

ADVANCE PLANNING THROUGH SCHEDULE ANALYSIS

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Abstract

Combining airline schedule data in one central repository would support evaluation of the day of operations impact of the future airline flight schedule. In this paper, three sample analyses are shown that use schedule data to project operational impact. The first simulates expected arrival delay at Chicago O'Hare International Airport (ORD) based on the schedule for July 2003 vs. July 2004. The second demonstrates the impact on arrival delay of a future schedule increase at Atlanta Hartsfield International Airport (ATL). The third shows the impact of single flight rescheduling or insertion on departure delay at Philadelphia International Airport (PHL). The need to account for unscheduled traffic, different scheduling implementations, and different operational scenarios is also addressed. This is not a comprehensive, rigorous study but is intended to demonstrate the types of analyses that can be conducted using schedule data. With this type of work, possible issues on the day of operations can be identified and potentially mitigated well in advance.

Introduction

Schedules for airlines are created independently of each other. Anti-trust laws dictate that each airline must develop its schedule individually, without knowledge of other airline schedules. The result is that the collective schedule at the airport is not seen until the schedules are published. The unintended consequence of this constraint is over-scheduling at airports. Additionally, and more importantly, the operational impact of the schedule may not be determined fully until the day of operations.

Airline scheduling beyond airport capacity can produce unmanageable levels of delay. If the over-scheduled airport is a central hub to the National Airspace System (NAS), as ORD is, delays can quickly propagate to other airports, causing congestion across the NAS. Ideally, an airport, the airlines, and passengers would not have to suffer the effects of over-scheduling first and have them resolved only as a reactive measure.

Background

The Result of Over-scheduling

Over-scheduling at airports has been a high-profile NAS issue in recent years. In order to mitigate rising levels of delay due to over-scheduling, in January and April 2004 the two major carriers at ORD, American Airlines (AAL) and United Airlines (UAL), reduced their schedules by 5% and 2.5% at peak operating times at ORD at the request of the Federal Aviation Administration (FAA) [1]. However, no restrictions were placed on other airlines at ORD, and competing airlines scheduled into the vacancies left by AAL and UAL. As a result, in Summer 2004 ORD experienced unprecedented levels of delay and congestion. In August 2004, the FAA once again requested schedule reductions from the airlines in order to curb over-scheduling at ORD and bring delays back down to acceptable levels [2, 3]. This time, restrictions were placed on addition of flights by other carriers. A temporary agreement was implemented to enforce these scheduling practices, and this will expire in April 2005.

Likewise, LaGuardia Airport (LGA) has seen operations heavily impacted by over-scheduling. Since 1969, the High Density Rule (HDR) has been in place at LGA, limiting the number of arrivals and departures at that airport. However, in April 2000, the Aviation Investment and Reform Act for the 21st Century (AIR-21) was enacted, permitting certain exemptions from the HDR restrictions. Because of the number of exemptions allowed at LGA under AIR-21, delays reached an unmanageable level by November 2000. In response, the FAA capped exemptions at LGA and allocated them via a lottery [4]. However, the AIR-21 calls for HDR restrictions to be lifted at LGA in 2007.

Addressing Over-scheduling

Many entities have an influence on operations and management of the NAS, and just as many potential solutions to over-scheduling have been proposed. Some parties believe that the best solution to the issue of limited capacity is to add runways to existing airports, expanding their capacity. However,

this is not always practical or economically feasible. Some airports have no available land for expansion, and some airports have environmental and noise concerns which prevent further expansion. Given these constraints, other methods must be developed to address capacity/demand imbalances in the NAS.

The FAA and U.S. Department of Transportation (DOT) have been studying market-based approaches to allocate limited NAS resources. In this context, the limited resources are arrival and departure slots at high-demand and/or low-capacity airports. The DOT defines *market-based approaches* as “the development and imposition of airport fees designed to encourage air carriers to use limited airport capacity in a more efficient manner.” This includes a range of options, including slot auctions, peak period pricing, and flat fees.

The structure and merits of auctions to allocate limited airspace resources has been studied extensively [5] and discussed with respect to the structure of different airspace systems—the NAS as well as the European airspace system [6]. Research is currently being conducted by the National Center of Excellence for Aviation Operations Research (NEXTOR) to make recommendations for implementing slot auctions at LGA when the HDR expires in 2007. The Massachusetts Port Authority (Massport) proposes imposing fees on aircraft that increase the delay above a predetermined acceptable level at Boston Logan International Airport (BOS) [7]. BOS does not currently experience levels of exceptional delay; Massport wrote this proposal in awareness of past delay issues and in anticipation of possible future issues.

Identifying Future Over-scheduling

The common theme in the above work is the awareness and anticipation of future problems, and the understanding of the need to develop solutions ahead of time to prevent operational issues. Massport is being proactive in their work, based on past experience and future expectations, and NEXTOR is rightly conducting research now, well in advance of the HDR expiring at LGA in 2007.

But what if over-scheduling problems are not so clearly anticipated? The HDR expiring at LGA in 2007 is a clear marker of potential issues. But the over-scheduling problems at ORD were not identified ahead of time. Months and months of delays were suffered before the FAA intervened with a solution that worked (and is only temporary).

The proposal of this paper is to develop an intelligent system that analyzes all proposed airline

schedule data stored in a central repository, to show the net effect of the combined schedule on the day of operations at an airport. This is very similar to what Massport has proposed for BOS – a schedule monitoring system to identify areas of unacceptable delay well in advance. What we suggest is to extend this type of analysis and over-scheduling monitoring to all major airports in the NAS. However, unlike the Massport proposal, which focuses on peak period pricing as their chosen solution to over-scheduling, we do not propose one particular solution to over-scheduling issues. Our goal is to develop a method to identify over-scheduling issues before they manifest operationally.

Massport also proposes performing schedule analysis months before schedules are set and published. (Airlines usually publish their schedules at least three months prior the day of operations). This provides time for Massport to first inform airlines of over-scheduling periods, and then for the airlines to change their schedule to mitigate the over-scheduling. There is an interactive, collaborative period between the airport authority and the airlines prior to the schedules being published in final form.

An extension of this idea is using our proposed system to support Human-In-The-Loop trials (HITLs) involving the FAA, airport authorities, and the airlines. HITLs would help identify unforeseen side effects of attempted scheduling controls, such as the reaction to the initial schedule reductions by AAL and UAL at ORD (i.e. of other carriers filling the vacated slots), and the consequences of the AIR-21 exemptions at LGA which led to disastrously high levels of delay. If these behaviors could have been simulated and anticipated, months of delays and stress on the NAS could have been avoided. The scope of this work will not discuss the broader and complex notion of HITL simulations. Instead, this work will demonstrate the type of analyses that could be used to identify future over-scheduling using a stand-alone tool.

Method

Overview

Delays at ORD in July 2003 and July 2004 were simulated based on scheduled flight data and at different airport arrival rates (AARs). Delay was also simulated based on the number of flights that actually operated. Comparing the simulated delays of scheduled and actual flight data gives an idea of how predictive schedule data can actually be and elucidates what other factors must be accounted for.

Schedule increases of 5% were also simulated at ATL and the amount of delay that would occur under typical reduced arrival rates calculated. Finally, the effect of inserting a single flight into the departure queue at PHL is examined.

Note that this is preliminary analysis only, performed on limited data sets. The results in this paper should not be construed as predictions of future traffic patterns at any of the airports studied. More extensive research on larger data sets is required to provide confidence intervals for any results. These results are intended only to demonstrate the types of analysis that could be possible under this proposed concept.

Data and Calculations

Aggregate Demand List (ADL) flight data were used except where otherwise noted. ADL data combines Enhanced Traffic Management System (ETMS) data and flight message data submitted by airlines. Several dozen fields are included in this data set, including actual flight wheels-on arrival and wheels-off departure times, and scheduled gate on and gate off times. ADL data is stored in files that are specific to one airport and that cover 24-hour periods.

Two types of data sets were used: “scheduled” flight lists, and “actual” flight lists. One data set is created using one day of historical ADL data. A “scheduled” flight list was created by removing all unscheduled flights, i.e. all flights that did not have scheduled gate out/in times in the flight data, and reinstating into the data set all flights that were actually cancelled on the day of operations. This was done to simulate what was “intended” on the day of operations, when the schedule was first set and published. Otherwise, delay is calculated using “actual” historical ADL data. For these data sets, the unscheduled flights are included in the flight list, and the cancelled flights are again removed from the flight list.

The calculations of delay required as input a value for AAR and the estimated time of arrival (ETA) for each flight. The AAR is used to determine how many arrival slots (ASLOTs) are in each hour. Flights are put in arrival order by the flight ETA and assigned an arrival slot with a time associated with it. The delay is calculated flight-by-flight and is the difference between the time of the flight ASLOT and the flight ETA. Delay is calculated in whole number increments and can only be a positive number. If (ASLOT – ETA) is a negative number, the delay is zero.

Results

ORD Simulation

The reason for choosing ORD as a study case is obvious. The schedule for a day in July 2003 and the schedule for a day in 2004 were recreated according to the methodology described previously, and the expected delays for each day were calculated and compared.

The amount of air traffic at an airport will vary by day of the week, with the least amount of air traffic expected on a weekend. A flight count was also done on the other days of the week around the selected days (not including the weekend). This would indicate if the days were aberrations (in terms of number of scheduled flights). Figure 1 shows that the number of scheduled flights in July 2004 is consistently higher than those in July 2003, for the selected week. The day of the week chosen for our calculations was Thursday (July 24, 2003, and July 29, 2004).

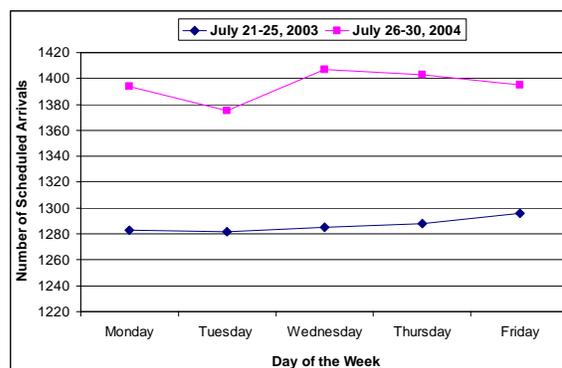


Figure 1. Number of scheduled arrivals into ORD for one week, July 2003 vs. July 2004.

Default AAR at ORD

The ETMS default AAR for ORD is 100 arrivals per hour. The expected flight delay was calculated at this arrival rate from 05:00 until midnight¹. The results of this calculation are presented in Figure 2. Delay calculations and flight counts are shown for three data sets: scheduled arrivals for July 2003, scheduled arrivals for July 2004, and actual arrivals for July 2004.

¹ All times are in local time and military format unless otherwise indicated.

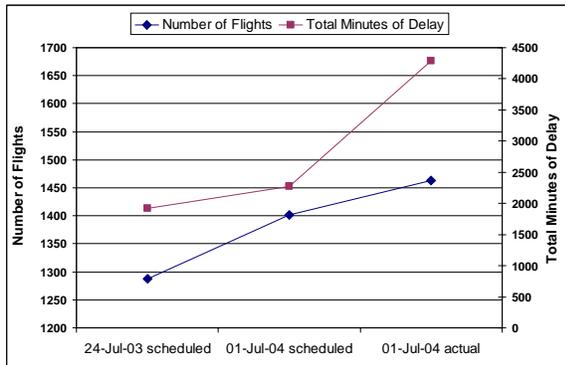


Figure 2. Number of flights (◆) and total minutes of delay (■) at ORD at the default AAR comparing: scheduled July 2003, scheduled July 2004, actual July 2004.

The flight count comparison of scheduled arrivals for July 2003 to scheduled arrivals for July 2004 is 1288 to 1402 – a nearly 9% increase (Figure 2). The amount of total delay also increased from 1925 total minutes to 2273 total minutes. The amount of total delay calculated for the actual arrivals for July 2004 is nearly double that of the scheduled – 4284 minutes. This is not surprising since the number of unscheduled flights for the day was 86, which is approximately 6% of the traffic scheduled into ORD that day. This is offset by 25 cancellations, which brings the total actual flight count for arrivals to 1463 for the day – a net increase of about 4% over what was scheduled for the day.

Aggregate numbers give some idea of the impact of schedule changes. However, operationally, air traffic controllers and aircraft dispatchers are more concerned with the amount of delay flights will experience over the course of the day. Many airports have arrival and departure peaks and valleys, and concomitant delay peaks and valleys. Additionally, a certain amount of delay is usually considered acceptable. Total arrival delay of 4000 minutes is actually considered a very good day at ORD. So a more insightful way of displaying these results is to plot the amount of delay that can be expected per flight, and show this over the course of the day.

Figure 3 shows the results in this format. It is easy to see the delay pattern that occurs over the course of the day at ORD. Another important feature of this format is that the magnitude of delay is prominent. The maximum delay for any of the three data sets is ten minutes. Typically, the FAA considers delays notable when they reach 15 minutes or greater.

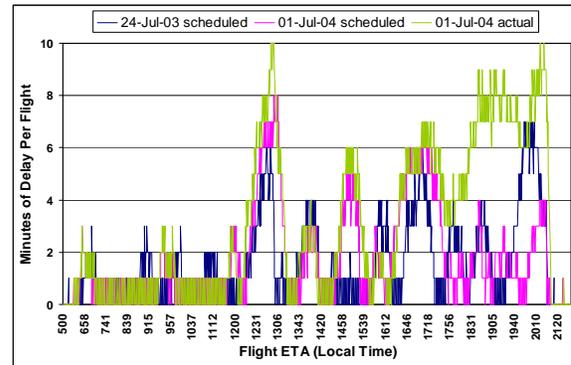


Figure 3. Minutes of delay per flight at ORD at the default AAR comparing: scheduled July 2003 (navy), scheduled July 2004 (pink), actual July 2004 (green).

While the magnitude of delays may be considered operationally acceptable, this graph still shows some interesting results. The first of these is that the July 2004 schedule has caused some increases in delay, even if these increases are still considered within the threshold of acceptable delays. For example, in all three data sets, there is a peak in delay just before 13:00. In the July 2003 schedule, the delays are at most six minutes. In the July 2004 schedule, the maximum delay at this peak is eight minutes; with the inclusion of unscheduled traffic, this delay increases further, to ten minutes.

Compared to the July 2003 schedule, the July 2004 schedule also increases the amount of delay at around 15:00, and at 17:00. One delay peak, at ~20:00, is actually reduced with the new schedule. In addition, the impact of unscheduled traffic is particularly obvious in the evening, from about 18:00 to 21:00.

Reduced AAR at ORD

The above analysis was assuming the default rate at ORD. However, more often than not, ORD is running at a rate less than optimal. At ORD, air traffic managers may drop the arrival rate for a number of reasons, for example, weather at the airport which limits visibility. When the arrival rate must be reduced, a Ground Delay Program (GDP) may be implemented to mitigate the imbalance between demand and capacity. GDPs are traffic management initiatives issued by the FAA that limit arrival flows into a given airport by delaying flights on the ground at their departure point. For further information on GDP definition and implementation, please see [8].

For this reason, the number of GDPs run for ORD can be used as an estimate of the number of

times ORD ran at a reduced arrival rate (although the arrival rate may also be reduced outside of a GDP). The number of GDPs was counted over the period of one year, from the 1st of September 2003 to the 31st of August 2004. The airports that had 20 or more GDPs are shown in Figure 4.

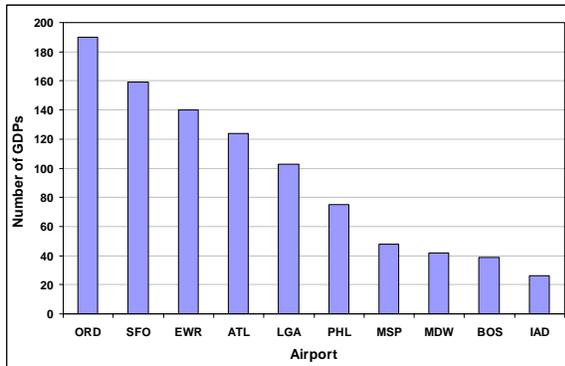


Figure 4. The number of ground delay programs (GDPs) implemented in the NAS from September 1, 2003, to August 31, 2004.

The graph in Figure 4 shows that ORD had 190 GDPs in this one-year period, the most of any airport in the NAS. This means for just over half of all days in this time frame, ORD was running at a rate less than optimal. For this reason, it makes sense to repeat the same delay simulation at ORD but using an AAR of less than 100 flights per hour.

The same scheduled and actual flight lists from the previous simulation were used; only the AAR was changed. The chosen AAR was based on historical patterns of GDPs at ORD. From the data set used to create Figure 4, GDPs are most frequently implemented at 13:00 local time, and the average and median lengths of a GDP are 7.5 and 8 hours, respectively. The historical average AAR during a GDP can not be determined from the data available. However, a typical reduced AAR implemented at ORD during a GDP is 85 arrivals per hour (and ORD frequently runs at lower arrival rates).

To simulate a “typical” GDP at ORD, the AAR was set to 100 all day except from 13:00 until 20:30, when the AAR was set to 85 arrivals per hour. The results from this calculation are shown in Figure 5.

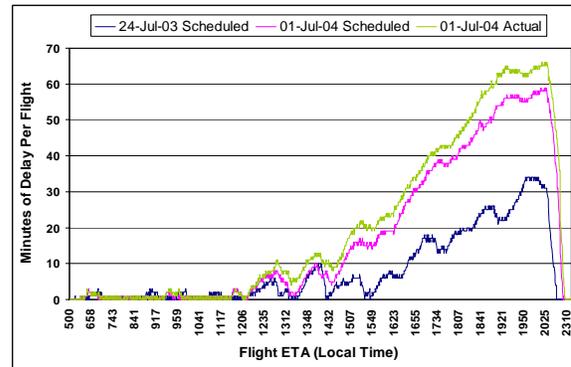


Figure 5. Minutes of delay per flight at ORD at a reduced arrival rate comparing: scheduled July 2003 (navy), scheduled July 2004 (pink), actual July 2004 (green).

At a reduced arrival rate, not surprisingly, the effects of increased scheduling are amplified dramatically. Based on the schedule in July 2003, the maximum delays at ORD at this reduced arrival rate are about 35 minutes. Delays are greater than 15 minutes for about three hours (~17:30 – 20:30). With the July 2004 schedule, the maximum delay is now nearly 60 minutes; the unscheduled traffic pushes delay to greater than 60 minutes (“actual July 2003”). Additionally, the delays are of a higher magnitude over a greater time range—more than 15 minutes for an additional 2½ hours (~15:00 – 20:30). The total minutes of delay for the July 2003 schedule are 10150 – for the July 2004 schedule, this jumps to 23733. This represents a 134% increase in the total delay for the day.

This type of analysis could be used to support discussions of administrative control measures at ORD (the current order expires in April 2005). Details that were debated in August 2004 included: what the arrival rate should be, what hours needed to be restricted (or not), and what number of unscheduled arrivals should be permitted. Changes to these different parameters can be made within the simulation, and the amount of expected arrival delay at ORD can be calculated. The effectiveness of the proposed initiative can be evaluated in advance, and proper adjustments made, to keep delay at acceptable levels.

For example, what if the July 2004 schedule was decreased by 5% between 09:00 and 21:00? This is very similar to what was implemented at ORD in August 2004. This is done without any consideration to carrier – 54 flights are dropped from the schedule, roughly 5% in each of those twelve hours. (Note: because actual flight data is used, the decrease in

schedule can be applied preferentially to certain air carriers; it is not for this simulation).

When the simulation is re-run with this 5% reduced schedule, the amount of delay drops dramatically; delay levels are now nearly at the same level as they were with the July 2003 schedule (Figure 6). What is even more interesting is that the number of flights remaining in the schedule is still 59 greater than the July 2003 schedule. What this demonstrates is that the time of day the schedule is increased can, depending on airport operating conditions, have a huge impact (or no impact) on the operations there.

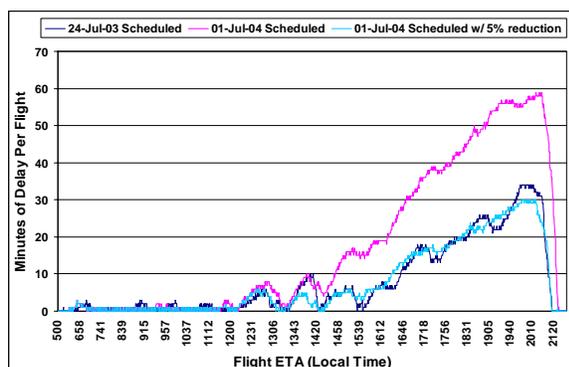


Figure 6. Minutes of delay per flight at ORD at a reduced arrival rate comparing: scheduled July 2003 (navy), scheduled July 2004 (pink), scheduled July 2004 with 5% reduction between 09:00 and 21:00 local time (light blue).

Table 1. Comparison of simulated delay at ORD.

Data Set	Number of Flights	Total Minutes of Delay	Delay Increase from Jul 03 Schedule
July 2003 – scheduled	1289	10150	N/A
July 2004 – scheduled	1402	23733	134%
July 2004 – actual	1463	29129	187%
July 2004 – scheduled + 5% decrease	1348	9948	-2%

ATL Simulation

ATL arrival patterns help illustrate the impact of different scheduling practices. A 5% increase in schedule was simulated at ATL but in two different implementations – adding these flights only at peak times, or adding them throughout the day. In reality,

many times airlines will increase schedules at already-existing delay peaks, to meet consumer demand for those prime arrival times. However, there are examples of airlines making an effort to actually de-peak their schedules and add schedule increases throughout the day, in an effort to limit congestion and delays [9]. The impact of both practices can be demonstrated.

Since ATL also experiences a high number of GDPs (see Figure 4), this simulation also used parameters of a “typical” GDP. Based on the one year of GDP data used in this study, GDPs at ATL are most frequently implemented at 13:00 local time and run for an average of 6.5 hours (the median is also 6.5 hours). The simulation used an arrival rate of 94, the default AAR at ATL, all day except from 13:00 to 19:30 local time, when the AAR is set to 86 (this is considered a standard IFR arrival rate at ATL). The data set used was one day from November 22, 2004. The results are in Figure 7.

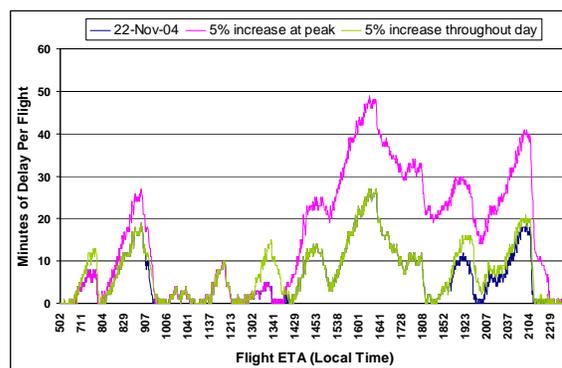


Figure 7. Effect of 5% schedule increase at ATL: schedule on Nov 22, 2004 (navy), with 5% schedule increase at peak times (pink), with 5% schedule increase throughout the day (green).

The effect of concentrating the schedule increase at peak times is marked. The magnitude of delays at the highest delay peaks doubles from ~25 minutes to just under 50 minutes (at ~16:00), and from 20 minutes to 40 minutes (at ~21:00). The delay in the schedule as-is is 8327 total minutes. With the 5% schedule increase concentrated at peak times, this jumps to 21851 minutes – a 162% increase.

When the 5% schedule increase is instead evenly distributed throughout the day, the delay pattern is relatively unchanged. In fact, the delay pattern is so similar that in Figure 7, the navy line (schedule as-is) is almost always covered by the green line (schedule increase throughout the day), since the delay patterns are so similar. The only differences are slight increases in delay at around

13:30, and from 19:30 to 21:00. These increases are enough to bring the total minutes of delay up to 10271 – an increase of 23% over the schedule as-is.

PHL Simulation

The two previous simulations demonstrated an aggregate effect – the impact a schedule increase has at an airport over the course of the day. However, the impact of moving or inserting even a single flight can also be shown. Additionally, the ORD and ATL analyses focused on arrivals, but airport departure delay can also be simulated.

The methodology of delay calculation for departures is similar to that for arrivals. An airport departure rate (ADR) is set, flights are put in order according to the flight Estimated Time of Departure (ETD) and assigned a departure slot with a time, and the amount of delay on the ground (“ground hold”) is the difference between a flight ETD and the time of the assigned departure slot.

PHL was specifically chosen because the number of departures is rising at PHL; with this, taxi out times are also increasing² (Figure 8). Taxi out time is considered the time that the aircraft pushed off the gate to the “wheels-up” time of runway departure. Since the number of operations will vary by month and season, the totals in Figure 8 are only shown for July of each year, to more clearly show the trend of increasing departures and taxi out time.

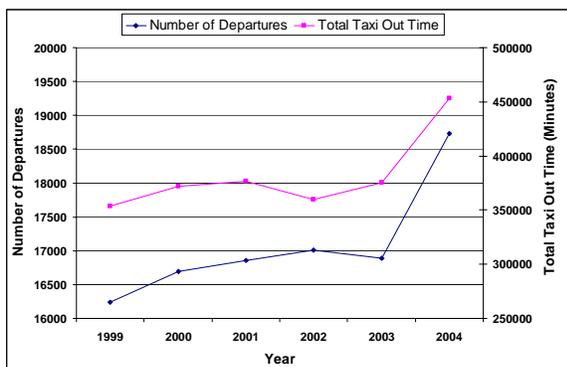


Figure 8. History of number of actual departures and total taxi out time at PHL (July only).

The results of moving or inserting a single flight in the schedule are shown in Figure 9. The data set used is schedule data from November 11, 2004, and the ADR is 54 departures per hour – the default ADR at PHL. The amount of total ground hold for the entire day is first calculated for the schedule as-is.

Next, one flight is moved within the 10:00 hour, and one flight is added. This time frame was chosen because the 10:00 hour at PHL sees a high demand for departures, and lengthy departure queues are common.

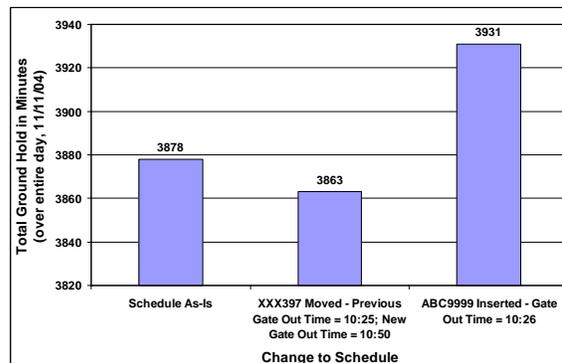


Figure 9. Impact of different scheduling initiatives on ground hold at PHL.

When a single flight (the carrier name has been masked here) is moved to a gate off time of 10:50 instead of 10:25, the total ground hold delay at PHL drops from 3878 minutes to 3863 minutes – a savings of 15 minutes. When fictional flight ABC9999 is inserted at 10:26, the amount of additional ground hold time this adds is 53 minutes. So even small flight movements and single flight insertions can have a visible impact on operations at an airport.

The number of minutes of delay can then be translated to a cost, whether that be in crew costs or fuel costs to the airlines, or in the amount of emissions the extra flight will produce. This sort of cost computing has already been suggested, where fees for peak period pricing would be determined by the “congestion cost” generated by adding an additional flight [10].

Conclusions

The impact of airline schedules on operations at an airport can be foreseen with proper simulation. Ideally, this knowledge would be used to reduce delays and congestion that could otherwise be avoided. The impact of both single and multiple flight increases can be simulated. Factors such as the appropriate arrival and/or departure rate at the airport, how scheduled data compares to actual airport operations, and where and how flights are added to the schedule should all be considered.

² Source: Aviation System Performance Metrics (ASPM). Developed and maintained by the Federal Aviation Administration office of Aviation Policy and Plans (APO).

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Airline scheduling, advance planning, decision support

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