200 linear feet (approximately 8 curbside parking spaces) of curb space in the middle of the innermost curb lane (immediately adjacent to the curb area) is closed for maintenance or construction work. Vehicles are not allowed to travel or to perform curbside parking in this area.

The same traffic flows collected in LAS are input in the model and everything else, such as vehicle moving logic and curbside dwell time distribution, is kept the same. Table 6 shows the traffic delay with and without the closure. Table 7 shows the impact to the number of vehicles that cannot find a curbside parking space due to insufficient curb space.

Table 6 Average Vehicle Delay with and without Lane Closure

Roadway	Peak Hour Delay (sec/veh)		Non-Peak Hour Delay (sec/veh)		Daily Delay (sec/veh)	
	No Closure	Lane Closure	No Closure	Lane Closure	No Closure	Lane Closure
Departure	25.9	32.5	12.5	16.3	16.0	20.6
Arrival	36.2	35.5	19.6	24.1	23.5	26.6

As it can be seen, the lane closure does cause significant impact to the traffic – especially for the arrival roadway and curbside. It is interesting to see that the peak hour delay in the arrival roadway with lane closure is less than the peak hour delay without the lane closure. The reason is that most (about 2/3) of the vehicles entering the arrival roadway during the peak hour could not find a curb space and they have to leave. They do not incur a lot of delays while traveling the roadway. As a result, the average delay is less as compared to the no lane closure situation.

Table 7 Number of Vehicles that Cannot Find a Curbside Parking Space with and without Lane Closure

Roadway	Peak Hour No Parker (veh)		Daily No Parker (veh)	
	No Closure	Lane Closure	No Closure	Lane Closure
Departure	*	9	1	52
Arrival	79	345	403	2,328

* indicates the average number is less than 1 vehicle

Various Traffic Demand Level

Three traffic demand levels (TDL): 10 percent (TDL1), 20 percent (TDL2), and 30 percent (TDL3) above the August 1996 traffic demand (TDL0) are created as input to the simulation model. Everything else remains the same. The traffic demand might have not reached the roadway and curbside capacity (except in the Arrival roadway during the peak hour).

1. The simulation model only has homogeneous traffic and passenger behaviors in the logic. The logic for vehicle and passenger behaviors remains the same regardless of traffic demand level and degree of congestion. To better model these behaviors, more extensive data collection and analysis must be performed.
2. Unrealistic traffic demand and vehicle re-circulation pattern. From the traffic survey data, there is no way to precisely identify how many vehicles were circulating around the terminal roadway if they could not find a curbside space. Using the survey data for the base case (TDL0) simulation analysis does not create a problem, since all the re-circulating vehicles are already contained in the traffic survey. However, the expanded traffic demands (TDL1 through TDL3) simply grows the base case traffic by a percentage, there is absolutely no way to tell if the re-circulating traffic is properly represented.

Table 8 exhibit the average peak hour, non-peak hour and daily traffic stopped-time delays of the four TDLs from the output statistics. Table 9 shows the average number of vehicles that cannot find a parking space in their desired parking zone along the curbside during the peak and non-park hours.

It is worth mentioning that the trend of traffic delay seems to be linearly dependent on the TDL. This result contradicts the intuition that the traffic delay should have an exponential increase with respect to the increase in traffic flows, especially at near roadway capacity flows.

Summary and Conclusions

In this paper we presented a working simulation model that can be used as a tool to assist airport planners and decision makers in evaluating the performance of the airport curbside parking facilities. The results of model validation indicate that the model produces very good traffic flow predictions for the Departure and Arrival roadways. These results also indicate that the model is fully capable to predict exit flows and vehicles' time spent in the curbside facilities. Although the vehicle parking validation results were not as good as the traffic flow prediction and the vehicle system time validation results; as discussed before, due to anomalies in data collection, an accurate parking validation analysis could not be performed and the results reported in the paper are at best inconclusive.

Table 8 Average Delay Comparisons of the Four TDLs

Traffic Type	Traffic Demand	Peak[1] Hour Delay (sec/veh)	Non-Peak[2] Hour Delay (sec/veh)	Daily Delay (sec/veh)
Departure	TDL0	25.9	12.5	16.0
	TDL1	31.1	15.7	19.6
	TDL2	36.3	19.4	23.5
	TDL3	39.1	22.6	26.9
Arrival	TDL0	36.2	19.6	23.5
	TDL1	36.2	23.1	26.3
	TDL2	37.4	25.8	29.2
	TDL3	37.1	28.8	31.6

1. Peak hour for the departure traffic is 10:15 to 11:15 a.m. and 10:00 to 11:00 p.m. for the arrival traffic.
2. Non-peak hour is defined as the time after 11:30 a.m. till the end of day for the departure traffic and the hours from 5:00 a.m. till before 10:00 p.m. for the arrival traffic.
3. Delays will not accumulate until the vehicle enters the curbside area.

Table 9 Number of Vehicles Cannot Find a Curbside Parking Space

Traffic Type	Traffic Demand	Peak Hour No-Parker (veh)	Daily No-Parker (veh)
Departure	TDL0	*	1.1
	TDL1	*	1.7
	TDL2	*	3.3
	TDL3	*	5.4
Arrival	TDL0	79.2	403.4
	TDL1	103.0	642.4
	TDL2	133.8	923.0
	TDL3	168.8	1203.7

* indicates the average number is less than 1 vehicle

The results of the model validation as well as model applications reported in the paper indicate that this simulation model can be a very useful tool in analyzing the airport terminal roadway and curbside parking operations. This model can easily be embedded in a decision support system for airport planners and decision makers to examine different what-if scenarios during the planning and design stages.

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Aviation Simulation with SIMMOD

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Abstract
Aviation simulation tools help planners make informed decisions. This paper discusses the role of simulation in aviation planning and the types of simulation tools used today. The FAA's airport and airspace simulation, SIMMOD, is described, and several SIMMOD applications are detailed.

What is Simulation?
Edward Russell (Russell, 1983) offered the following working definition for simulation:

- *A simulation of a system is the operation of a model that is a representation of the system.*
- *The model is amenable to manipulation that would be impossible, too expensive, or impractical, to perform on the system it portrays.*
- *The operation of the model can be studied and from it properties concerning the behavior of the actual system can be inferred.*

Clearly, an airport system is one that lends itself well to simulation. The system is complex, and using a computer model to analyze the system is more feasible, cheaper, and safer than experimenting with the system itself.

Analytical methods may also be used to more quickly and cheaply solve aviation problems, but the results of these analyses tend to be less accurate. FAA Advisory Circular 150/5060-5 Airport Capacity and Delay, for instance, lists capacity and delay estimates for airports with various runway configurations and fleet mixes. The results in the Advisory Circular assume a specific flight schedule and runway layout which may not exactly match the conditions of the particular airport under study. The circular also incorporates limited estimates of airspace, taxiway, and gate capacity at the airport which may not correspond with the airport under study. These limiting assumptions serve to make the problem more manageable in relation to the analytical methods employed. In many ways,

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simulation is a tool that enables an analyst to manage the complexity of the analysis so that more interactions and issues can be considered within a single effort.

Several computer simulation tools exist today for aviation modeling, covering airside, landside, and environmental planning. Airside simulations analyze the movement of aircraft through airspace, runways, taxiways, and gates. Some also measure controller workload. Landside simulations examine terminal operations, including the movement of passengers, baggage, and ground transportation. Environmental models study noise levels and air quality at airports.

Aviation Simulation Models
Figure 1 lists some of the major aviation models available today.

	Airside	Landside	Environmental
Available Models	SIMMOD: FAA's Airport and Airspace Simulation Model	Sabre's ArcTerm	INM: FAA's Integrated Noise Model
	TAAM: Preston Group's Total Airspace and Airport Modeller	PBFM: ATAC's Passenger and Baggage Flow Model	EDMS: FAA's Emissions and Dispersion Modeling System
	Airport Simulation International's The Airport Machine	ARENA-based Models	
	RAMS: Eurocontrol Experimental Center's Reorganized ATC Mathematical Simulator	ALPS: JKH Mobility's Airport Landside Planning System	

Figure 1. Aviation Simulation Models

Airside capacity and delay models include SIMMOD, TAAM, The Airport Machine, and RAMS. SIMMOD is a low-cost model, produced and validated by the FAA, which has been used internationally since the late 1980's. The TAAM model is a high-cost model developed in the mid 1990's with sophisticated graphics capabilities and a rule-based decision system. The Airport Machine is an intermediate-cost model which simulates ground movement and a limited airspace. RAMS has limited availability, focuses on the airspace, uses a rule-base for conflict resolution, and calculates controller workload.

The ArcTerm and PBFM tools model the movement of passengers and baggage through airport terminals. ARENA is a general-purpose simulation tool from Systems Modeling Corporation that has been used to model passenger, baggage, and curbside vehicle movement. The ALPS model analyzes airport roadway systems, pedestrian, and vehicle flows, and features a terminal demand/capacity module.

Two environmental models are available from the FAA: INM, which calculates aircraft noise, and EDMS, which analyzes airport air quality.

A Look at SIMMOD

Let's focus on SIMMOD, an airport and airspace capacity and delay model. SIMMOD is a useful tool to quantify travel time, delay time, and capacity for an airport and airspace system. It can be used to measure the impact of increased traffic, and evaluate the benefits of physical or procedural modifications. Three types of data go into a SIMMOD study:

- the airport and airspace infrastructure, which is depicted as a link-node network,
- Air Traffic Control rules and procedures, and
- the aircraft schedule.

Rather than relying on textbook estimates, SIMMOD simulates the movement of all aircraft, step by step, resolving conflicts and keeping track of the travel and delay time along each segment. SIMMOD then produces tabular results of aircraft travel and delay time, and displays an animation play-back.

SIMMOD is an event-driven simulation written in Simscript II.5. The program runs on both PC and Unix, with the latest version running on a PC under Windows 95/98/NT.

Tampa Capacity Study

SIMMOD was used recently as part of the Tampa Master Plan to calculate annualized capacity. The existing condition at Tampa (TPA) was modeled with the flight schedule for an average day in the peak month. Figure 2 displays the SIMMOD link-node network for Tampa, including aircraft labeled with their flight ID.

Three future traffic scenarios were developed to reflect the forecast by duplicating a percentage of the existing flights, and scheduling the duplicate flight within the same time interval as the original. SIMMOD was used to calculate Tampa's long term (20-year) capacity and delay. Each runway configuration (North flow and South flow) and weather condition (Visual Flight Rules (VFR) and Instrument Flight Rules (IFR)) of the airport was analyzed with each of the traffic samples. A graph of the annualized delay per number of operations (delay curve) is shown in Figure 3.

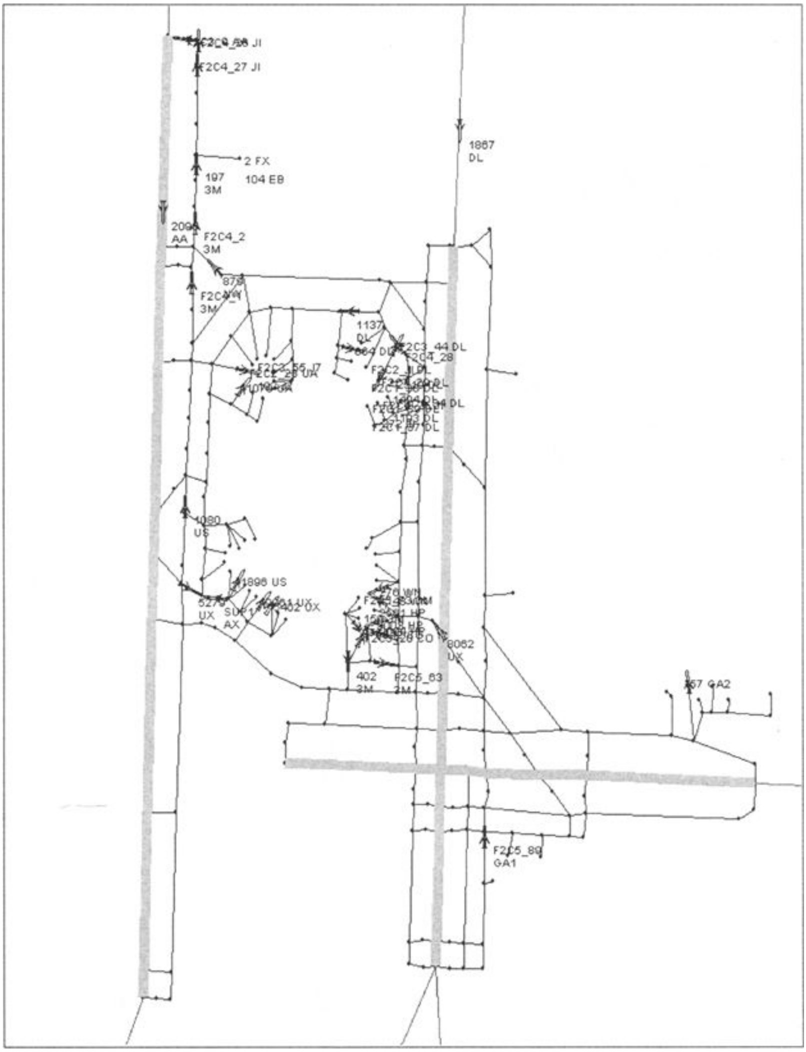

Figure 2. Tampa SIMMOD Animation

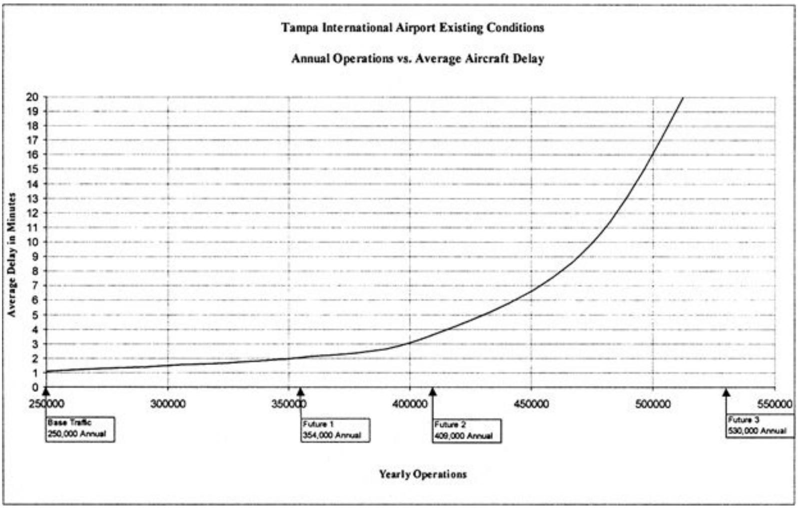

Figure 3. Tampa Annualized Delay Curve

The delay curve is used to estimate the practical capacity of the existing airport. Further, by examining a proposed improvement with the SIMMOD model and adding the improvement scenario's delay curve to the graph, one can quantify the impact of that alternative. The delay savings of the alternative may be weighed against the cost of implementing the alternative through a Benefit Cost Analysis.

Minneapolis/St. Paul Runway Reconstruction

A short-term SIMMOD study of Minneapolis/St. Paul (MSP) airport was performed to estimate delay and travel times during runway reconstruction. MSP is the major hub and headquarters for Northwest Airlines, with 510,421 operations in 1999. The airport has two parallel runways 1036 meters (3400 feet) apart and a 3353 meter (11,000 foot) crosswind runway that intersects both parallel runways. The level of traffic requires use of the two parallel runways a majority of the time.

Immediate, major reconstruction was required on Runway 12R/30L (the south parallel runway). SIMMOD was used in the planning of the runway reconstruction, both to test various runway use options and to prove to airlines that the construction delays could be minimized. The runway reconstruction was performed in two phases:

1) The northwest 1219 meters (4000 feet) of the runway was closed in Summer 1998, leaving 1829 meters (6000 feet) operational, and