# The Effects of Schedule Disruptions on the Economics of Airline Operations

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**Abstract**

Airlines depend on their ability to meet the requirements of their published schedules. However, various events ranging from severe weather to the failure of a crewmember to report for duty inhibit their ability to always satisfy their schedules. In some instance, as in the case of thunderstorms, only a single airport may be affected for a few hours. In others, a large weather system can disrupt airline schedules over thousands of square miles for several days. This paper examines the economic effects of disruptions to schedules at two levels. First, it examines the costs incurred by the airlines that resulted from severe weather affecting operations at Boston, MA from 8–10 October 1998. Second, the annual costs of disruptions to airline operations in the United States during 1998 were estimated and their significance discussed. This paper shows that regular events that disrupt airline schedules are an inescapable element of airline operations. In some cases the effects of these disruptive events are minimal. However, disruptions to airline operations can become severe, causing the airlines to delay, cancel or divert substantial numbers of flights and imposing substantial costs on them.

**Overview**

Severe disruptions in the National Airspace System (NAS) significantly affect the economics of airline operations. Thunderstorms, blizzards, equipment outages, and other unscheduled, erratically occurring disruptions wreak havoc on air carriers' ability to fly published schedules, causing them to lose passenger revenues and incur additional costs. Because hubs only function effectively when passengers are able to make scheduled connections and often are located at congested airports, the effects of disruptions are magnified when hubs are affected. These effects become most visible when the disruptions occur during peak arrival or departure pushes.

Delays, cancellations and diversions are the most visible evidence of the effects of these disruptions on the airlines. Generally, each of these results in aircraft and crews being out of position relative to planned itineraries. Passengers are inconvenienced as arrivals are delayed and scheduled connections missed. As a result, an airline may become responsible for the cost of alternative transportation, lodging, food and, if the delay is sufficiently long, a cash payment to compensate the traveler for any inconvenience.

This paper has resulted from work performed by The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) for the Federal Aviation Administration. It is but one element of a multi-year effort that is focused on the impact of air traffic management on the economics and performance of airlines.

The research reported in the first section of this paper provides an overview of the types of disruptions that affect air carriers and the challenges these disruptions pose for them. Two case studies follow. The first case study estimates the cost to the affected airlines of a specific event[1] in the Northeast United States in the fall of 1998. Estimates include the primary[2] and secondary[3] effects of delays, diversions and cancellations on airline costs. The second case study aggregates the costs of disruptions for the domestic operations of the ten largest United States airlines, those with at least 1-percent of total domestic scheduled-service passenger revenues, for 1998. The results of that study include an estimate of the magnitude of the effects of severe disruptions above those of the more minor disruptions that are a part of normal day-to-day operations.

**Introduction**

The fundamentals of airline operations are no different from those of any other firm operating in an open market: control costs to earn a profit within the price structure imposed by the market place. On the cost side of the equation, each firm faces two categories of cost: fixed and variable. Fixed costs are those that mangers cannot change in time to affect the outcome of events. On the other hand, management is able to control variable costs to shape events to their liking.

Manufacturing firms and some service providers, when confronted with disruptive events, are able to react to preserve the uninterrupted flow of product and service to their customers. The customers of airlines, on the other hand, are either trying to board or are already on the airplanes when flights are cancelled, delayed or diverted. There is nothing an airline can do to avoid inconveniencing their customers; and their only option is to mitigate, as best they can, the resulting adverse consequences. Regardless of what actions they may take, the consequences of these events are such that the airlines can do little that will correct all damage to its competitive position that results from the customers' dissatisfaction. Confronting largely uncontrollable events that impose additional costs while, at the same time, directly affecting service quality and competitive market position is a problem that is particularly applicable to airline operations.

The airline industry sells their ability to transport passengers and freight safely to their intended destinations. Their schedule embodies their service. Events of varying severity compromise their ability to fly their schedules. At a basic level, airplanes break, crews fail to report, caterers fail to keep their delivery schedules, and congestion in the National Airspace System compromise the ability of airlines to meet their schedule commitments in the short term.

Relatively small numbers of flights are delayed or cancelled for the majority of these events. Inconvenience to airline customers is minimal. Most importantly, the airline industry recognizes that these occurrences, at a minimal level, are inherent to airline operations.

Some disruptions are so severe that they cause flight operations in an entire region of the country to be curtailed. Weather is the primary cause of these severe disruptions although air traffic control outages, labor actions by unions, the closing of runways and airport construction can also severely affect the flow of air traffic over a wide area. When faced with these severe disruptions, even if only one airport is affected directly, the effect ripples and relatively large numbers of flights may be delayed, cancelled, or diverted. The integrity of bank operations at hub airports is disrupted and passengers and freight miss connections. When such severe disruptions occur, they have major economic implications for the affected airlines. Estimating the costs of severe disruptions is the focus of this paper.

**The Scope of Disruptions**

The range in the magnitude of the disruptions that can affect airline operations is considerable. A single flight may be delayed a few minutes to correct a false warning in the cockpit, or numerous flights from all over the country may be cancelled because a storm has closed a major hub in the Northeast. Events such as a severe line of thunderstorms may curtail traffic at a single airport or a major

[1] In the context of this paper, the term "event" generally refers to weather, mechanical failure and other causes of disruptions to airline schedules.

[2] The primary effects of a delay include its direct consequences on the affected flight (e.g., crew costs, tickets for delayed passengers on competitors' flights, etc.)

[3] Secondary effects of a delay reflect the consequences of the aircraft not being able to meets the requirements of its schedule (e.g., flights on additional legs scheduled for the aircraft are delayed, crew is not able to connect with other aircraft as scheduled, passengers miss connections, etc.)

snowstorm can shut down traffic at major airports in an area that encompasses several states. A strike can effectively shut down an airline; and, if it is one of the major carriers, the entire national air transportation system can feel the effects. On relatively rare occasions, an airline will hold one or more flights because a particularly critical connecting flight has been delayed. Accommodation of large groups traveling together or a desire to avoid repeating a missed connection that had recently occurred are among the factors that could motivate such a self-imposed delay.

For example, if an airport is severely impacted by a storm, the Federal Aviation Administration's (FAA) Air Traffic Control System Command Center (ATCSCC) may institute ground stops on traffic heading toward that particular airport, disrupting the flow of traffic over a wide geographic area. The result can be an over-crowding of gates and parking spaces at the airports not directly affected by the storm but serving as points of departure for flights bound for the weather-impacted airport. When ground stops are lifted, if the aircraft are released at a time that conflicts with a later departure bank, they can cause queues to build up for departure runways. The arrival volume of released flights at the airport that necessitated the ground stop could, in turn, challenge its capacity.

Delays and cancellations are the most frequent results of disruptive events. For the airlines, these are the least damaging in terms of creating schedule disruption and customer dissatisfaction. Aircraft are at least located at a point that was included in their itineraries and the crews assigned to them are likely to be available for service. If the delayed or cancelled flight is at a hub, the airline is likely to have alternatives on its own system for accommodating affected passengers and freight.

On the other hand, when a flight is diverted, the affected passengers and crew are likely to find themselves at an airport where the airline has substantially fewer rebooking or substitution options. First, the airline may have few, if any, operations in and out of the airport to which the flight was diverted. Passengers either have to be transferred to another carrier or be accommodated until their flight is able to proceed to its original destination. Second, the airline may have neither gates nor service facilities at the alternate airport. Consequently, it may find itself paying higher than usual prices for fuel, catering services and access to gates at which it can off-load passengers rather than keeping them confined within the aircraft.

**Alternatives Available to the Airlines for Handling Disruptions**

When an event has not been forecast, affected airlines have no choice but to react to the event. However, when some notice of an impending event is available, airlines are able take preemptive actions designed to mitigate the effects of the disruption. For example, they may choose to cancel flights in the face of a snowstorm and move aircraft from the affected airports in order to have them available to serve stations that will not be affected directly by the adverse weather.

Generally, airlines have demonstrated a marked preference for delays and cancellations over diversions. Diversions are the most costly of the three alternatives in terms of both direct cost and the creation of ill will among the passengers. However, assuming that the FAA has not imposed a ground stop, some airlines will choose to launch flights in the face of significant forecast delay in the hope that the weather will have lifted by the estimated time of arrival and that the aircraft will be permitted to land. If the aircraft is unable to land at its destination, it must be diverted to an alternate airport, causing the airline to incur the costs of a diversion.

Airlines also develop strategies for dealing with an actual or anticipated ground delay program. The ATCSCC clears flights for specific take-off times, but the airlines retain the option of substituting another flight for one originally scheduled for each slot. Using this flexibility, they will use a variety of business and operating factors to choose to operate those flights that the airline perceives to be in its best interest.

Within limits, airlines also have the ability to modify the itineraries of the aircraft it has available. In many cases, the aircraft available are sufficiently similar to those scheduled for a flight and one can be substituted easily for another. When this is true, flights may be cancelled so that the aircraft assigned to them may be used for other operations the airline deems to be operationally advantageous. Some flights, as a result of an airline's analysis of its options, may be intentionally delayed rather than cancelled in the belief that an aircraft to operate them will be available from the pool of delayed incoming flights.

The options available to the airlines for dealing with disruptive events are constrained by crew availability and aircraft maintenance schedules. Crews approaching their limits with respect to duty time may not be able to continue with a flight that has been delayed or diverted. In such a case a “fresh” crew may have to be called upon to operate the diverted aircraft. Similarly, a delay or diversion can take an airframe out of service if it is operating close to its limits in terms of required scheduled maintenance. If an aircraft due for maintenance is diverted, it may have to “dead head” to the maintenance facility rather than reaching it at the end of a scheduled revenue operation. Crew time and the maintenance schedule play a vital role in the ultimate delay/cancellation decision.

**Cost Implications of Disruptions to the Airlines**

Disruptions to schedules affect airline costs through three distinct paths. First are the direct costs such as those that are incurred for additional fuel, crew time and maintenance. Second are passenger-related costs that include such varied items as meals and lodging for individuals subject to delay or payments to other airlines and fare revenue lost when passengers switch to competitors. Third are secondary costs such as the ill will created in passengers that are subject to delays and the lost revenue from trips that are cancelled.

Data needed to estimate some of these cost items are available, data for others are not. “Secondary costs” are difficult to measure; and, therefore, not all airlines attempt to estimate these types of costs when determining the cost impact of delays or diversions. Placing a value on ill will presents problems for cost estimation that are particularly difficult to resolve while estimating the revenues lost to other airlines by passengers transferring to them is not as odious.

Each event that disrupts airline schedules, regardless of its magnitude, is unique. Costs to the airlines of disruptive events vary widely. Even within a class of events, for example, snow storms, the costs will vary greatly depending on the specifics of such items as the airports involved, the airlines and the type of aircraft they use, and the magnitude and duration of the storm.

However, although each event is unique, case studies can provide insights that are useful. While the results of case studies are not scientifically rigorous, they do help identify variables and relationships among them to be considered, creating a higher level of understanding.

Disruptive events influence airline economics at two levels: the individual airline and the industry. At the level of individual airlines, losses to one may be gains for another, and the loss of revenues to the industry as a whole is likely to be minimal. For example, when an airline needs to cancel a flight, passengers may be ticketed on competitors’ flights so that only the smallest inconvenience is endured by each. On the other hand, losses due to interruptions to flight operations computed at the industry level are not likely to be recoverable. Trips will be cancelled rather than rescheduled and fixed costs incurred will not be balanced through generation of additional revenues that could cover them.

Therefore, research reported here was conducted at two levels. One, a particularly severe snow storm event that affected operations in the northeast was analyzed to investigate the pattern by which an irregular operations event evolves and the economic effects that it has on the affected airlines. The second example analyzes the magnitude of the economic effects of disruptions to airline operations when they are aggregated to the national level. The analysis shows that there is a minimal, inescapable level of disruptions that airlines, in the aggregate, view as an ongoing fixed cost of operations.

**Snow Storm Event at Boston**

The disruptions to airline operations that centered on Boston on 8–10 October 1998 were chosen as the first case study. Over a period of three days, the area affected expanded from the immediate area of Boston to cover a substantial portion of the country. Before it was over, ground delays had been instituted for a sizeable portion of the United States. Arrival data for these three days clearly show the pattern of delays that emerged as the event progressed, and that of the recovery that took place on the third day. These data also showed how the lack of scheduled activity during the night provided a respite during which the airlines were able to partially recover their schedules.

Figure 1 shows variations in delays, cancellations and diversion at Boston on 8–10 October 1998 as a severe weather pattern that affected flight operations first developed and then dissipated. They began during the afternoon and evening of 8 October, peaked during the afternoon of the 9th and dropped off during the 10th.

The vertical bars in Figure 1 show the number of flights that were unable to meet their scheduled arrival time during each hour of the three days analyzed. For example, at the height of the disruption during the early evening of the 9th, virtually all incoming flights were delayed.

Three aspects of this chart are of particular interest. First, note that no flights were diverted until late (one each in the hours beginning at 1600, 1700 and 2100 hrs) on the 10th. This reflects a definite hesitancy on the part of airlines to accept diversions as they are the most costly of the options for dealing with the disruptive events. Secondly, delays were by far the most common effect of the disruptive events. Thirdly, the absence of scheduled flights during the night provided the airlines a chance to recover from the effects of disruptions that occurred the previous day. As the curve shows, large numbers of flights scheduled to arrive in Boston during the day were delayed. Many of these were able to land in the evening during the lull (not shown) when few flights were scheduled and any queues built up during the day could be dissipated.

Note, also, the cumulative pattern of delays, cancellations and diversions shown in Figure 2. Of particular interest is the significant slope of the curve on the 9th (A) showing the increase in delays as the intensity of the weather activity grows. Conversely, the comparatively flat segment of this curve on the 10th (B) demonstrates the decreasing frequency of delayed flights as the recovery from irregular operations evolved.

As noted, the effects of the disruptive activity were widespread, covering a substantial portion of the northeast coast. Although this paper focuses on the events at Boston and the costs the airlines operating there incurred, other major airports were involved. For example, two of the airports affected by the same weather event were Philadelphia and Newark. Although not as great as the cost burden imposed on airline operations at Boston, it was substantial at each of the other two airports, demonstrating how substantial and widespread the affects of a large weather system can become.

Table 1 “Initial Estimated Irregular Operations Losses” shows the cost categories for the losses incurred at Newark and Philadelphia in addition to those experienced at the focal point of the disruption, Boston. In this calculation, only crew costs are attributed to the delay. Data for each of the three days of the event are shown. Clearly, the costs incurred on the 9th at Boston are the largest for one day at any one of the three locations for which data are available. Again, the data shows the preferences of the airlines for choosing delays and cancellations in preference to diversions.

A more refined computation of delay costs that includes costs such as fuel in addition to crew costs and estimates the revenue lost due to a delay raises the estimated total for Boston alone from just over $1 million United States Dollars (USD) to about $2.3 million (USD). This is a more realistic measure of the cost of disruption and reflects more of the true magnitude of the costs that irregular operations can impose on the airlines operating from an affected airport.

Because of the severity of the implications of irregular operations, airlines and the FAA take proactive steps whenever possible to mitigate the losses suffered. In doing so, they take as much of their destiny into their own hands as is possible and often are able to mitigate the overall effects of disruptions on operating costs. On the other hand, if the airlines are in a position where they can only react to events as they occur, their options are much reduced and, therefore, the costs of disruptions are likely to be higher than they could have been otherwise.

**Aggregated Costs of Disruptive Events**

For the year 1998, the total estimated direct costs to the airlines of irregular operations incurred by the 10 United States airlines that report Airline Service Quality Performance (ASQP) data to the Department of Transportation was $1.826 billion (USD). Cancellations and delays dominated with total costs of $858 million (USD) and $909 million (USD) respectively while diversions imposed an additional $59 million (USD) in costs.

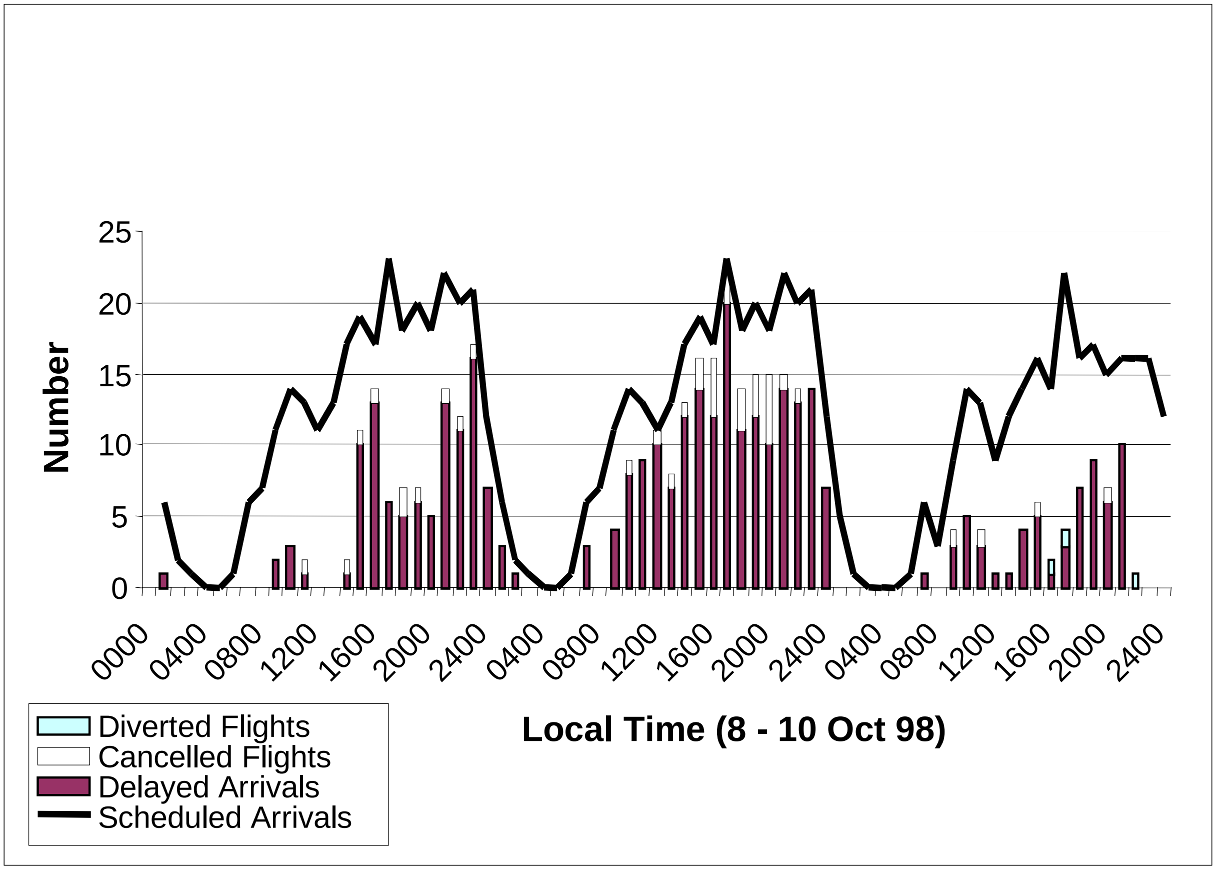


**Figure 1. Delays, Cancellations and Diversions for Boston**

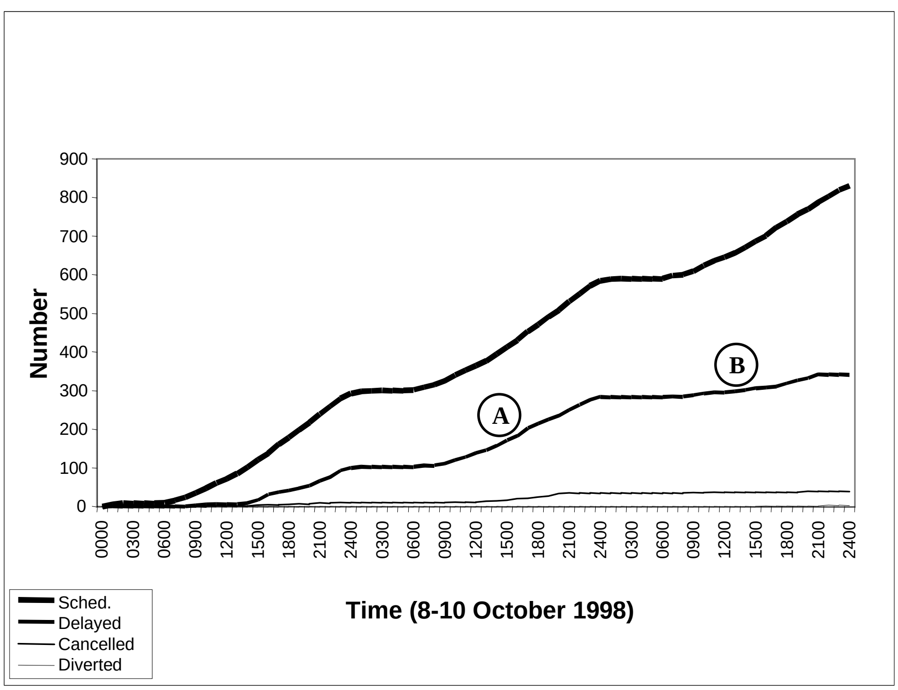


**Figure 2. Cumulative Cancellations, Delays and Diversions**

**Table 1. Initial Estimated Irregular Operations Losses (USD)**

| Boston | Costs (K) | Newark | Costs (K) | Philadelphia | Costs (K) |
|---|---|---|---|---|---|
| October 8, 1998 | | | | | |
| 10 cancellations | $116 | 10 cancellations | $116 | 6 cancellations | $70 |
| No diversions | $0 | 2 diversions | $45 | 1 diversion | $22 |
| 9514 minutes of arrival delay | $127 | 10337 minutes of arrival delay | $138 | 8462 minutes of arrival delay | $113 |
| | $243 | | $299 | | $205 |
| October 9, 1998 | | | | | |
| 25 cancellations | $290 | 9 cancellations | $105 | 11 cancellations | $128 |
| No diversions | $0 | 1 diversion | $22 | 3 diversions | $67 |
| 23852 minutes of arrival delay | $318 | 15187 minutes of arrival delay | $203 | 14380 minutes of arrival delay | $192 |
| | $608 | | $330 | | $387 |
| October 10, 1998 | | | | | |
| 4 cancellations | $46 | 3 cancellations | $35 | 6 cancellations | $70 |
| 3 diversions | $67 | 1 diversion | $22 | No diversions | $0 |
| 4015 minutes of arrival delay | $54 | 3212 minutes of arrival delay | $43 | 2188 minutes of arrival delay | $29 |
| | $167 | | $100 | | $99 |
| Estimated Total Cost | **$1,018** | | **$729** | | **$691** |

Calculation of costs of delays, cancellations and diversions for the nation as a whole during 1998 was somewhat easier than for the events at a single airport. For example, no allowance for lost revenue was needed as it was assumed that an individual who was not able to complete their travel plans on time on the airline originally chosen would make the trip on another. The national data when examined for the year also provided insights that were not apparent from the Boston case study.

The plot of total costs due to disruptions incurred by the airlines reporting ASQP data is shown in Figure 3. It shows that disruptive events were spread throughout 1998.

Two periods during which the costs of disruption were relatively high and sustained can be seen: mid-June to early July and late August to mid September. The latter is the more severe of the two and was largely attributable to a labor action by Northwest Airlines' pilots. Sharp peaks are also visible in February and December. However, this curve in itself does not imply that these periods are indicative of a systemic propensity of disruptive events to cluster during specific periods of the year.

Also, the data show that, in general, days that experienced particularly severe disruptive events are followed by ones where the airlines are able to deliver on their schedules. Rarely are two or more disrupted days grouped together. This suggests that when faced by severe disruptions, the airlines tend to forgo short term solutions aimed at fixing the immediate problems and focus, instead, on positioning resources to provide as complete a schedule as possible on the following day. On the other hand, when disruptions are less severe, there is reason to believe that the airlines will attempt to recover the current day's schedule rather than deferring its recovery to the following day.

When, as shown in Figure 4, costs are plotted by day in decreasing orders of magnitude, the picture becomes somewhat clearer. The slope of the curve decreases shortly after crossing the 90$^{th}$ percentile line, pointing to the fact that relatively few events account for a disproportionate share of the total costs attributable to disruptive events. The leftmost portion of the curve clearly suggests that a relatively small number of days were subject to disruptions that were substantially more costly than most. In fact, the 20 percent of the days with the highest cost from irregular operations in 1998 averaged about 27 percent above the average for the year. Further, the worst 5 percent of the days (19 days) accounted for 12.8 percent of the total annual cost of disruptions to the ASQP airlines in 1998.

The right side of the curve also suggests the existence of a baseline of low-level disruptive events that constitute an inescapable element of airline operations. Included in this baseline are routine mechanical failures, in-flight medical emergencies that result in diversions, unanticipated congestion at airports and en route, and failure of aircrew and other personnel to report as scheduled.

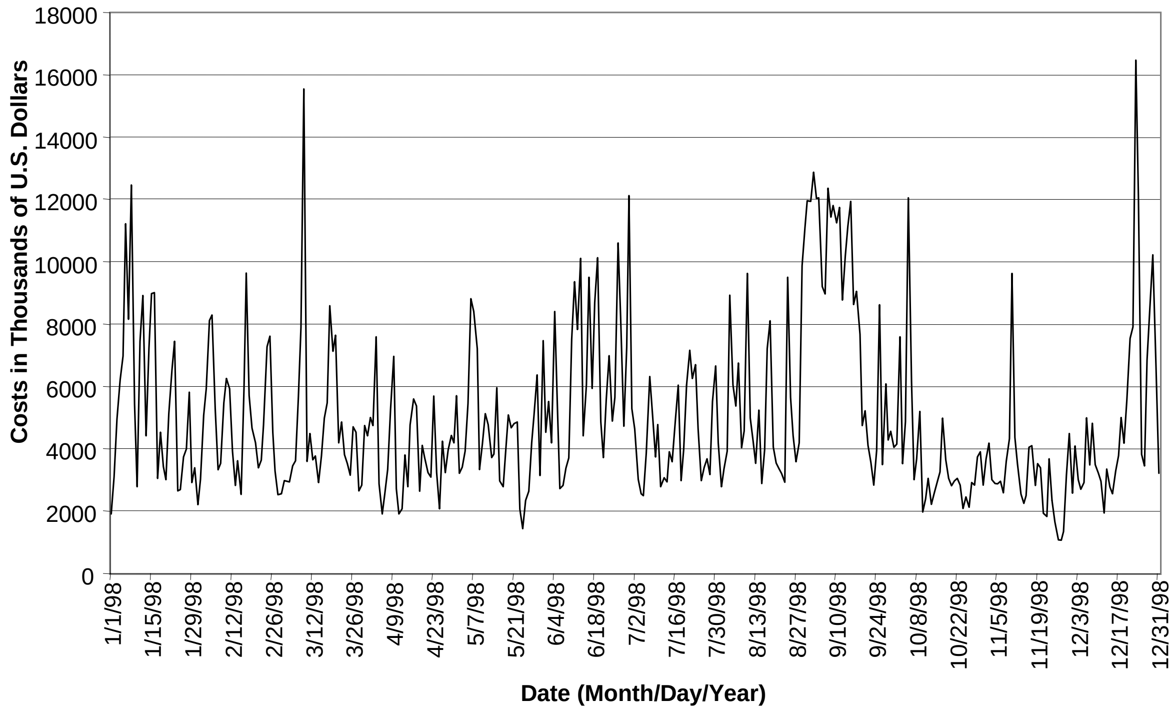


**Figure 3. ASQP Cost by Day**

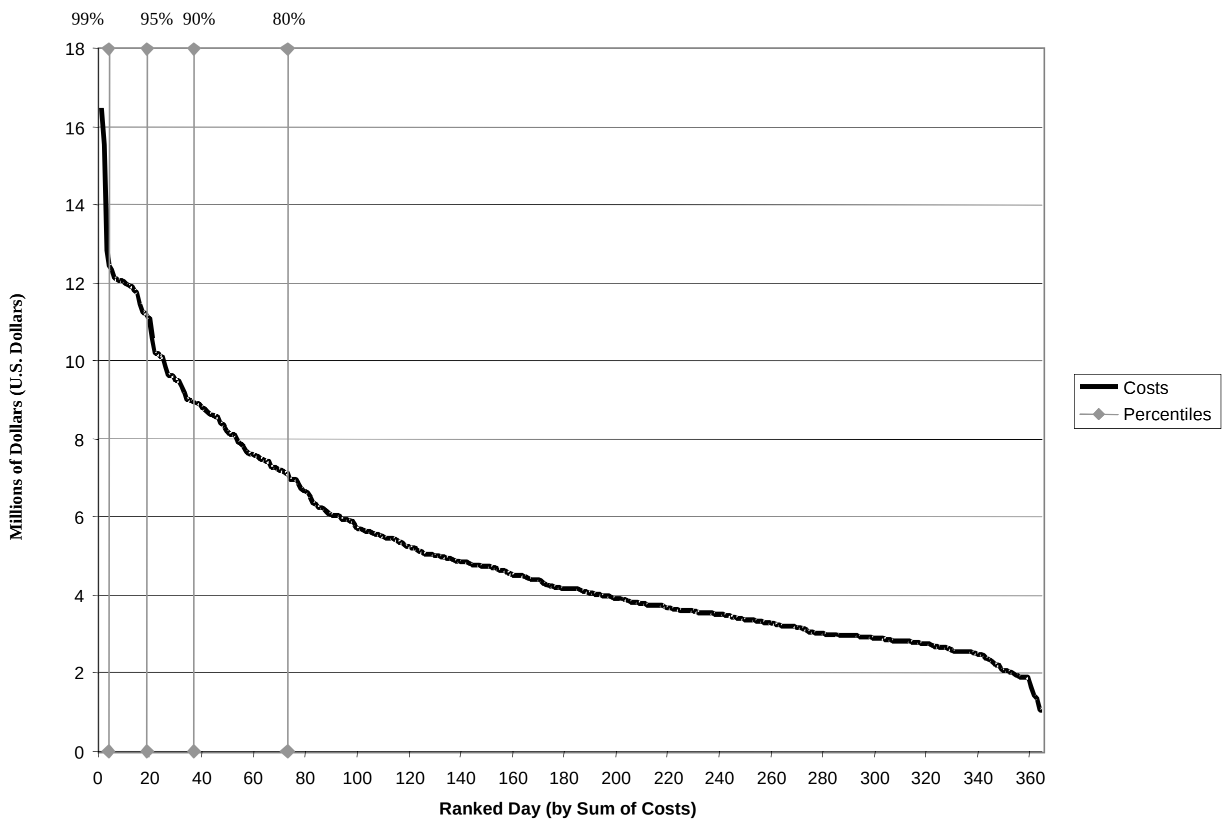


**Figure 4. Rank Order of the Sum of ASQP Carrier Costs (1998)**

Specifically, the curve suggests that 20 percent of the days (73 days) can be taken as forming the baseline of the cost of disruptions to the ASQP airlines. About $3 million (USD) per day comprise the unavoidable cost of delays, diversions and cancellations inherent in the system.

While the data that have been presented are for 1998 only, Figure 5 shows that 1998 was not particularly unusual in terms of the events that disrupt airline operations and the costs for the airlines that result. January in each of the four years for which data are plotted is the worst month of the year. Again, the large cost shown for September, 1998 is attributable to the labor problems of Northwest Airlines. More importantly, the consistency of the values shown for each of the months supports the conclusion that the findings of this study are representative of the costs airlines incur when faced with disruptive events.

In addition, as shown in Figure 6, the effects of disruptive events on airline operations have also been consistent across at least four years. The distribution of delays, cancellations and diversions are constant for the years 1996 through 1999, further supporting the conclusion that the results presented here have broad applicability.

**Conclusion**

Airlines, more than most businesses, are subject to external events that affect both their costs and the attractiveness of their product, their schedule, in the market place. These costs are substantial and difficult to estimate.

The unpredictability and uncontrollable nature of most disruptions make it difficult to mitigate their effects. Variations in cost and revenue structures among air carriers make it difficult to estimate their economic impact. However, as shown in this paper, the economic impact of severe disruptions is very significant. Therefore, air carriers, the FAA, and other aviation organizations should continue developing means for providing more advance notice of pending disruptions, sharing information about existing disruptions, and collaboratively making decisions regarding air traffic affected by disruptions.

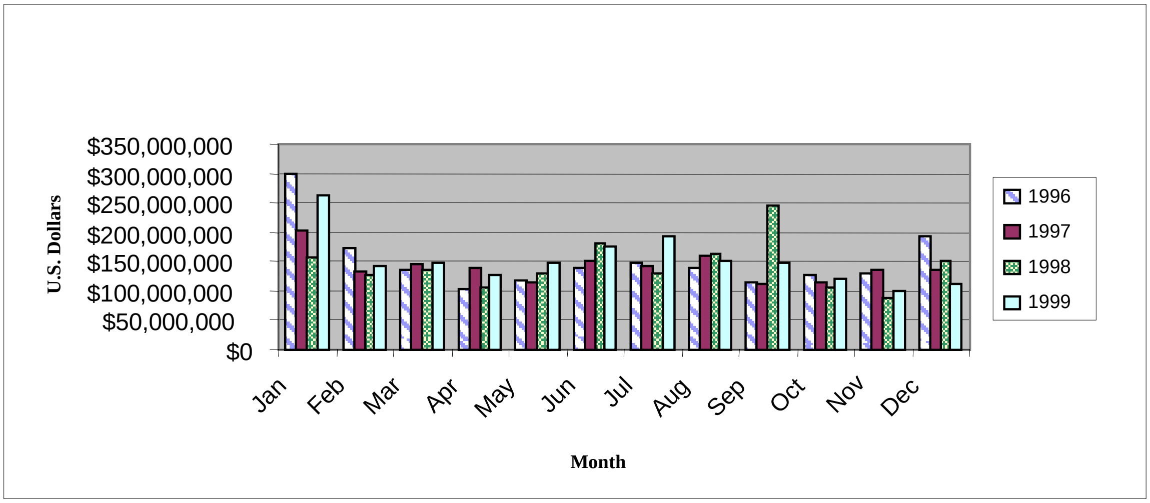


**Figure 5. Total Disruption Costs (Major Airlines)**

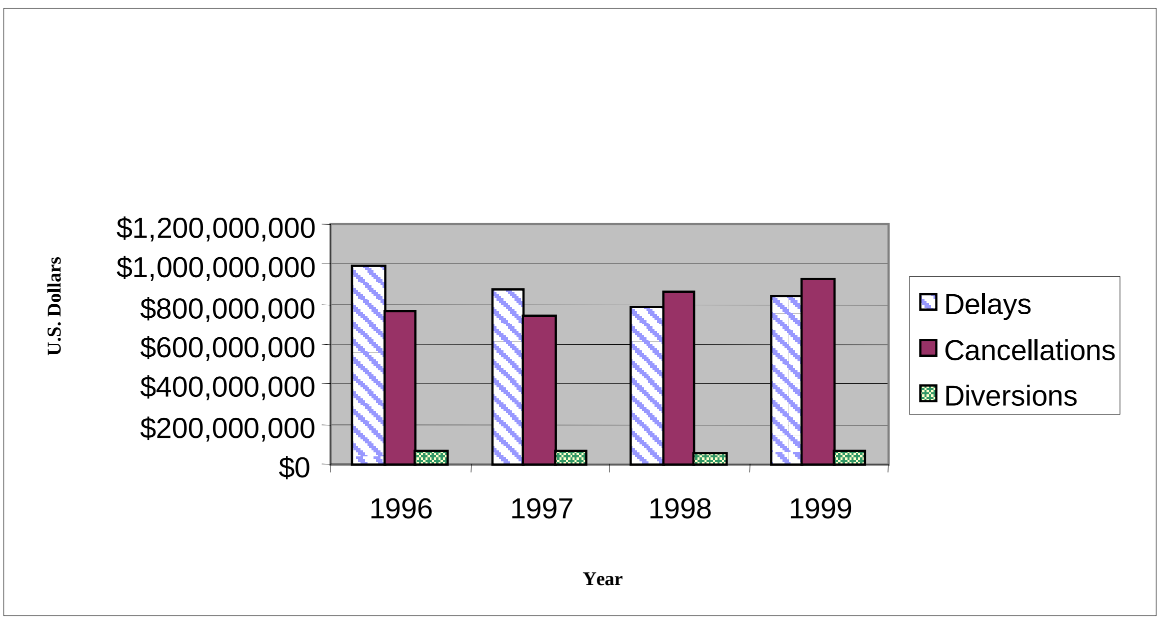


**Figure 6. Annual Disruption Costs by Source (Major Airlines)**

Biographical Sketch

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Dr. Zalman A. Shavell is a senior member of the technical staff of The MITRE Corporation where he focuses his efforts on issues related to the economics and performance of the National Airspace System (NAS). His recent work has included analyses of the influence of regional jets on NAS performance and the costs of irregular operations. Currently he works in the area of measuring air traffic system performance in both the continental United States (CONUS) and in oceanic airspace. Prior to joining MITRE, Dr. Shavell was on the staff of the Congressional Office of Technology Assessment where he analyzed air traffic control technologies presented in the Federal Aviation Administration's National Airspace Plan. He holds degrees in aeronautical engineering and economics from Rensselaer Polytechnic Institute and the University of Maryland, College Park, respectively.