

ASSESSING THE BENEFITS OF COLLABORATIVE DECISION MAKING IN AIR TRAFFIC MANAGEMENT

Michael O. Ball* (mball@rhsmith.umd.edu), Robert L. Hoffman⁺ (hoff@isr.umd.edu), Dave Knorr[#]
(Dave.Knorr@faa.gov), James Wetherly[#] (James.Wetherly@faa.gov), Mike Wambsganss⁺
(wambsganss@metsci.com).

*Robert H. Smith School of Business, University of Maryland, College Park, MD 20742, USA

⁺Metron Scientific Consulting, Inc., 11911 Freedom Dr., Ste. 800, Reston, VA 20190, USA

[#]Federal Aviation Administration, 800 Independence Avenue, S.W., Washington, DC 20591, USA

April 13, 2000

Abstract: Collaborative Decision Making (CDM) embodies a new philosophy for managing air traffic. The initial implementation of CDM within the US, has been aimed at Ground Delay Program Enhancements (GDP-E). Work is currently underway to apply CDM technology and concepts in other areas including the distribution of NAS status information and the management of en-route traffic (Collaborative Routing). In this paper, we analyze the initial implementation of CDM. Our work is principally aimed at GDP-E since the other application areas are only now emerging. We show that CDM has had a positive impact on the quality of information and its distribution through increased accuracy of flight departures and the submission of more timely flight cancellation notices. The impact CDM has had on GDP planning and overall airline decision making is assessed. We also discuss the status of the Collaborative Routing effort and the issues involved in measuring its effectiveness.

1. CDM Background

Collaborative Decision Making (CDM) was conceived within the FAA's Airline Data Exchange (FADE) experiments that began in 1993. These experiments proved that having airlines submit real-time operational information to the FAA could improve air traffic management decision making. CDM is an effort to improve air traffic management through information exchange, procedural improvements, tool development, and common situational awareness.

The initial focus of CDM, known as Ground Delay Program Enhancements (GDP-E), began its prototype operations at San Francisco (SFO) and Newark (EWR) airports in January of 1998. Under GDP-E, participating airlines send operational schedules and changes to schedules to the Air Traffic Control Systems Command Center (ATCSCC) on a continual basis. This schedule information includes, but is not limited to, flight delay information, cancellations, and newly created flights. Through the use of the Flight Schedule Monitor (FSM), the ATCSCC uses this information to monitor airport arrival demand and to conduct ground delay programs (GDPs). The airlines are also able to monitor arrival demands and model ground delay programs via FSM but do not have the capability to alter or

implement ground delay programs.

In addition to improving the execution of GDPs, CDM has been found to have application to other air traffic management problems, such as airspace congestion due to heavy traffic or en-route weather. The Collaborative Routing effort is intended to improve handling of potential flow problems that are likely to require rerouting or other flow management actions. The National Air Space Status Information activities are aimed at employing CDM technology and concepts to share critical safety and efficiency data among NAS users.

While one can point to a variety of concepts and technologies that are fundamental to CDM's success, probably the most vital underlying element has been a strong and continuous interaction among all important players, including the Federal Aviation Administration (FAA), the airline industry, other NAS users and members of the research and development community. Regular, e.g. monthly, meetings of the larger CDM group as well as smaller sub-groups have been held throughout the life of the CDM project. Through these interactions a new GDP paradigm was developed and agreed upon by

all the players. Essential to this paradigm is the implicit definition of new fair allocation principles that are embodied in the ration-by-schedule and compression algorithms. These algorithms are key components of FSM, the CDM decision support tool. Another fundamental CDM technology is the CDMnet, a private extra-net that connects the ATCSCC, the participating airline operational control centers (AOCs), the hubsite of the Enhanced Traffic Management System (ETMS), as well as certain other parties. More detailed descriptions of CDM technologies and concepts can be found in [Hoffman et al, 1999] and [Wambsganns, 1997]

A final key aspect of the CDM effort is its reliance on data analysis and objective critique. In support of this, an analysis sub-group has worked closely with the CDM community to highlight its accomplishments and to point out those areas in which it needs to be more effective. With regard to the benefits of CDM, there have been two major reviews of CDM activities: one in the Spring of 1998 by NEXTOR, the National Center of Excellence for Aviation Operations Research [Ball et. al. 1998], and one in December of 1999 by the FAA's Free Flight Phase I Office [FAA, 1999].

Since CDM has had the most impact to date on GDPs, this will be the primary focus of our discussion of benefits assessments. Section 2 of this paper contains the results of analysis on the impact of CDM on information quality. Section 3 presents results related to the system and user impacts of CDM. Section 4 summarizes on-going activities and challenges in the area of collaborative routing.

2. Improvements in the Quality of Information and Information Distribution

The goal of the initial implementation of CDM was to support GDP planning at San Francisco (SFO) and Newark (EWR) airports. The infrastructure put in place to achieve this goal involved broad information collection and distribution mechanisms. In this section, we organize the presentation of our analysis by first considering the quality of the new information infrastructure, then the impact on SFO and EWR GDPs and, finally, the impact on more general decision making.

The use of CDM has produced new information by combining FAA and airline data sources. All CDM airline participants,

including American Airlines, Continental Airlines, Delta Airlines, Northwest Airlines, Southwest Airlines, Trans World Airlines, United Airlines and US Airways have implemented data feeds from their operations systems into the AOCnet. Using these data feeds, the airlines provide information on flight cancellations, mechanical delays, and other events that impact the demand on the NAS. This information is merged with FAA generated information by systems at the Volpe Center into a real-time data feed, known as the "CDM String".

Through the CDMNet, the CDM-enhanced information has been distributed in an unprecedented fashion. In fact, probably the most significant aspect of the new CDM information infrastructure is that the airline operations centers receive the same information as the FAA ATCSCC specialists. Such information is critical in enabling airline operations specialists to plan responses to changing conditions and possible FAA control actions. Previously, such information was not available to airline operations planners or was only available "after-the-fact", when it could no longer be used to influence decision-making.

Our analyses have found that the information flowing over the CDM string is of higher quality. Moreover, we have found that the improvements are most dramatic when the system is under stress and the information is most critically needed. Below, we summarize the results by data type: flight departure prediction and cancellation data.

2.1 Predictive Accuracy of Flight Departures: the IPE Metric

CDM has made a concerted effort to improve the accuracy of flight departure predictions. Participating air carriers have voluntarily augmented ETMS flight data with their own departure predictions. The premise is that each airline has the most complete picture of its operations (delays due to connectivity, gates, etc.), thus enabling it to make more accurate predictions of its departure times than ETMS.

We used the Integrated Predictive Error (IPE) metric to monitor long-term trends in flight departure predictive accuracy. IPE is a weighted average of the errors in a stream of predictions made over time for a single event. This number is called the IPE of the event. A numerical suffix indicates the number of hours

over which the metric was tracked. IPE units are normalized by the tracking time and can be thought of as an average error (usually given in minutes). For instance, an ipe-6 value of 10 minutes would be obtained by making a steady stream of predictions over 6 hours each of which is off from the actual departure time by 10 minutes.

For each day between January 1997 and June 1999, we computed the average ipe-6 departure error over all flights bound for San Francisco (SFO) or Newark (EWR) airports. This process was repeated for the metrics ipe-5, ipe-4, ..., ipe-1, to arrive at six averages for each airport, for each day in the 30-month period. The results were then stratified into GDP days and non-GDP days, and averaged over the month in which the day occurred. In order to detect long-term trends, we smoothed the natural variance in the monthly IPE values by plotting a cumulative average (over all prior months) for each of the six metrics. The results appear in Figure 1.

The monthly IPE averages for GDP days are substantially higher than for non-GDP days. This is to be expected, since the reassignment of arrival times by the FAA in a GDP leads to unpredictable variance in departure times and, subsequently, higher IPE values. Also, a GDP throws air carriers into a state of irregular operations that can have other adverse consequences affecting departure prediction.

The most notable feature of the results is that on GDP days, when accurate flight data is most crucial, the average error in departure prediction dropped over most of the 30-month study, indicating an improvement in the accuracy of flight data. For instance, between January of 1998 (the inception of CDM) and June of 1999, the average ipe-6 departure error for GDP days at SFO dropped by 3.40 minutes per flight (5.58 minutes per flight for GDP days at EWR).¹ Average IPE values for non-GDP days at SFO and EWR have dropped as well. In fact, for both airports, the departure prediction error has been pushed below 15 minutes, the industry-wide standard for an on-time event.

¹ These are changes in the *cumulative* average since January of 1997. The non-cumulative average ipe-6 values for GDP days at SFO in Jan98 and Jun99 were: 28.82 minutes and 26.02 minutes, respectively (25.46 minutes and 22.33 minutes, respectively, for EWR).

These positive (downward) trends actually began *before* the inception of CDM prototype operations at SFO. However, we note that the CDM participants began submitting flight data several months before the prototype operations period, which is characterized by the use of the FSM resource allocation tools.

All the metrics ipe-6, ipe-5, ..., ipe-1, exhibit a common pattern for both GDP and non-GDP) but that the lower the tracking period, the lower the IPE value. For instance, the ipe-5 curve is essentially a downward shift of the ipe-6 curve, the ipe-4 curve is a downward shift of the ipe-5 curve, and so on. This indicates that, on average, departure prediction accuracy increases (has less error) as the departure of a flight approaches.

It is unlikely that departure prediction error for GDP days will ever be reduced to the levels obtained on non-GDP days; both FAA and air carrier manipulations of departure schedules during a GDP will always introduce unpredictability in departure time predictions. Also, it is possible that improvements in departure time accuracy are approaching a limit, due to the fact that, in the aggregate, there will always be an inherent amount of uncertainty in prediction of aviation events.

2.2 Timeliness of Flight Cancellation Messages

We analyzed the impact of CDM on the notification of flight cancellations. Prior to CDM, there was no mechanism by which the airlines could notify the ATCSCC of a flight cancellation other than a telephone call or a flight substitution message. The ATCSCC relied solely on NAS-generated cancellation messages. Via the CDMnet, CDM has enabled the airlines to directly submit a flight cancellation message independently of all other ETMS cancellation fields. This is intended to generate a more accurate picture of demand for NAS resources, especially during a GDP.

In order to measure the timeliness of cancellation messages received, we chose the Original Estimated Time of Departure (OETD) of a flight as the base time against which to measure the amount of notice given for a flight cancellation. For all effective purposes, this is the time of departure listed in the Official Airline Guide (OAG). (More strictly speaking, we used the first estimated time of departure for each flight listed in our database, which is

based on aggregate demand lists). Usually, the OETD appeared in our database 12 hours prior to the OETD. Although there are strong arguments for using an arrival-oriented metric as opposed to a departure-oriented metric, it seems reasonable that a cancellation notice should be submitted prior to the scheduled departure time of a flight.

In order to compare the ETMS and CDM systems, two groups of cancellation fields were established: group G5+, which models ETMS cancellation messages, and Group G6, which models the CDM cancellation messages. G5+ is based on five out of the six ETMS cancellation fields (The diversion field, “dv”, was excluded from the study due to lack of usage.) The “+” indicates that we have added a logic that mimics the ETMS time-out cancellation field; this models what would have happened in the ETMS system if an airline cancellation message (“fx”) had not been received (fx messages suppress the activation of the ETMS time-out field). G6 is based on the fields in group G5+ plus the CDM-provided airline cancellation field, fx.

Since G5+ is contained in G6 and since G5+ contains a time-out logic that eventually records flights canceled by an fx message, the groups share the same knowledge of cancellations. For each group, we defined the cancellation notice time of a flight f to be the amount of time *before* the Original Estimated Time of Departure (OETD) of f that the earliest cancellation notice was received in any of the fields in that group. Thus, this is the earliest time that the cancellation group had knowledge of the cancellation and the analysis is reduced to comparing the cancellation notice times of each group for each canceled flight. Note: A flight is considered to be canceled if and only if at least one of its cancellation fields turned positive and the flight showed no activity (i.e., no departure, no arrival, etc.).

We partitioned flight cancellation times that occurred at SFO between January 1, 1998 and May 31 1999 into the two groups, G5+ and G6, and averaged the results to form two distributions of cancellation times: one with CDM messages and one without CDM messages. Figure 2 shows the results. Note the shift in the distribution from left to right, which indicates that cancellations are known earlier after CDM cancellation data is added. In fact, without CDM, the average cancellation notice was received 29 minutes *after* the OETD, but with CDM, it was received 48 minutes *before*

the OETD. for a difference of 77 minutes.

The 77 minute performance gap at EWR is a very conservative figure, given that the default time-out mechanism used to model ETMS cancellation notice times was set at 0 minutes. This assumes that ETMS would have canceled each non-active flights immediately after its OETD. Experts at the Volpe National Transportation Systems Center claim that a more realistic default time-out would be 120 minutes after OETD.

Figure 3 gives the distributions of cancellation notice times for a time-out default time of 120 minutes. Again, we see a shift in the distribution toward earlier cancellation notice times. This time, the average cancellation notice time was 49 minutes *after* the OETD while with CDM, it was received 44 minutes *before* the OETD. That is, the average notice was received 93 minutes earlier under CDM. Similar results have been obtained for SFO. Since most traffic flow initiatives are made on a planning horizon of a few hours, this is certainly enough of an improvement to have a positive impact on traffic flow management decisions.

Further analyses have shown that after May 1998, the gap between CDM performance and ETMS performance continued to widen, especially on GDP days when timeliness of flight cancellation information is most crucial. Informal examination of the average cancellation times for individual cancellation fields has revealed that the superior performance of the CDM flight cancellation mechanism is attributable to the direct submission of flight cancellation messages by CDM participating air carriers via the CDM-provided ‘fx’ field. These messages were often received several hours in advance of an OETD, hence, drive up the average cancellation notice time considerably.

3. System and User Impact

Based on a series of interviews, we observed a consensus among ATCSCC specialists that CDM procedures yield more effective GDPs. It is difficult, if not impossible, to measure the total impact of CDM on GDP planning, since the improved information quality and FSM decision support features can influence GDP planning in subtle and varied ways. The measure of success of a GDP depends on several factors such as the throughput achievable for the existing weather conditions, the amount of assigned ground delay, and the

airborne delay encountered. In this section, we isolate some of the CDM benefits.

3.1 Compression Benefits

The compression algorithm is a procedure unique to CDM. It eliminates vacant slots and reduces overall delays by altering the assignment of slots to airlines in a way that treats all airlines fairly. Between January 20, 1998 and July 15, 1999, the ATCSCC executed 1,385 cycles of compression over a total of 21 airports and 539 GDPs. The percent of planned (ATCSCC assigned) delay reduction (at airports with 10 or more compression cycles) ranges from 7.5% at Atlanta's Hartsfield Airport to 18.2% at Boston's Logan Airport. The percent savings in planned delay at EWR and SFO, respectively, were 13.0% and 9.7%. The average over all GDP airports was 12.7%.

Figure 4 shows the rise in cumulative delay savings over the period from January 20, 1998 to July 15, 1999. The time horizon is marked by three 'epoch' periods of CDM history. The first is the time at which GDP prototype operations went into effect at all airports. The second is the snow season of 1999, which lead to notoriously bad weather conditions. Since this induced many more GDPs there were many more executions of compression and the rate of growth of compression savings began to climb noticeably. In the third period, the RBS and compression algorithms were run in a combined fashion known as RBS++. By the end of the overall time period, July 15 of 1999, the total compression savings climbed to 3,165,925 minutes.

We estimate that roughly one-half of this 3,165,925 minutes is savings (approximately 1,582,962 minutes) could be obtained by intra-airline substitution processes that existed prior to CDM. The other half could only be obtained through the inter-airline slot swapping mechanism provided by the compression algorithm peculiar to CDM. Just to put these savings in perspective, at a conservative industry standard of \$25.00 per minutes, this 1,582,962 minutes of planned delay savings due to compression represents a savings of (approx.) \$39,574,000 for an average of (approx.) \$28,574 per compression cycle.

We note that these are savings in *assigned* ground delay. Further analysis is required to determine the degree to which these savings could be mitigated by corresponding changes

in airborne delays.

3.2 User Reported Benefits

A major component of CDM benefits for GDPs should lie in providing each airline with greater ability to control the allocation of unavoidable delay among their flights. CDM allows an airline to reduce the impact of delays on passengers and airline operations by shifting delay away from flights where the delay has the most detrimental (and costly) impact. As an indication of the benefits in this area, we note that United Airlines has reported that it has derived significant delay reduction from the use of CDM-based GDPs at SFO and EWR and also from the use of FSM to plan its responses to GDPs at O'Hare (ORD) airport. United estimated that the total savings over the initial 1½ months of CDM prototype operations was 11,000 minutes with a value of \$3,000,000 to \$4,000,000.

3.3 A New Measure of GDP Performance: The Rate Control Index (RCI)

GDP enhancements have brought with them the need for metrics that evaluate the performance of a GDP as a whole, rather than just a single component of a GDP. One such metric is the Rate Control Index (RCI). RCI measures the flow of air traffic into an airport and compares it to the targeted flow that was set by the traffic flow managers at the ATCSCC during a ground delay program. A single index, or percentage, is reported for the entire performance of a GDP on a single day. A higher score (e.g., 95%) corresponds to better performance, meaning the flow of traffic into the airport closely matched the targeted pattern of traffic, both in quantity and in distribution. See [Hoffman and Ball 2000] for more details on the metric.

Though still in development, RCI has been applied to traffic flow into the terminal space of San Francisco Airport (SFO). Figure 3 shows the trend of the RCI metric for SFO over the 30-month period from January 1997 to March 1999. We smoothed out the variance of the monthly points by computing a moving average over four months (see the lines with the square icons). Further smoothing was obtained by computing a cumulative average over all months since January of 1997 (see the lines with the triangular icons). Three "checkpoints" are worth noting: the first month for which a four-month cumulative average had been computed (April 1997), the

start of CDM (January 1998) and the last point (March 1999). For SFO, these points were 91.42, 92.33 and 92.75. This indicates a slight rise in the (cumulative average) RCI value for SFO since the start of CDM². However, this trend is probably not statistically significant. We feel that a longer history is required to judge the significance of CDM's impact.

Preliminary applications of the metric to EWR show lower index rates (poorer performance) than at SFO and little change in the long-term trend. Lower index values at EWR are to be expected because of the complexity of its terminal space (bordering on different traffic centers) and the less predictable nature of east coast traffic. Also, we caution that the results at EWR are less conclusive than at SFO because the computation of this metric is dependent upon the modeling of airborne holding, which is more difficult at EWR than at SFO.

3.4 Added Benefits

3.4.1 Revisions

Prior to CDM, the ATCSCC did not have the capability to revise a program once it was in effect, meaning they were not able to modify ground delay program parameters such as the airport acceptance rate (AAR) and the scope or duration of the program. While they did have the ability to affect GDP-controlled traffic flow by means such as blanket delays (adding a fixed number of minutes of delay to all flights), the methods for program modification were cruder and less effective than the revision capability now provided by CDM.

One of the most powerful revisions that can be made to a GDP is to extend the length of a program. This allows the ATCSCC to control later-arriving traffic when adverse weather effects last longer than expected and to smooth out pent up demand (a stack) that may accumulate toward the end of a program. This tool has been used frequently since the inception of CDM and has proven to be highly

² Since the number of ground delay programs varies with the month, these results do not give equal weight to ground delay programs. Different results are obtained when equal weight is given to each program, i.e., averaging over all prior ground delay programs. The method we have adopted screens out some of the seasonal effects of weather. The legitimacy of this method is confirmed by averaging over each season of the year (results similar to those above are obtained)

effective for controlling traffic flow. Log entries made by the ATCSCC attest to the effectiveness of revisions to smooth out the traffic (and reduce) departure delays. The flexibility of this tool has resulted in the avoidance of underutilized capacity and excessive airborne holding.

3.4.2 Near-term GDP Cancellations

A *near-term* cancellation of a GDP is when a GDP is aborted within 30 minutes of its planned start time. Since ground delay is served by flights prior to take off, many flights will have absorbed delays well in advance of the start time of the GDP. Thus, all assigned ground delays absorbed prior to the start of the canceled GDP are (in hindsight) unnecessary. For this reason, near-term cancellations of GDPs are considered undesirable.

We tracked the number of instances of near-term GDP cancellations both pre- and post-CDM at six major airports. We conjectured that the combination of improved demand information and the power run feature of FSM that allows ATCSCC personnel to delay the implementation of a GDP to the last possible minute should decrease the number of near-term cancellations. Some airports showed improvement, others not at all. However, there has been a remarkable improvement (decrease) at St. Louis (STL) airport in the percentage of near-term GDP cancellations. We believe that this is the result of superior data quality of the two major airlines that dominate the airport. This caliber of data quality is attributable to the use of *daily download*, the replacement of potentially obsolete OAG information with fresh airline operational data at the start of each day.

3.4.3 Impact on Overall Airline Decision Making

Information provided by airlines indicates that the CDM-enhanced information has been used by airlines to improve decision making outside the realm of GDPs at SFO and EWR. On at least two separate occasions United Airlines used CDM information to reduce the number of flights canceled in anticipation of a GDP by 25% over the number that would have normally been canceled; the estimated total cost savings was \$1.5 M. We have also identified instances where airlines have solved capacity-demand imbalances by reducing demand in response to CDM information, thereby eliminating the need for an FAA action such as a GDP.

Somewhat surprisingly, we have also found that the airlines have used CDM-supplied information for a variety of purposes totally outside the intended application domain of GDP planning. Specifically, airline operations managers have used this information to support fuel planning, diversion decisions and management of flow into hubs. Delta Airlines reports that the more accurate information provided by FSM has allowed them to preserve the destination of flights that normally would have been diverted to other airports.

4. Collaborative Routing

Early on it was recognized that CDM had applicability to en-route airspace management and a subgroup has been actively pursuing this area. A set of Initial Collaborative Routing (ICR) tools and procedures were prototyped and tested during the 1999 severe weather season. These included, national CRCT (Collaborative Routing Coordination Tool), a concept prototype tool developed by the Mitre Corporation, which provides the FAA traffic flow management specialist automated features that support the identification of flights impacted by congestion and aid in the development of alternative routes; CCFP (Collaborative Convective Forecast Product), a national convective weather forecast, which represents a consensus based on inputs from AOC and ARTCC weather units; use of information and application distribution products (PictureTel and World Wide Web) to support Collaborative Routing decision making; LAADR (Low Altitude Arrival and Departure Routes), which embodies a set of procedures for allowing the use of low altitude routes in order to avoid congested airspace;

CDR Coded Departure Routes, which involves a set of procedures and a database for the creation, storage and dissemination of alternate routes to be used in order to avoid airspace blocked by severe weather.

In anticipation of the 2000 severe weather season in the US, a number of collaborative routing tools and procedures are now being tested and put in place. These include deployment and use of more major versions of the CDR, CCFP and LAADR capabilities from ICR. A national “playbook” database containing standard reroute strategies to be used to avoid closed or impeded airways has been created with access provided to both the FAA and NAS users. A new Strategic Planning Team has been established at the ATCSCC to design and implement national route planning strategies, which in many cases will be based on the playbook.

Longer term efforts are on-going to develop new decision support tools for en-route airspace management. The fundamental challenge for these efforts is to adapt the resource allocation principles developed for GDP-E to the en-route setting. Another challenge of similar difficulty is to analyze the performance and assess the impact of such Collaborative Routing tools and procedure. While GDP planning decomposes on an airport-by-airport basis, the typical en-route planning problem must take into account a wider set of flights and airspace components. This difference implies that en-route problems have a much larger “systems” nature and this leads to substantial challenges for both tool development and analysis.

References

- [Ball et al, 1998] Ball, Michael, R. Hoffman, W. Hall, and A. Muharremoglu, 1998, “Collaborative Decision Making in Air Traffic Management: A Preliminary Assessment”, NEXTOR technical report RR-99-3.
- [Ball et al, 1999] Ball, Michael O., R. Hoffman, C. Chen, and T. Vossen, 1999, “Collaborative Decision Making in Air Traffic Management: Current and Future Research Directions”, Proceedings of Capri ATM-99 Workshop, pp 267-276.
- [FAA, 1999] Free Flight Phase I Office, Federal Aviation Administration, 1999, “An Operational Assessment of Collaborative Decision Making in Air Traffic Management,” Document Control Number: R90145-01
- [Hoffman and Ball, 2000] Hoffman, Robert and M. Ball, 2000, “The Rate Control Index for Traffic Flow”, submitted for publication.
- [Hoffman et al, 1999] Hoffman, Robert, M. Ball, A. Odoni, W. Hall, and M. Wambsganss, 1999, “Collaborative Decision Making in Air Traffic Flow Management”, manuscript in preparation.
- [Wambsganss, 1997] Wambsganss, M., 1997, Collaborative Decision Making Through Dynamic

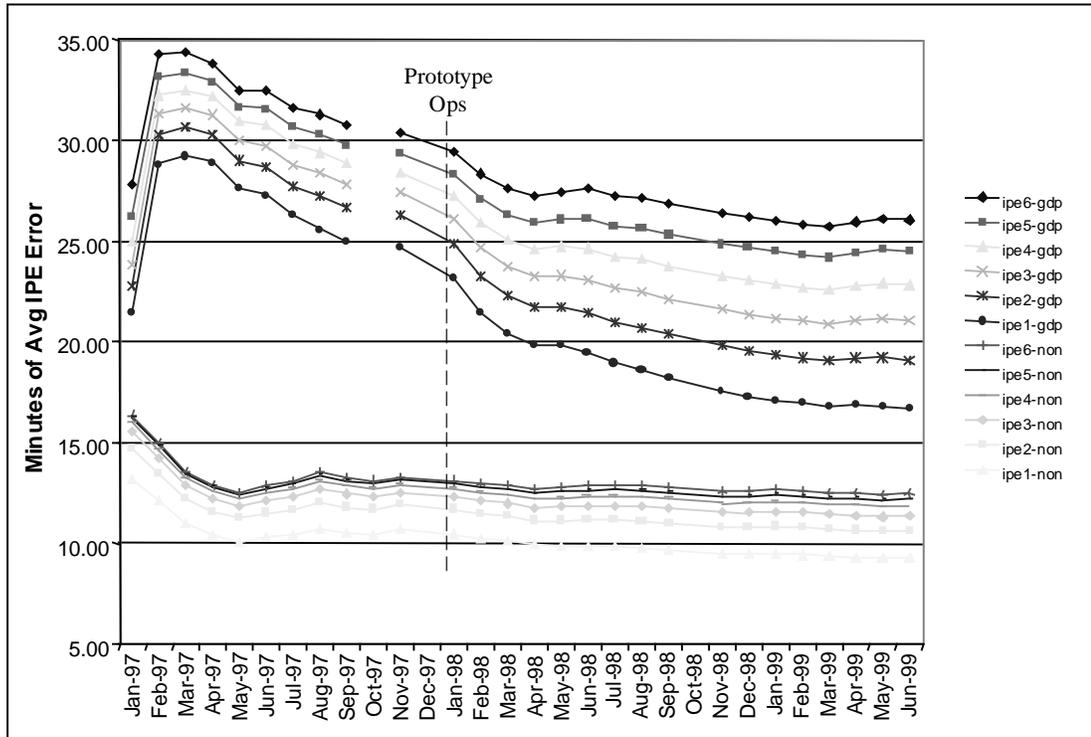


Figure 1: IPE results for SFO, January 1997 through June 1999.

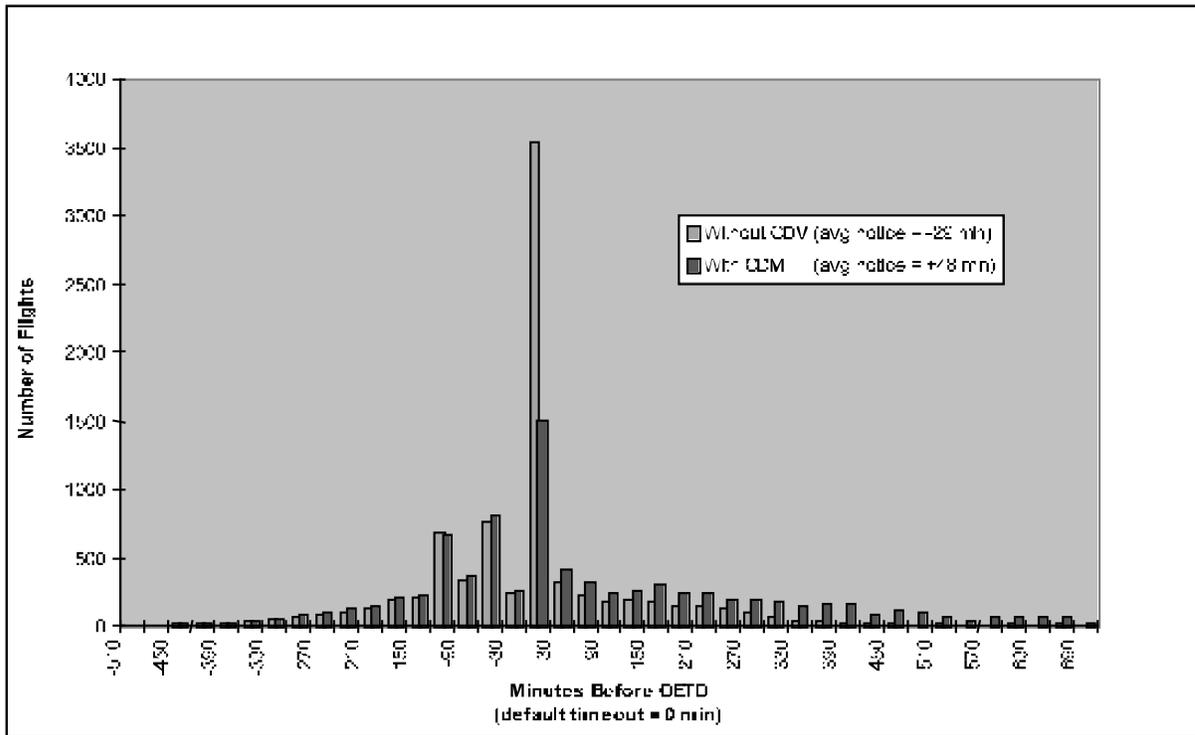


Figure 2: Average cancellation notice times for SFO with default timeout of 0 minutes

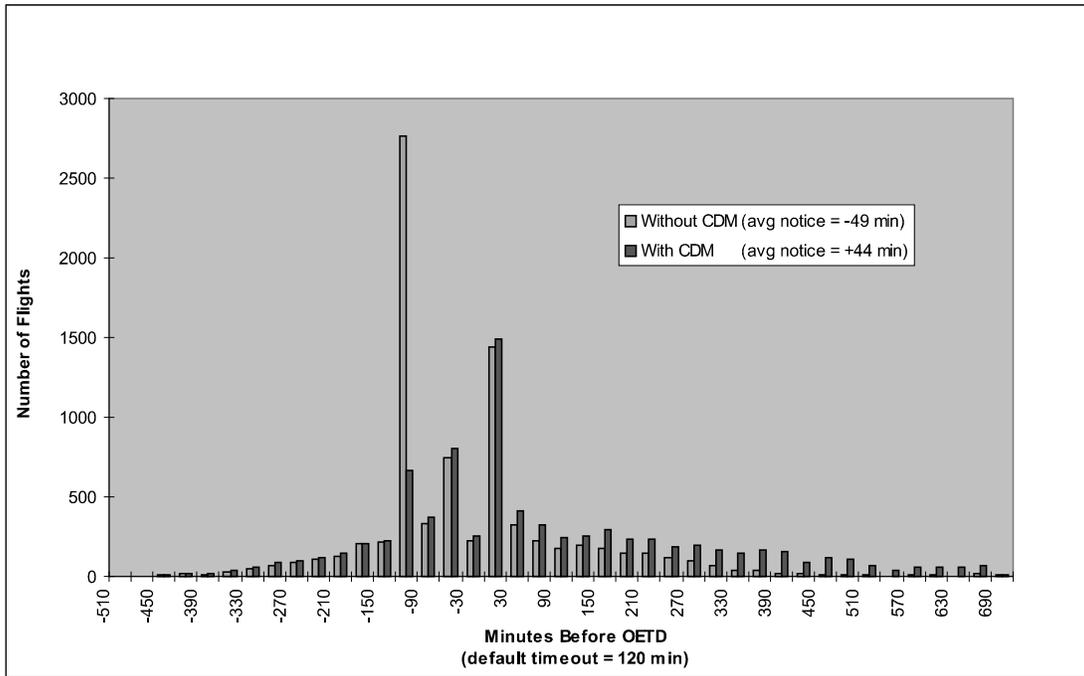


Figure 3: Average cancellation notice times for SFO with default timeout of 120 minutes

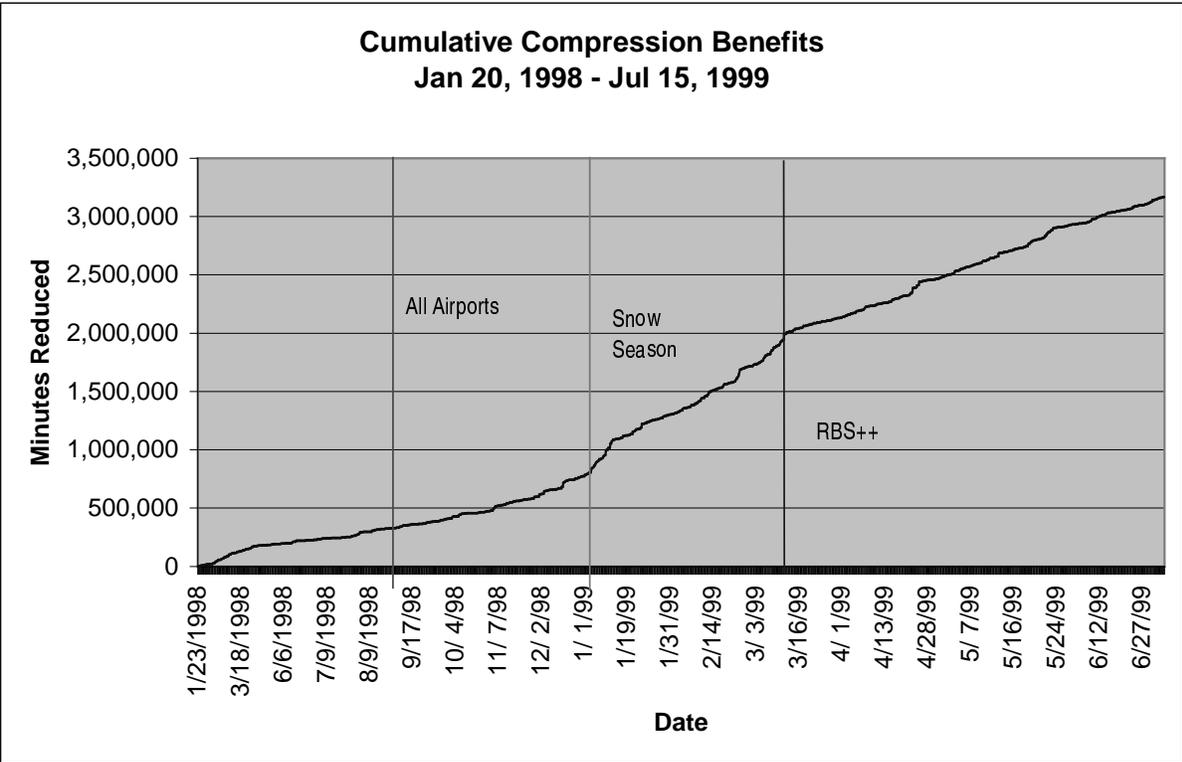


Figure 4: Cumulative planned delay savings from the compression algorithm