AIR TRANSPORTATION DELAY IMPLICATIONS OF A LOCAL GPS OUTAGE IN THE U.S.: A SIMULATION STUDY

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Abstract

This paper reports the results of a simulation study of the impact on delay of local Global Positioning System (GPS) outages, with and without back-up secondary surveillance radar. This analysis will be used to help determine if the expense of back-up secondary radar is warranted at smaller airports in the U.S. once Automatic Dependence Surveillance – Broadcast (ADS-B) surveillance is available.

1 Introduction and Background

A key component of the Next Generation Air Transportation System (NextGen) is ADS-B, which will replace conventional radar as a surveillance source for Air Traffic Control (ATC) purposes [1]. With ADS-B an aircraft determines its own position and periodically broadcasts that position to ATC and other aircraft. When using GPS to determine the position of the aircraft such a system is as least as accurate as a secondary radar system.

Even though GPS is becoming more reliable, it is still subject to failure modes that may affect a local area. The GPS signal can become unusable due to interference (intentional or unintentional) from nearby sources that affect the frequencies in which GPS operates. Without any back-up surveillance system, ATC would have to revert to procedural separation to safely separate arriving and departing aircraft, as is currently done at airports without adequate radar coverage or during a radar failure. Consequently alternative back-up systems are being contemplated.

Since secondary radar is a proven technology it is a logical candidate for a reliable back-up system. While the Federal Aviation Administration (FAA) will maintain radar systems at the largest airports, the question remains whether back-up radar is needed at mid-sized airports to mitigate delays that might result from a local GPS outage. To help answer this question we used the MITRE Corporation's *runway*Simulator model to estimate the capacities of 30 candidate airports in three scenarios: with the anticipated ADS-B surveillance and associated NextGen procedures, with current radar procedures and local radar surveillance (corresponding to a failure of GPS and ADS-B), and with current procedures but without local radar (corresponding to a GPS failure but with no local radar). We then used these airport capacities in the FAA's National Airspace System Performance Analysis Capability (NASPAC) model to estimate the overall system delay given a local GPS failure, with and without local back-up radar.

The difference in delay between the scenarios with and without back-up secondary radar, once valued and adjusted for the probability of a local GPS outage, represents the cost of eliminating the back-up radar, in an expected value sense. This delay cost is compared to the life-cycle cost of keeping the radar capability at each airport.

2 Model Descriptions

2.1 *runway*Simulator

The capacities of the candidate airports were estimated using a simulation model developed by The MITRE Corporation's Center for Advanced

Aviation System Development (CAASD) called *runway*Simulator [2]. The definition of runway capacity used in this model is the *average maximum sustainable throughput* for a given fleet mix and arrival-departure ratio. *Throughput* is defined as the number of aircraft that use the runway system per hour, in a use pattern obeying the arrival-departure ratio and aircraft fleet mix. The fleet mix is the percentage of each aircraft type that uses the airport. There is an allowance for enough excess spacing between aircraft to account for typical controller and aircraft variability. Hence the throughput is *sustainable*, i.e., the airport can maintain this average throughput indefinitely. The *average* is over a long period of time. Although the fleet mix remains constant, the sequence and performance characteristics of the aircraft vary, so the hourly throughput varies over time.

The *runway*Simulator model has been used by MITRE for the domestic US and international projects to estimate the capacity of a system of runways. The model is very general and can be easily applied to any airport using any set of air traffic control rules. It is particularly useful for studying the dynamic interactions between traffic flows at complex runway systems involving several runways and using advanced Air Traffic Management (ATM) concepts.

The main output of the model is the capacity curve, as shown in Figure 1. Each dot in the diagram represents the number of arrivals and departures in a single hour of simulated time. Each cluster of dots contains the results for a particular arrival-departure ratio in the demand. The capacity curve is the line drawn between the mean values of each cluster.

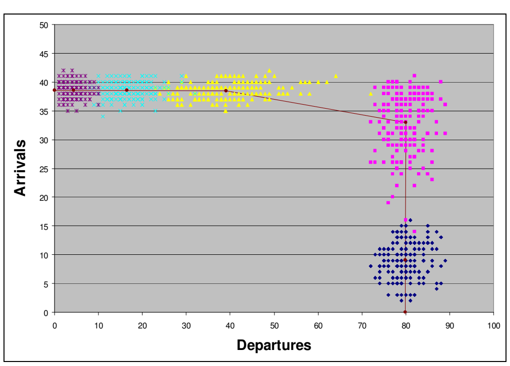

Fig. 1. Capacity Curve Example

All ATC separation rules are statements governing pairs of aircraft, stating how an aircraft in one phase of landing or departure restricts the areas in which another aircraft can be located. For example, in Instrument Meteorological Conditions (IMC) an aircraft within 2 miles of the threshold of the runway prevents a departing aircraft that is trying to use the same runway from beginning its departure roll. In the *runway*Simulator model, each ATC rule is expressed in terms of the points, segments, traffic streams, and restrictions implied by the applicable rules. The simulation then uses that information to "fly" as many aircraft as possible through the runway system while obeying all the rules.

2.2 National Airspace Performance Analysis Capability (NASPAC) model

NASPAC is the FAA's standard system-wide model, used for cost-benefit analysis of individual capital investments, budgetary analyses, and trade-off studies. NASPAC's elements represent the entire NAS, including U.S.-controlled domestic and oceanic airspace, airports, and individual flights. The model is typically used to simulate one day of air traffic through the NAS, including weather effects; a full year is analyzed by running several different days (currently eight days, with differing traffic and weather patterns, are used to represent the year).

NASPAC was originally developed by MITRE [3], and is now maintained and used by the FAA's Air Traffic Organization. Over the past few years it has been substantially updated to take advantage of modern computer technologies and enhance its capabilities [4]. NASPAC is a fast-time, discrete-event simulation that represents the NAS as a network of airport and airspace queues. The core simulation is written in SIMSCRIPT II.5, with pre- and post-processors written in JAVA. Inputs to the model include aircraft itineraries, flight plans, miles-in-trail restrictions, wind/weather data, time-varying airport arrival and departure capacities, and airspace sector geometries and capacities (also time-varying). Model results are typically summarized by the following metrics: flights accommodated, delay per flight segment (gate, surface, and airborne), and fuel burn per flight segment (both origin to destination and within US airspace). Figure 2

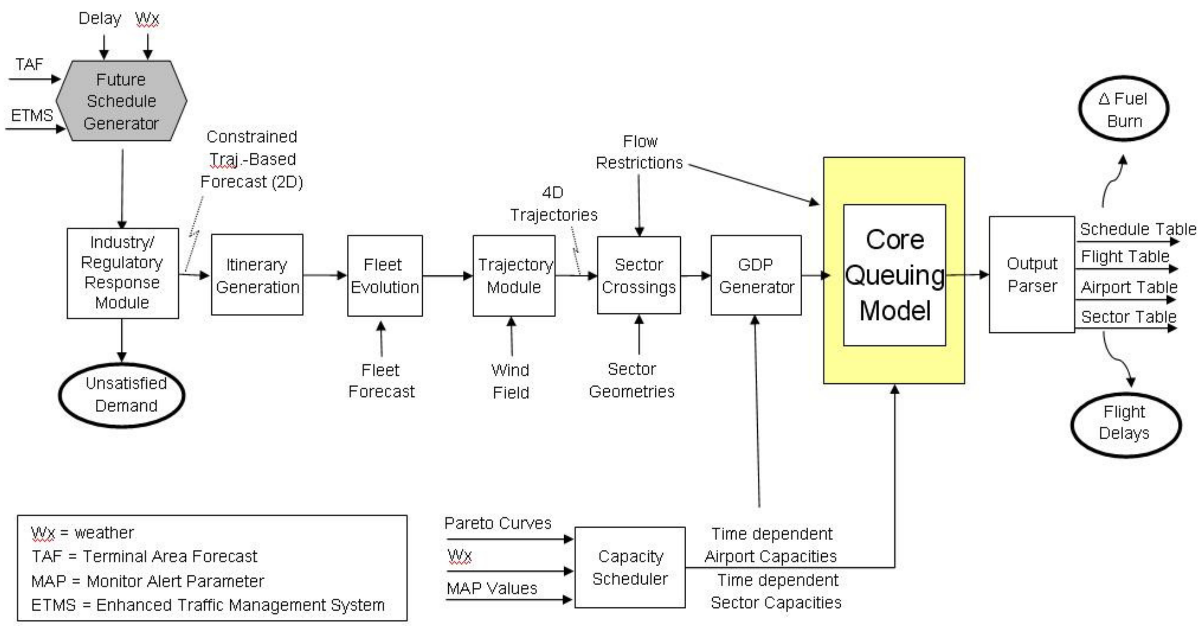

Fig. 2. Modernized NASPAC Software Architecture

illustrates the software architecture of the model.

3 Analytical Methodology

3.1 Future Demand

One of the first steps in conducting an ATM simulation study is to generate the input flight schedule, or "demand." The future demand for this study depicts eight days in 2025, representing one peak and one off-peak traffic day for each of the four seasons. These sample days have been selected by the FAA to represent the overall distribution of traffic and delay in 2008. The traffic files for the days in 2025 are derived from actual traffic on the base days in 2008, then increased using the FAA's traffic forecast at each airport [5]. Since the FAA's traffic forecast does not generally consider airport infrastructure limitations (i.e., it is based on macroeconomic and demographic trends), we employ an algorithm to constrain growth at capacity-constrained airports [6]. This algorithm is intended to mimic, in general terms, the response of operators and the Federal government to excessive flight delays (for example, by rationing demand through increased fares and/or slot restrictions).

Once the eight sample days have been run through the simulation, annual metrics are calculated using a weighted average.

3.2 Candidate Airport Selection

After generating the input flight schedules, we identified the candidate airports for the analysis using the NASPAC model with anticipated NextGen-enabled airport capacities. We used *runway*Simulator to estimate the airport capacities for the 110 NASPAC airports with their anticipated airfield and NextGen improvements in 2025. We ran the NASPAC model for the eight days in 2025, and calculated annual operational delay by airport for the 110 airports. Excluding the 35 Operational Evolution Partnership (OEP) airports, where back-up surveillance radars will be maintained, we identified the 30 airports with the largest projected delays in 2025. These 30 candidate airports are:

- **ABQ**: Albuquerque, New Mexico
- **ANC**: Anchorage, Alaska
- **AUS**: Austin, Texas
- **BDL**: Bradley, Connecticut

- **BHM**: Birmingham, Alabama
- **BNA**: Nashville, Tennessee
- **BUF**: Buffalo, New York
- **BUR**: Burbank, California
- **CMH**: Columbus, Ohio
- **DAL**: Dallas - Love Field, Texas
- **FXE**: Fort Lauderdale Executive, Florida
- **GSO**: Greensboro, North Carolina
- **HOU**: Houston Hobby, Texas
- **HPN**: White Plains, New York
- **IND**: Indianapolis, Indiana
- **LGB**: Long Beach, California
- **MCI**: Kansas City, Kansas
- **MKE**: Milwaukee, Wisconsin
- **MSY**: New Orleans, Louisiana
- **OAK**: Oakland, California
- **PBI**: Palm Beach, Florida
- **RDU**: Raleigh-Durham, North Carolina
- **ROC**: Rochester, New York
- **RSW**: Fort Meyers, Florida
- **SAT**: San Antonio, Texas
- **SDF**: Louisville – Standiford Field, Kentucky
- **SJC**: San Jose, California
- **SNA**: John Wayne – Orange County, California
- **TEB**: Teterboro, New York
- **VNY**: Van Nuys, California

Figure 3 shows the 110 airports represented in NASPAC with finite capacities, with the 30 candidate airports highlighted. Note that all IFR traffic in the U.S. is represented in the model. Airports not shown in Fig. 3 are represented as sources and sinks.

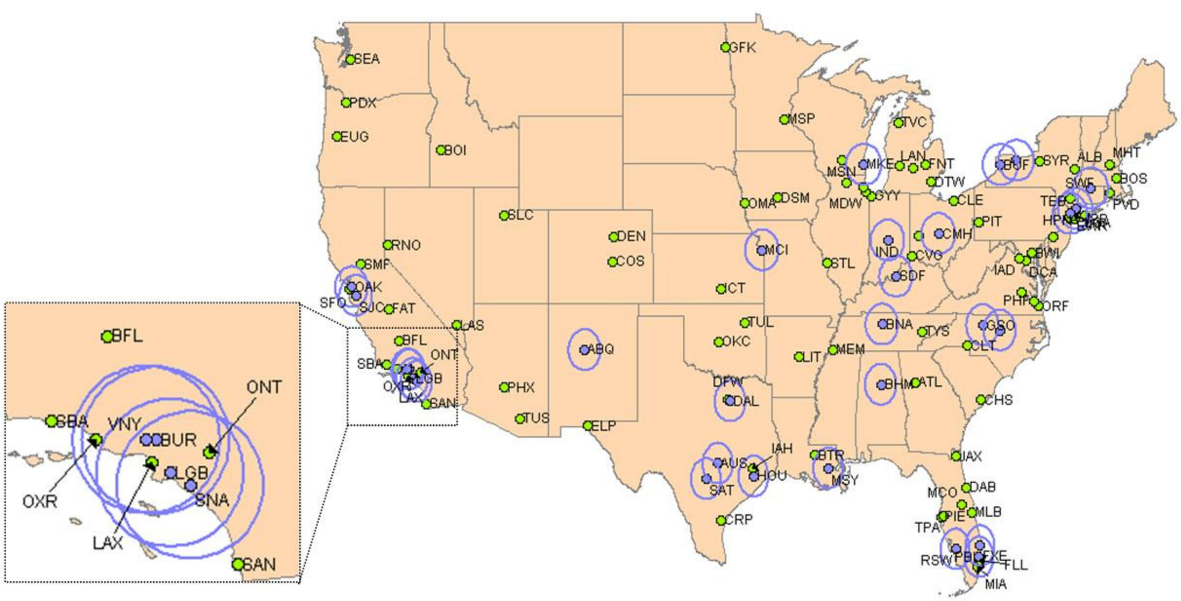

Fig. 3. NASPAC Airports and Candidate Airports with 60 nmi Range Circles

3.3 Airport Capacity Estimation

We estimated the capacities of the 30 candidate airports under three different sets of assumptions (or treatments):

1. **NextGen** – ADS-B Surveillance and improved ATC procedures
2. **Back-Up** – GPS outage, with current radar service
3. **Loss** – GPS outage without current local radar surveillance (in which case the airport must rely on nearby or en route radars).

When aircraft are below radar coverage, procedural separation must be provided. In Visual Meteorological Conditions (VMC) pilot-applied visual separation can be used to separate aircraft. In Instrument Meteorological Conditions (IMC) the flow of traffic will be reduced by the requirement to apply procedural separation. This means that only one aircraft at a time is permitted to occupy airspace that has no surveillance coverage.

If back-up radar coverage extends down to the decision height (DH), then neither single-runway arrivals nor departures will be affected by the loss of ADS-B surveillance. However, dual parallel approach operations would not be possible in IMC or Marginal Meteorological Conditions (MMC) without radar approach monitors.

If the radar coverage ends above the glide slope intercept (GSI) altitude, then arrivals must be either separated procedurally during localizer intercept or the localizer must be intercepted farther out from the airport to be within radar coverage. The result is increased separation between arrivals along the length of the final approach. Arrival capacity decreases as the length of the approach increases.

For consecutive arrivals in IMC, if backup radar coverage extends to an altitude between the GSI altitude and the decision height (DH), as shown in Figure 4, then normal radar procedures are used for the turn-on. When the aircraft breaks out of the clouds it can then be monitored visually from the tower. In-trail separations must ensure that at least one of the two aircraft is either visually acquired by the tower or under radar coverage. In many cases the in-trail separation may not be significantly greater than the standard wake vortex separation requirement, so the capacity impact could be negligible.

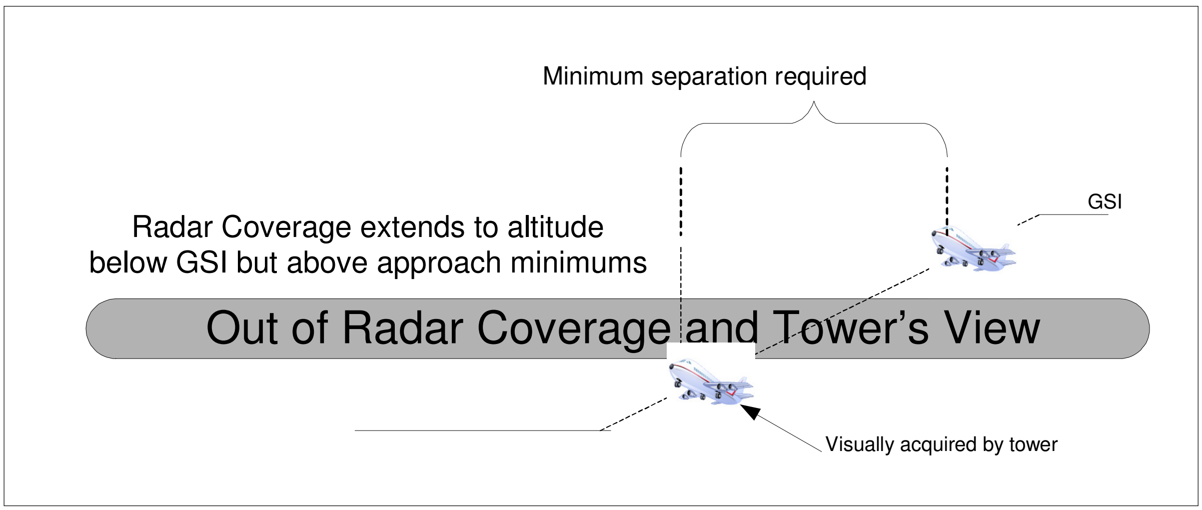

Fig. 4. Absence of Radar Coverage on Portion of Approach

3.4 Scenario Runs

In general we treated the candidate airports independently, unless they are close to one another, since we are investigating the impact of local GPS outages. We simulated three distinct surveillance treatments:

- *NextGen* – ADS-B Surveillance and improved ATC procedures
- *Back-Up* – GPS outage with current local radar surveillance
- *Loss* – GPS outage without current local radar surveillance.

To model the *NextGen* case, we ran one scenario with *NextGen* airport capacity curves for all modeled airports. In particular, we ran NASPAC with *NextGen* airport capacity curves for the eight future schedules for 2025. We then annualized the resulting delays.

To model the *Back-Up* case, we analyzed 30 scenarios, each assuming a GPS outage centered at one candidate airport with local back-up radar surveillance. We assumed that the GPS outage would extend for a 60 nmi radius around the candidate. Therefore, for each *Back-Up* scenario, we identified nearby airports affected by the outage and adjusted their airport capacities accordingly. Thus for each scenario, the candidate airport and any airports within 60 nmi received the *Back-Up* airport capacity, while all other modeled airports received the *NextGen* airport capacities.

To model the *Loss* case, we analyzed 30 scenarios, each assuming a GPS outage centered at one candidate airport *without* local back-up radar surveillance. Again, we identified airports near the candidate airports and adjusted their capacities accordingly. In particular, for each scenario, the candidate airport and any airport sharing the same back-up radar received the *Loss* airport capacity, any other airports within 60 nmi using different local radar received the *Back-Up* capacity, and the remaining modeled airports received the *NextGen* capacities.

For the remainder of this section, we highlight the candidate airports and scenarios that required special consideration in the simulation run matrix. First, we identified some cases that could be eliminated from the run matrix because of their proximity to other airports and their associated radars. For example, the candidate airports OAK and TEB; these airports share local radars with the OEP 35 airports SFO and EWR, respectively. Since the FAA will maintain the local radars at SFO and EWR, we eliminated OAK and TEB from the candidate airport list.

There were 10 candidate airports within 60 nmi of modeled airports. The candidates and the airports nearby are as follows:

- BUR: LAX, ONT, OXR
- DAL: DFW
- HOU: IAH
- FXE: FLL, MIA
- HPN: EWR, ISP, JFK, LGA, SWF
- LGB: LAX, ONT
- PBI: FLL
- SJC: SFO
- SNA: LAX, ONT
- VNY: LAX, ONT, OXR.

The capacities of the airports nearby these 10 candidates were adjusted for the candidate airport's *Back-Up* and *Loss* cases.

The candidate airports FXE and PBI are within 60 nmi of each other, so they have identical *Back-Up* cases. That is, given a GPS outage with radar back-up surveillance at either airport, both airports receive the *Back-Up* case airport capacities. FXE and PBI have distinct local radars so they have distinct *Loss* cases. The same is true for candidate airports BUF and ROC.

Some proximate airports share local and even back-up radars. The candidate airports BUR, LGB, SNA, and VNY are all within 60 nmi of each other. BUR and VNY share the same local and back-up radars, so they have identical *Back-Up* and *Loss* cases. Similarly, LGB and SNA share the same local and back-up radars, so they have identical *Back-Up* and *Loss* cases. We also noted that LGB and SNA will receive back-up airport capacities in the BUR/VNY *Back-Up* and *Loss* cases because they are within 60 nmi of the candidate (BUR/VNY) airport. BUR and VNY airport capacities are similarly affected in the LGB/SNA cases.

3.5 System-Wide Analysis

The final run matrix consisted of one *NextGen* case, 26 *Back-Up* cases, and 24 *Loss* cases. For each case, we ran the NASPAC model using the eight 2025 flight schedules and capacities corresponding to the surveillance case. The NASPAC model computes gate, taxi-out, en route, and arrival delay, as well as propagated delay for multi-segment flight itineraries. For each case, we annualized and monetized the total delay. We computed the difference between the *NextGen* case and each alternative case: *Back-Up* and *Loss*. The benefits of maintaining back-up radar for each candidate airport were then ranked and compared to the associated costs.

4 Results and Conclusions

4.1 *Back-Up* and *Loss* Cases compared to *NextGen* Baseline

We compared the projected total annual delay in 2025 for the *NextGen* case to that for the *Back-Up* and *Loss* cases for each candidate airport. We calculated the difference in total annual delay between the *NextGen* case (baseline) and the *Back-Up* and *Loss* cases. We applied Airline Direct Operating Costs (ADOC) for each phase of flight and Passenger Value of Time (PVT) to the annual total delay to calculate the cost of the projected delay. Table 1 shows the cost factors that we applied; these are the standard values used by the FAA for cost-benefit analysis. We further assumed an average aircraft capacity of 101.2 passengers, and an average load factor of 81.3 percent [5].

Table 1. Delay Cost Factors

ADOC, FY10$/min			Passenger Time Value (FY10$/hr)
Gate Delay	Surface Delay	Airborne Delay	
$28.43	$34.26	$68.02	$28.60

In addition, we assumed that a cancellation is equivalent to 165.9 minutes of delay, and we valued cancellations accordingly [7].

Figure 5 shows the delay plus cancellation costs for one day of local ADS-B surveillance loss, for the *Back-Up* and *Loss* cases.

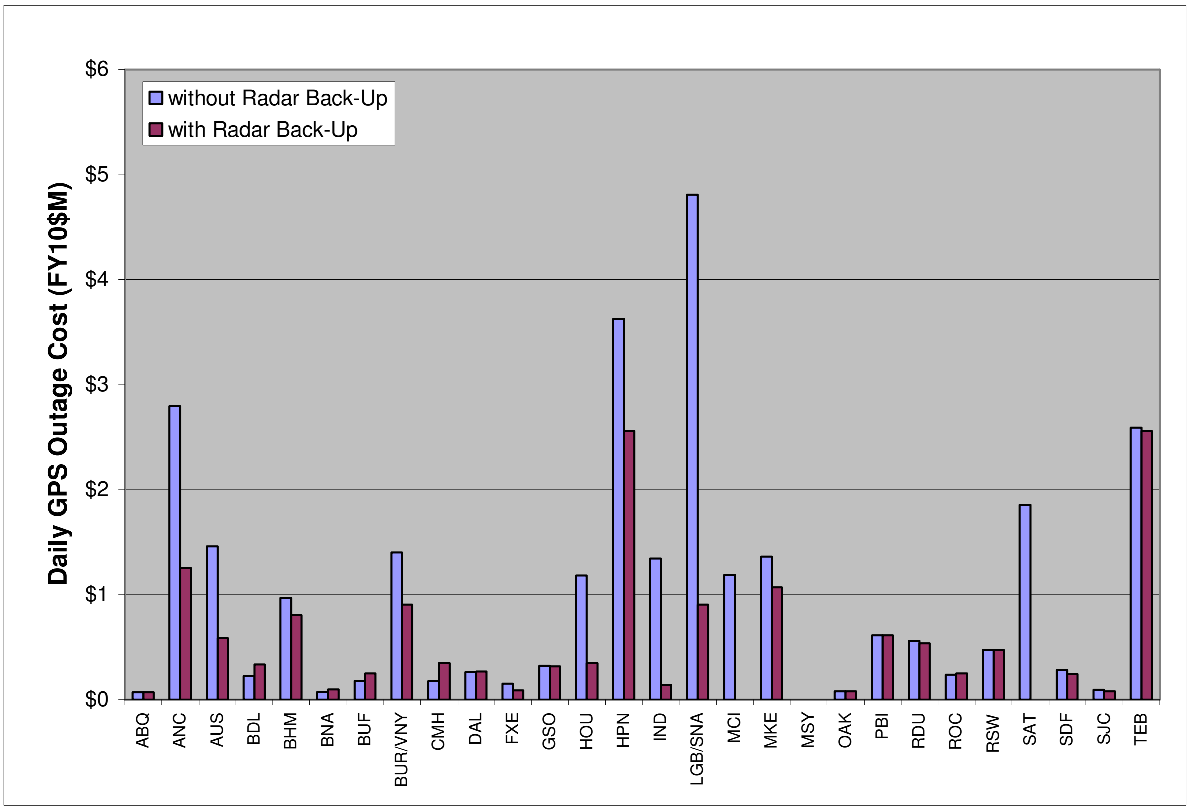

Fig. 5. Daily Cost of Delays and Cancellations from Local GPS Outage in 2025

Figure 6 shows the difference in delay cost between the *Back-Up* and *Loss* cases for one day of local ADS-B surveillance loss, rank ordered from most to least costly location. This represents the delay savings associated with maintaining back-up radar surveillance at each location given a one day GPS outage.

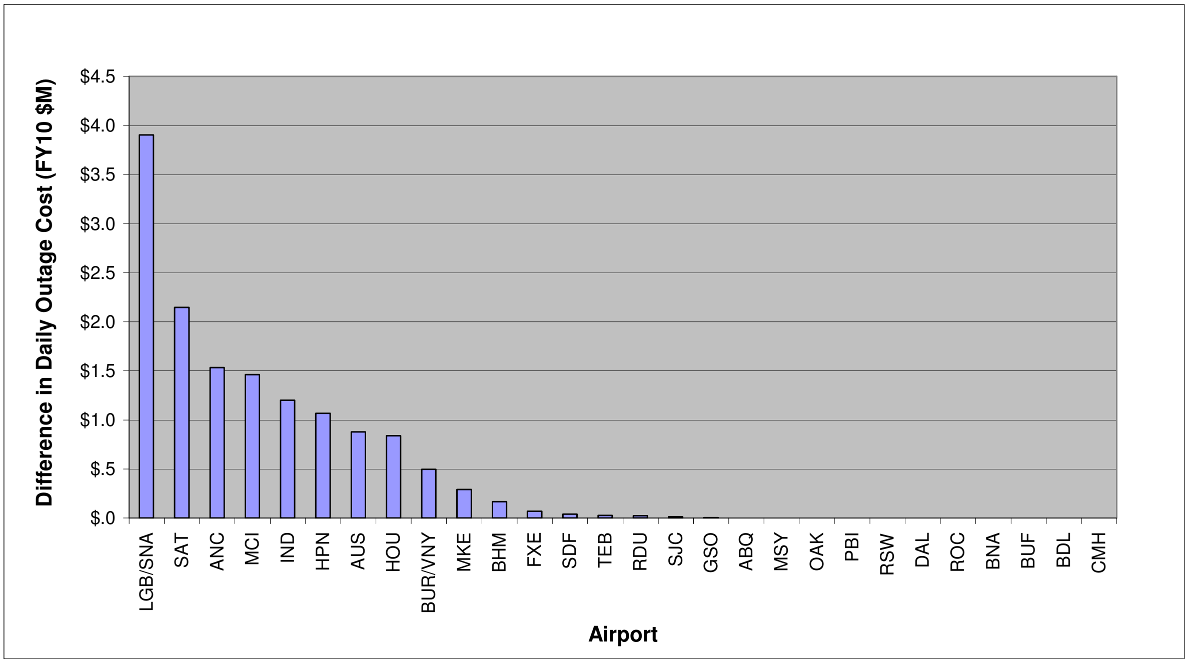

Fig. 6. Daily Cost of Local GPS Outage, No Back-Up Less Radar Back-Up

4.2 Cost Benefit Comparison

To ascertain whether it is cost–beneficial to maintain back-up surveillance, we need to make an assumption regarding the likelihood and expected duration of a local GPS outage. Based on expert opinion within FAA, we assumed an average GPS outage duration of three days with a probability of 0.1 in any given year. We calculated the delay and cancellation cost of such an outage, and compared this cost with that of maintaining the back-up radar. We assumed a 20-year life-cycle cost for a secondary surveillance radar of $2.243 Million, regardless of location. As can be seen from Figure 7, for eight of the candidate airports the expected value of the combined delay and cancellation cost of a GPS outage exceeds the cost of the back-up radar. For example, the net present value (NPV) of maintaining the back-up radar at LGB/SNA is over $10 million. The NPVs for SAT, ANC, MCI, IND, and HPN range from $5 million to $1 million. The NPVs for AUS and HOU are nearly $1 million.

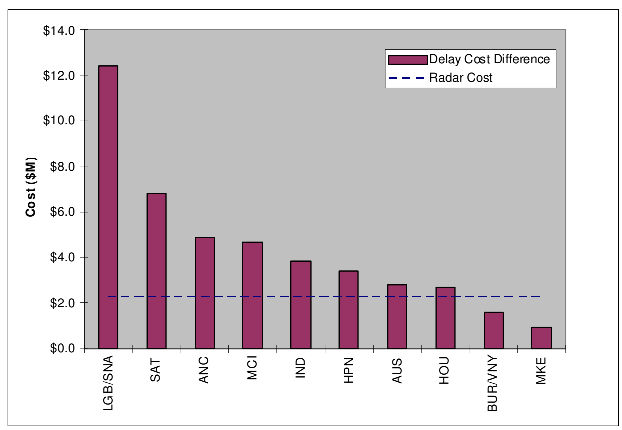

Fig. 7. Expected Value of Delay/Cancellation Cost with Radar Acquisition Cost

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