An enhancement to the current cooperative decision making process for capacity allocation: Tradable permits

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1. Introduction

The current mechanism for allocating scarce runway or airspace capacity on the day of flight depends primarily on the user's share of the flight plans filed. A carrier with many flight plans at a given airport is granted a larger share of available capacity than one with only a few flight plans. Such an allocation mechanism may be fair, in some sense, but it does not necessarily reflect the users' willingness-to-pay for priority in times of demand-capacity imbalances. Some higher-valued users may be delayed or face potential cancellations when they would be willing to pay to avoid disruptions in their flight schedules while other airlines may be willing to forego their current priority for compensation. This paper discusses alternatives to the current cooperative decision-making mechanism used by air-traffic control to allocate air space and runway capacity. We recognize the desirable traits of the current system and consider how that system might be enhanced rather than replaced.

One remedy to any economic inefficiency in the current system is to implement a market-based traffic flow management scheme. When we speak of "efficiencies", we are specifically considering the economic meaning of the term, namely that the product (in this case, permission to takeoff) is provided to those that value it the most and are, therefore, likely to use them best. A wide variety of market-based concepts are conceivable. In this research, we evaluate a variety of alternative market-based mechanisms and chose three promising mechanisms to test via computer simulations. The simulations examined how each market-based alternative impacted system-wide delays, average passenger delay, cost to each airline, and the overall cost to the system. By examining the results of these simulations coupled with informal conversations with airline decision makers, two important concepts emerged: (1) The industry was leery of any market-mechanism whereby the government collected new revenues; and (2) Carriers would be willing to buy priority access (from other operators) for some flights, which otherwise would not be accommodated in today's CDM system when the consequences of delay for the carrier are expensive.

With these concepts in mind, we realized that a simple trading scheme across airlines might have the greatest effect on economic efficiency without disruption to air traffic management's current system. The idea is relatively simple: a small fraction of the total runway capacity of an airport is allocated via permits that, when used, allow a flight to go to the head of the queue. These permits are owned by the airlines for the period allocated and can be traded and sold. Thus, airlines are provided with a mechanism to sell or buy access rights according to their own circumstances, and without funds being diverted outside of the industry..

We discuss a human-in-the-loop simulation whereby airline specialists were given the opportunity to participate in such a system. We end the paper with "lessons learned."

2. Background

This paper will discuss mechanisms for handling the allocation of scarce runway and airspace capacity during weather disruptions. We note that the current system of user taxes, weight-based fees and the absence of any allocation system prior to the day of flight[1] probably have adverse effects on the allocation of day of flight access. We acknowledge that the lack of a service standard (essentially time of day limitations on flight plans filed in sectors or terminal areas that have limited capacity) causes excess demand, which percolates through time and across airspace. Over time, as capacity fails to keep up with demand (which has a free claim on capacity), delays and block times increase. When there is severe weather, the demand-capacity imbalance is magnified, which makes the task of allocating access on the day of flight more difficult and costly for everyone. While this thesis deserves more empirical analysis, it is clear that the impacts may be very large. In the final regulatory evaluation of New York Airports, the FAA found that net benefits of imposing slot control at JFK and Newark Airports and of reducing the number of slots at LaGuardia totaled $3.5 billion dollars over 10 years [FAA, 2006]. It is important to note that these net benefits incorporate estimates of losses to consumers due to the elimination of some flights from the schedules at the three New York airports. There are clearly airports other than these slot-controlled airports and airspace where, even under good weather conditions, flights are delayed because of congestion.

But, even if a service standard were imposed that limited airlines to the approximate "normal day" capacities, there would still be events (e.g. storms, air turbulence, mechanical or electrical failures) that would reduce the capacity of the airspace and runways. Thus, congestion is a daily reality in the aviation sector and the current system for realigning demand with supply is a "first-come, first-served" approach based on the published OAG schedule.

Whenever it is determined that there is a misalignment of supply and demand, air traffic management uses a set of procedures and technologies that work to assure the safety of all flights through the airspace and while taxiing to the runway and during takeoffs and landings. Air traffic managers regulate the timing and speed of takeoffs and landings, provide re-routes to assure the proper spacing of aircraft and provide for flight conditions that do not cause undue aircraft turbulence. For more specifics of how air traffic control makes these decision see; de Neufville and Odoni (2003) and Ball, et al. (2007). Here, we present a cursory overview of the procedures.

Excess demand for airport capacity has been studied much more intensively than airspace congestion. At the busiest airports, airlines schedule flights up to or beyond the capacity that is determined by evaluating the safe separation of aircraft during Visual Meteorological Conditions (VMC), i.e. good weather days. As a result, when conditions deteriorate to Instrument Meteorological Conditions (IMC), there is often a large shortfall in capacity. Congestion problems can worsen throughout the day, as delays cascade from one hour to the next, and can spread quickly to other parts of the National Airspace System (NAS.) Airspace congestion occurs in the NAS when loading in sectors approaches or exceeds capacity. Loading and capacity can be difficult to forecast because weather affects both.

Air Traffic Management (ATM) responds to changes in weather conditions by announcing a Ground Delay Program (GDP). This short-term strategy attempts to reduce air traffic congestion by decreasing the rate of arriving flights to a given airport in order to balance the incoming traffic with the available capacity. The motivation behind GDPs is to convert the foreseen airborne delays into safer and cheaper ground delays [Ball and Lulli, 2004]. First, air traffic control determines the portions of the airspace

[1] Except at airports where FAA has instituted slot controls.

and/or runways that are impacted. It then assigns priority to the *arrivals* to a given airport based on its published arrival time in the Official Airline Guide. ATM restricts the arrivals to adhere to the capacity constraints and "holds" the aircraft at the departing airport. This ordering is called "Ration by Schedule" (RBS). It is considered to be fair in that the ordering is consistent with the announced schedule, the amount of flying each carrier intends to carry out on that day. Using this approach, flights at the beginning of the GDP are assigned shorter delays compared to those towards the end of an announced delay period.

Once the RBS allocation is made, the airlines now "own" these slots for the announced GDP time period. Each airline impacted may choose to reorder their own flights in this GDP ordering; they may also cancel flights. When a flight is cancelled, it results in a schedule with holes in the ordering. A "compression" algorithm is invoked to fill these holes by moving flights up along the schedule with the added provision that the airline that cancelled its flight has the right to insert some other flight into the schedule as needed, through a system called "Collaborative Decision Making" (CDM), instituted in 1998. The idea of CDM is to increase the information exchange between all the parties involved: airlines, airports, the FAA and air traffic controllers. This is done using a common situational awareness system that allows operational problems to be solved in a timely and coordinated manner [FAA, 2005a]. This, in turn, increases the efficiency and equity of GDPs while ensuring that available perishable resources (arrival time slots) are more fully utilized. The basic premise is that "shared information and collaboration in planning and executing ATFM initiatives benefits all ATM users as well as the ATM service provider" [Ball, et al., 2000].

Thus, through continual communication regarding cancelled flights, changes in weather conditions, up-to-date information regarding flight cancellations and delays throughout the system, the CDM allows a compression mechanism that incentivizes airlines to provide up-to-date information on each of their flights, since an early announcement of a cancellation allows an airline to obtain a slot later in the day. Some advantages of the CDM include: (1) All parties are provided with an aggregated picture of the airspace and the expected delays; (2) Projections about cancelled and delayed flights allows the GDP system to instantly update the ordering and provide these changes to all parties; (3) Such information may allow the GDP to end earlier than originally planned because of reductions in demand. This early end to a GDP can occur when there is a weather system over a broad area and cancellations in one part of the system reduce the number of arrivals at a given airport. And, (4) under CDM, airlines have a right to swap their slots with competitor's flights as well as their own. Further details about CDM and its implementation can be found in [Manley, 2008, Ball et al, 2007 and de Neufville and Odoni, 2003].

A further enhancement to the GDP system is the implementation of Slot Credit Substitutions (SCS), implemented in May, 2003. SCS allows an airline to enter a "conditional cancellation" opportunity. That is, it announces that it is willing to give up a certain slot (by cancelling a flight) in return for a later, desirable slot. The system considers these requests and tries to match pairs of flights for potential substitution. This pairing is termed as "bridging" in the SCS environment. An analysis by Metron Aviation [Wright, 2004] regarding SCS benefits suggested that SCS requests produced around 3000 bridging opportunities with an average savings of 20 minutes per bridging flight, resulting in a total of 120,000 minutes of delay savings.

GDP, CDM and SCS, together, provide a system based on the fairness of RBS and the ability of airlines to make corrections to the system, where necessary. The system works well when an airline has a large share of the flights and can reorder the flights to assure that there are no serious disruptions to their most-valuable flights. However, an airline with only a small percentage of the overall flights at a given airport may not have this flexibility. This airline might find that delaying a given flight has a significant impact on the larger network and yet can do little to avoid the resulting delays.

Another problem associated with the current system is that, because airlines care about published online performance and because marketing carriers may have incentives in their codeshare agreements to assign delays to their smaller regional partners.

Finally, the RBS approach is considered fair and equitable only if there are no exemptions to a group of flights. However, in the current system there are several exceptions to the rule. Often when a GDP is invoked, it is tiered according to distance and only cities within a given radius around the GDP airport are affected by it. All airborne flights are already exempted as are many international flights. This results in favoring carriers with long hauls and penalizes regional flights.

Many alternative ideas have been considered in the literature to overcome the issues with the current system. [Vossen and Ball, 2006] studied the consequences of allowing the airlines to trade slots among themselves unconditionally, unlike Slot Credit Substitution that only allows “one-for-one” trades. They suggest a general model to perform “*k*-for-*n*” trades and provide details of a implementation of “two-for-two” trades where the solution is determined by optimization where one maximizes the number of accepted offers.

Other researchers have examined alternatives to the original ordering of Ration-by-Schedule. [Vossen, 2002, Pourtaklo and Ball, 2009, Pourtaklo and Ball 2010 and Pourtaklo, 2010] consider alternative proportionality schemes whose basic idea is that each airline has slots proportional to the number of slots in the announced schedule, with the concept that each airline should receive a “fair share” of the slots available. Once meeting this concept of equity, how the slots are allocated varies and considers such concepts as: an airline’s preferences regarding those slots it wants to use for what flights. Such allocations can also consider the value of different time slots, flight distance, or may consider the likelihood of a very long delay. [Manley, 2008] compares rationing schemes using a variety of alternative equity measures.

Another approach suggested for allocation of slots during a GDP is suggested in [Sheth and Gutierrez-Nolasco, 2008 and 2009]. In this approach, each airline is allocated a fixed number of credit points. Airlines assign credit points to each flight and then the flights are sorted in descending credit-point order.

3. Economic arguments for a market-based

Economists have long argued that market-based tools for allocating scarce resources would be the most effective and efficient solution to aviation congestion. The proposed tools include both quantity-based and price-based allocation systems. In a quantity-based system, regulators would set the quantity of flights (capacity) at an appropriate level. A market-based tool would then be used to allocate this capacity among market participants. In a price-based system, regulators would set a price for access that would result in the appropriate level of flights. The goal in either type of system would be to allocate aviation resources to the users that value them the most.

[Rossenti, Smith and Bulfin 1982] were the first to consider the use of auctions for runway slot allocation. [Ledyard 2007] examined features of efficient markets that apply to both congestion pricing and auction mechanisms for aviation resource allocation system. Both papers argue that efficient markets enable trades to be made with low transaction costs, have high liquidity, and are transparent. To set up a market, the property right must be defined, qualified participants must be identified, the market design must be determined, and clearance/settlement mechanisms must be established.

Some foundations for the establishment of market-based allocation of aviation resources exist. For example, the FAA currently uses CDM to allow airlines to participate in the decision of which flights to cancel. This system operates on the principle that queue position belongs to an airline operating a flight rather than the specific flight itself [Neels, 2002].

However, arguments against the use of market-based allocation of aviation resources also exist. The primary argument against the use of the traditional economic tools for allocating scarce resources based on marginal-cost pricing (e.g. congestion pricing and slot auctions) is that the "real-world markets for airport capacity are incomplete and less than fully competitive." Airlines have made significant long-term investments in infrastructure and aircraft based on assumptions that they would have the ability to use the airports and airspace as they had in the past. [Levine, 1969] also argues that an airport owner (a government entity in the US) has a monopoly position and the may have conflicting economic and political goals to that of the airlines or the Federal Government. Politically motivated exceptions to any market-based allocation mechanism will result in economic inefficiencies.

Currently, *access* to airports and airspace in the United States is allocated on a first-come, first-served basis. There are a few airports that operate on a slot system due to high demand for limited capacity. And, even in the four slot-controlled airports in the US (LGA, JFK, EWR and DCA), the slots are administratively allocated to airlines based on past usage of the airport. The practice of administratively allocating slots at these slot-controlled airports through the use of grandfathering may encourage the inefficient use of airport resources. Slot holders have incentives to use slots inefficiently solely to preserve them for future use or to discourage competition. A report by the US Bureau of Transportation Statistics [http://www.transtats.bts.gov/HomeDrillChart.asp] concludes that grandfathering slots serves as a barrier to entry. They further conclude that any type of administrative slot allocation procedure is inefficient because it is extremely costly or impossible for the administrator to determine the relative social benefit that users could produce from a slot. [Brueckner, 2010] uses evidence from slot control programs at JFK, LGA, and ORD to demonstrate the ineffectiveness of the current system of managing airport access rights. The relaxation of FAA slot controls at these airports led to a surge in flights, accompanied by massive delays. This evidence is used to support the argument that market based allocation would result in large efficiency gains.

Thus, the consensus from the economics literature is that, in the presence of congestion, a market-based system of resource allocation would allow demand to be matched with supply more efficiently than current systems allow [Neels, 2002]. Furthermore, market-based allocation could contribute to improving competition in the US air transportation market and give smaller and medium sized carriers greater access to airports [Betancour, Rus, and Nombela 2003].

In terms of how airport use is paid for, users currently pay a weight-based landing fee. Weight based landing fees are likely to be efficient when there is no congestion, because runway infrastructure and wear and tear are function of landed weight. But, as soon as one flight precludes another, each flight (regardless of weight) imposes costs on others and all flights should pay the same landing fee. [Levine, 2009] argues that the inefficiently high level of airport and airspace use is the result of users not internalizing the external costs of delay. On the other hand, Brueckner argues that carriers do internalize the delay costs that they impose on themselves when making scheduling decisions. The costs of delay are offset by the value of being the dominant carrier at a given airport. He argues therefore that congestion prices (however they are set) should vary inversely with airport share and be distinct for each carrier. In other words, since dominant carriers at an airport internalize the effects of their own flights on their system, their landing fees during congested periods would be lower than those of other carriers that account for far fewer flights at the airport. Others argue that even if airlines internalize these costs, the congestion prices should be the same for all carriers. [Mayer and Sinai, 2003] argue that the network benefits of an airline's hub and spoke network exceed the self-imposed delay costs resulting from flight bank-related congestion.

The result of a system whereby airport access is (by-and-large) freely available to all and where the fees do not reflect any congestion costs but are instead weight based, has resulted in a system that system suffers from high levels of congestion and delay. In 2008, only 70 percent of flights arrived at their destination on time. Many economists characterize this delay as a result of market failure. Airlines fail to internalize the full costs of their airport and airspace usage because the access costs that they pay do not include the marginal delay costs that their actions impose on other users. In addition to directly influencing congestion levels, a market-based allocation can signal where capacity should be expanded. If users are willing to pay (through auctions or congestion pricing) for access to a resource in excess of its marginal operating costs, then capacity should be expanded if the premium above current operating costs due to the expansion is less than the premium being paid today.

Thus, economists agree that there should be efficiency gains from market allocation of aviation resources. They also agree that although market based allocation of aviation resources will reduce the amount of congestion, it will not entirely eliminate it. This is because the optimal level of congestion is not zero; in other words, some positive level of congestion is efficient due to factors such as the network benefits of hubbing and both demand and supply uncertainty (due to weather and other unpredictable factors).

Economists believe that either auctions or congestion pricing would result in efficiency gains relative to first-come, first-served or administrative allocation systems but disagree about whether one should use auctions or congestion pricing. With congestion prices (that reflect marginal delay costs), users would consider the full social costs of their airport/airspace use (including delay imposed on other users) rather than just the private costs that they consider under the current system. The congestion cost would vary over time, due to different levels of delay at different times, and because delays early in the day impact more flights than delays later in the day. [Daniel 2009] argues that congestion pricing must play a role in airspace congestion because both demand and capacity are stochastic. In other words, they are subject to random variation due primarily to weather. Therefore, setting a fixed quantity of slots to be auctioned is ineffective because some aircraft will arrive later and some slots will go unused; when the delayed aircraft arrive, demand for slots will exceed supply. The quantity of slots could be set lower, but that would result in unused capacity. Others argue that congestion prices – although useful for the stochastic component of congestion – does not consider the more long-term capital investments made by the users. [Czerny, 2006] further argues that congestion pricing cannot account for the demand complementarities caused by the network character of the airline industry. Since the regulator does not have perfect information of the social costs and benefits of airline operations, it will not be able to efficiently set congestion prices and the outcome will be lower social welfare than a nationwide auction of slots.

Alternatively, in an auction setting of limited access permits (or slots), those users willing to pay the most (presumably as a result of having the highest value demand) will gain access. In this approach, bidders are forced to explicitly value slots and consider the opportunity costs of retaining them. Those opposed to auctions argue that the quantity may not be known with certainty. Most agree that if auctions are chosen as the allocation method then a secondary trading must be allowed to ensure that as situations change the slots can be re-allocated so that efficient solutions remain. Another argument in favor of auctions is that they provide rights over an extended period of time (e.g. 5-10 years) thereby allowing airlines to plan and schedule on multi-year investment decisions that include aircraft purchasing decisions, infrastructure costs, and marketing issues.

For more on arguments related to market-based mechanisms and their possible use for allocation of runway access see [Ball et al. 2006, Brueckner, 2002a and 2002b; Czerny, 2006; Daniel 1995, 2009;, Hoffman, et al. 2011; Mayer and Sinai, 2003].

3.1. Political issues with auctions and congestion pricing

In the U.S, carriers have been able to buy, sell, and trade slots since the mid-1980's even though the ownership of slots remains ill-defined in the law. The US Department of Transportation (DOT) has consistently maintained that slots are owned by the government, can be withdrawn at any time and are not private property. The law is confusing because there have been fairly low volume of trades for money and the buying of slots has occurred almost exclusively either in anticipation of or in bankruptcy proceedings. On the other hand, carriers have used slots as collateral in financial transactions and intermediaries have occasionally taken title to slot assets. The title to slots and the rights of the holder would needs clarification. In 2008, when the DOT attempted to auction slots at New York Airports they defined the property right as "a lease from the government to the operator for up to 10 years". In the notice of public rulemaking, [Federal Registry (October 10, 2008), the FAA developed an explicit program to auction 10 percent of the slots at each of the three New York Airports. Carriers would receive 90 percent of their incumbent slots in the form of 10-year leases; the remaining 10 percent would be auctioned using a sealed bid, second price package format. The auction process was fully developed and demonstrated to industry on December 5, 2008.[2] The auction was challenged in Federal Court and was suspended pending either a ruling or a change in policy by the new administration. In May of 2009, the Secretary of Transportation announced that the auction was to be abandoned because of industry opposition [FAA, 2008].

More recently, DOT has allowed a trade of slots between Delta and USAirways with the condition that 16 slots at LGA and 8 slots at DCA be sold to new entrants. The proceeds from the auction of these 24 slots will go to the current holder. The LGA slot revenue reverts back to Delta and the DCA revenue reverts back to USAirways [FAA, 2011]. The auction design (blind auction with proceeds going to the incumbent slot owner) was similar to that proposed by Levine (2009). Airlines did not object since the wealth transfers were among the carriers and participation in the auction was voluntary. Participation in this auction was limited to those that had less than a 5% share at the airport in order to increase competitiveness at each of the airports.

Another issue may be that current policies require airport revenue neutrality, i.e. the airport should be supplied with revenues equivalent to the cost of maintaining the services of the airport. Such pricing may inhibit the effectiveness of congestion pricing by limiting the amount that can be collected to levels that do not remove enough delay; this would be a serious problem mitigating the effectiveness of tolling at airports that are congested throughout the day. Congestion costs and other externalities are not permitted to be included in the calculation of the cost base from which landing fees are calculated in the current landing fee system. Congestion pricing may be difficult to implement for some time at airports that have long-term contractual agreements with airlines. In addition, many regulations are phrased ambiguously, creating uncertainty as to the legality of proposed congestion pricing schemes. Finally,

[2] FAA Bidder Information Package

regulatory action and new legislation is likely required before congestion pricing schemes can be implemented [Murphy and Worth, 2001]

Before leaving this topic area, it is important to note again that most of the research on aviation congestion pricing and auctions pertains to airport access. While this literature provides a useful framework for examining airspace delays, the analogies are not perfect. For example, the internalization debate may be far less relevant to the airspace. In fact, it may be possible to charge a flight for its marginal contribution to delay based upon its flight trajectory. Assessing tolls based on each segment of the flight would likely result in fewer aircraft having to be delayed on the day of flight since the most congesting flights would pay the highest tolls and might instead choose to delay their operation or file a revised flight plan avoiding congested airspace [Hunter, 2010].

3.2. Conclusions about the use of congestion pricing or auctions for the airspace congestion management problem

By setting a service standard for access to runways, one could significantly limit the amount of delay that is caused by over-scheduling by limiting airline schedules to more closely align with the observed capacity of runways. A regulatory evaluation conducted by the FAA of a plan to reduce operations at LaGuardia Airport found very large benefits from setting a service standard; see [FAA, 2006]. Even with a properly set service standard, there will be occasions when severe weather creates additional capacity reductions. Given the stochastic nature of such capacity changes, one would need a market-based mechanism to control this Day-of-Flight congestion. This is the topic for the research reported here.

Beyond the issues of prior conditions and product definition, we focus on the central question of market design: what is a "desirable" outcome that might result from a day of flight market? Clearly, the market would have to facilitate a better outcome than may be possible with the current allocation process. Outcomes that we suggest would be improvements include:

- ✈ A market may improve the allocation of scarce resources if it facilitates an outcome where users who are most willing to pay are given priority;
- ✈ A market may facilitate greater use of available scarce capacity; if some capacity is not used today and a market can either facilitate its use or, at a minimum, not prevent its use, then that also would be desirable.
- ✈ Trading may be an essential feature of any design in order to accommodate the inevitable logistical problems users face in operating in an environment where capacity and demand are affected by weather and other stochastic factors including scheduling and maintenance problems.
- ✈ Trading may also facilitate the use of an otherwise unused capacity; any market mechanism will need to be consistent with or help to facilitate a useful trading protocol that results in the fuller use of available capacity.

These observations lead us directly to a discussion of alternatives to the current system of allocating scarce TFM capacity. In this research effort, we considered a collection of alternatives that were variations on congestion pricing schemes and auctions. In all, we considered literally thousands of variations on market-based approaches. For a complete description of these approaches, see [Berardino, et al. 2010 c and d].

Throughout this review of possible alternatives, we were focused on mechanisms that could be used for congestion management on the day of flight. We first consider two alternative allocation processes. One controls the number of operations available and then allows bidding for the announced capacity. The other approach has the amount of capacity utilized determined by prices assigned in the day of flight market. The distinction is essentially one between an auction and congestion pricing. In the latter, prices in the market place would have to rise to a level high enough to cause enough users to delay or cancel their flights in order to bring capacity and demand into balance on the day of flight. In the former, the TFM provider would define the amount of capacity available and then auction it off.

In the discussion about the day of flight market below, none of the alternatives relies exclusively on price to regulate demand during a capacity shortfall. Instead, we choose market-mechanisms that continue to leave it to the TFM provider to define the appropriate balance between demand and capacity and ultimately to be responsible for the number of flights in the system at any one time.

Under the current system, users are granted access to capacity based primarily upon the flight schedules they have loaded in the system. The alternatives proposed here are to use a combination of the administrative CDM program with a day of flight market. Such a combination process might improve the allocation of resources and the use of airspace while preserving many of the cooperative elements of the current system and not add extra burdens to Air Traffic Management. We chose this approach in lieu of a system which would represent a complete break with the current system, and might preclude some of the cooperative elements that have proven to be desirable in the current system. It is likely that any market process that we define here would be based on the combination element where both administrative and market processes would operate simultaneously.

During the evaluation of alternatives, we consider the current TFM benefits that incentivize airlines to cooperate and evaluate alternatives with this desirable trait in mind. Access[3] to the airspace system on the day of flight when capacity is in short supply is defined in terms of arrival slots at airports and/or congested airspace. Both definitions translate primarily into ground holds at the departure airport. On the day of flight, if there is insufficient capacity in a region of airspace, some flights destined there are held at their departure points (ground delay program or GDP).

A better outcome means: a better allocation of available capacity and increased use of available capacity. We focus on the following design features:

- Matching the definition of the product to the allocation process
- Designing a day of flight market process that can close fast enough
- Increasing the opportunities for users to trade allocations or alter their flight plans, both in the interest of increasing the use of available airspace.

[3] For this discussion, we are not focusing on other factors that may adversely affect access at an airport including long term exclusive contracts, strategic scheduling, or other practices that may inhibit free entry and exit. Some of these factors (e.g. long term contracts) may not easily be influenced by either the TFM provider or the federal government.

We have used these design features to create three potentially useful market designs. We believed that each of these three designs had sufficient desirable properties to warrant further testing via simulation.

4. Three Market Designs

In this section we describe three market designs that were believed to satisfy the objectives listed above and yet simple enough to be workable. Each is a hybrid of ideas associated with tradable rights, congestion pricing or auctions. But, none is a direct application of these concepts. Each was designed to be easy for air traffic management operators to implement, provide incentives for airlines to be cognizant of the congestion that they impose on the system, and to put their assets to their highest and best use. The three market designs are:

- Permits with secondary market trading
- Filing willingness-to-pay at time of filing flight plan
- Day of flight tolling

4.1. Free-pass flight permits with secondary trading

In this concept, priority permits are issued with flight plans and traded in a secondary market. A flight permit provides a *free-pass* that exempts the flight from any TFM restrictions.

In this concept, a free-pass, is issued and allocated by the TFM provider. Each airline is granted a limited quantity of these permits. A permit is a right to land at a given airport within a fifteen-minute time window without any GDP or AFP delays imposed. Thus, when an airline chooses to use a permit, that flight is allowed to takeoff at its scheduled departure time without delay provided that the arrival airport has not completely stopped all operations into the airport.

The service provider limits the total number of these permits distributed to each airline in order to control the total NAS-wide congestion levels. This concept offers the airlines more flexibility to optimize their operations, account for user preference, ensure their on-time performance of high-valued flights and improve market efficiency.

The airline must choose how to use its permits (which have been allocated for use daily during a specified period of time (e.g. six months). During this period, the airline is free to use them, lease them to another airline or sell them on the day of operation for that one-day use. Because the use of free-pass permit guarantees an exemption of the flight from being delayed or rerouted, the number of such permits to distribute should be a very small percentage of the total flights that are scheduled to arrive during that time period. For our simulation and human-in-the-loop exercises, the number of these priority permits was set at 20% of the total number of flights arriving at the airport that hour.

One important feature of this concept is that an airline "owns" these permits for a given period of time (e.g. six months) and so has the ability to use them to overcome congestion issues. However, the airlines can also trade them for permits at another airport where their access is more limited. Selling permits is also a possibility. Finally, another use might be to provide a new product, i.e. guaranteed on-time performance regardless of weather conditions, other than a complete shutdown of airspace or airports.

One important feature of this concept is that all transactions take place between carriers. No money is collected by the airport, Air Traffic Management, or the FAA.

4.2. Day-of-flight tolling

In this concept the flights imposing the greatest congestion costs are assessed a toll and given limited time to pay the toll or accept a delay. Multiple rounds would result in the balancing of demand and capacity in a defined time period. A toll would be assessed on the most congesting flights first; these flights would be given a period of time to either pay the toll or accept a ground delay. The process would proceed in rounds until the projected congestion level reached a target or service standard level.

This concept has at least three important characteristics:

- Because it focuses on tolls for the flights imposing the greatest delays on all other flights, the number of flights that would have to be delayed will be reduced;
- The flights that are exposed to the toll will vary each day, depending on weather and demand – capacity conditions;
- Funds would be collected by the ATM provider, and so would leak out of the industry; this feature would be a major concern for airlines and other operators.

Air-space flight simulations determine the flights that impose the greatest congestion. This is done by removing a flight from the simulation schedule, and recalculating the delay consequences for the NAS. A very fast time simulation would be required to make this concept feasible.

An interesting wrinkle to this concept would be to allow the airline exposed to a toll to offer an alternative routing (presumably one that avoided some or all of the congested sectors utilized in the original flight plan.) This option has been described in the SEVEN program. The timing for this option would be challenging, but would likely improve the outcome by causing a reallocation of demand across sectors, thereby utilizing capacity that might otherwise go unused. The carrier would have to be convinced that the incremental fuel and other operating costs of a less advantageous routing would be to its advantage.

This concept most closely resembles a congestion-pricing scheme with the variation that users are tolled sequentially, so there is less guessing about what might be needed to eliminate the congestion.

4.3. Willingness-to-pay

In this concept users declare their willingness-to-pay at the time of filing their flight plans. In this way users offer a “bid” for priority. In the event of a demand-capacity imbalance the bid would be used, along with an estimate of the congestion cost the flight would impose on all other flights, to establish priority.

The flight will be evaluated based on its bid amount and the congestion that the flight imposes on the NAS. Flights would be given priority based on the bid net of the delay costs imposed. Thus, the most congesting flights would be given the lowest priority, unless a carrier’s bid offset the delay impacts. The advantage of this concept is that it accounts for both the user’s willingness to pay for priority and the congestion cost each flight imposes. The concept, like the previous one, depends on a fast time simulation, but does not require multiple rounds. Instead, carriers would have incentives to bid an amount for priority that reflected the costs they would incur if the flight were delayed.

An interesting feature of this concept is that money need not leave the industry. Instead, money collected from the bids could be used to partially compensate operators that are delayed..

5. Testing via simulation market-based approaches

A NAS-wide simulation package called the "Probabilistic NAS-wide simulation Platform" (PNP) was used to model the flow of aircraft throughout the national airspace. The package used intelligent agents to model the decisions of airlines under the three market-based mechanism considered. In all cases, there was an agent that served as the air traffic controller (ATC). This ATC agent decided on what tolls to charge to each flight in the day-of-flight toll scenario. In the permit scenario, the ATC agent accepted bids for permits and reordered flights based on the permits received. In the willingness to pay scenario, the ATC agent reordered flights based on a function of the flight's willingness to pay and the amount of congestion caused by the flight.

The simulation included airline agents. These agents represented airline teams that would normally interact with air traffic control making decisions as they currently do in the Cooperative Decision Making process (CDM). These agents were provided with access to all of the traffic data, were given estimates of delays for each flight under each scenario, and given estimates of the costs associated with incurring delays.

These agents made decisions regarding when to use, trade, buy or sell permits.

- In the permit concept, permits were sold on an open market where a holder of a permit announced its willingness to sell at a given price. The first agent that accepted this bid price obtained the permit.
- In the willingness to pay scenario, the airline would calculate the likely amount of delay a flight would incur if it did not pay for entry and based on this delay calculation, would provide to the ATC agent its willingness to pay. These estimates were based on the predicted weather at the time the flight plan was announced. In this scenario, agents had to make decisions about willingness to pay relatively early in the day.
- For the day-of-flight toll scenario, the airline agent would decide whether to accept the toll or choose to delay the flight until the next time period. For this scenario, the airline would need to make a similar decision for each time period until the flight was either cancelled or departed. Airline agents were responsible for making any cancellation decisions.

The ProbTFM simulation package uses stochastic descriptions of both NAS capacity and demand to derive flight congestion, and the associated congestion costs.

We briefly summarize the results obtained from these simulation runs. For a more detailed description of the simulation package and its output, see [Hunter, 2010]. Each scenario was tested using the same weather conditions and flight schedule. The simulation package uses stochastic descriptions of both NAS capacity and demand to derive flight congestion costs and initiate TFM restrictions based on flight track data estimated through the underlying point-mass trajectory generator.

For these experiments, the demand schedule used was based on data collect from Nov.16 (Thursday), 2006. The NAS traffic volume was relatively high, with 47,754 instrument flights, with a round of storms affecting the Midwest and Northeast corridor. In the simulation, we chose to have only six airline agents representing six of the major carriers. The intention of the simulation was not to represent perfectly all actions of all participants, but rather to better understand how decisions made by these computer agents might impact the overall congestion, the costs to an airline and the delays within the system. The six airlines modeled were: American, Continental, Delta, SkyWest, Southwest and United Airlines. Each agent made decisions about flights flown by their airline and their associated regional carriers. These six commercial air carriers represent 33.13% of the total NAS-wide operation in this demand data.

The goal of this experiment is to gain insights into the consequences of the possible decision-making under various types of market-based traffic flow management designs. Therefore, we first ran a baseline simulation run in which no advanced market-based alternatives were used. Then we enable free-pass, day-of-flight tolling and willingness to pay decisions within separate simulation runs. In each run, we vary the level of capacity available (low, medium, high) and evaluate the decisions in terms of their effect on delays to the airline and to the overall system. We also examine how these decisions impact passengers whose delays may be significant when there is no flight available later in the day to take them to their final destination.

The key finding in each of the three alternative approaches is that, compared to the baseline, the delay per flight was substantially reduced for participating airlines. As congestion increased, the amount of delay savings increased nonlinearly. One note is that flight delay costs are higher for those with less ability to control their delays, e.g. when an airline had little ability to control the delay of a valuable flight because flight permits were not available to buy or trade. On the other hand, for airlines that did not have agents that made decisions, in all three alternative scenarios, their delays increased substantially. This result is not surprising given the fact that the participating airlines received new technologies to overcome delays and the non-participating airlines were pushed farther back in the queue.

6. Human-in-the-loop simulations

Based on these observations, we next had discussions with airline schedulers and planners to discuss whether there was any preference for any of these three market-based approaches. Universally, we heard that *any* approach that meant that the government would be collecting additional fees from the airlines would be received with significant concern. There is a feeling within the industry that fees collected are not put to their best uses and that any new congestion tolling would simply be viewed as an additional tax. When we reported that our simulation results indicated that the airlines might be able to save money through this tolling, they were, at best, suspicious. When making the final decision related to which of these three alternative to pursue, we also considered the fact that any approach must be constrained by the number of decisions that need to be made in a very short period of time:

- One needs time to close any market (so a multi-round auction is unlikely to work)
- Decisions are interrelated and must be made by those that understand the interactions among flights
- Ideally, markets should trade using some price mechanism so that all decisions are based on a common metric
- One wishes to maintain the cooperative nature of the current CDM approach
- The process cannot add additional burden to air-traffic control managers.
- All players should have access to the resources if they are willing to pay for such access
- It would be beneficial to expand the current CDM mechanism in terms of its trading capabilities.

We kept these issues in mind and decided to pursue an approach that required no collection of fees by the government, namely the free-pass permit idea. This idea is relatively easy to include within the current CDM process, allows monetary transactions without the government receiving any new revenue, and allows trades across airports.

To test the idea, we decided to assemble a team of participants with direct experience in handling GDPs and AFPs for airlines and presented them with two alterative scenarios:

1. Free Permits without sales: An airline can apply a free-pass permit to any flight capable of arriving at the given airport during the time period that the free-pass permit specifies. "Capable of arriving" means that the airplane can depart and fly a flight-plan that allows for a safe arrival at the designated airport in that time period. For this experiment, trades among airlines are not allowed.

2. Free Permits with sales: In this case, the airline may use its allocated permits on its own flights or they may choose to sell these permits to another airline at an amount specified. Thus, airlines can provide "asks" to the system that state that they are willing to sell a permit to another airline for $X. The first bidder meeting the ask price would receive the permit. In this second experiment, airlines had a lump sum of cash at the beginning of the day that they could use to buy permits. .

Each participant was also provided with:

1. A description of the weather conditions expected for the day studied
2. A list of all flights that the airline had scheduled that day
3. A list of the permits available to that airline for that day
4. A description of each of the screens that they would be using during the simulation.

One added feature of the software design was that all of the participants could participate remotely. This made our ability to recruit knowledgeable airline participants possible.

Once the user has connected to "Probabilistic NAS-wide simulation Platform" (PNP), the My Flights window (shown in Figure 6.1) appears. This window contains a list of flights that have been selected for delay by the traffic flow management service. It contains two sections: one listing current departures at risk of delay, and another listing relevant future departures. The list of current at-risk departures allows the user to apply free-pass permits to individual flights, if the user is in possession of appropriate permits. The list of future departures is provided for reference, and lists future departures with the same destinations and arrival time bins as current departures at risk of being delayed. This information is provided to aid the user in deciding whether to use an available permit for a current departure or to keep it for a future departure.

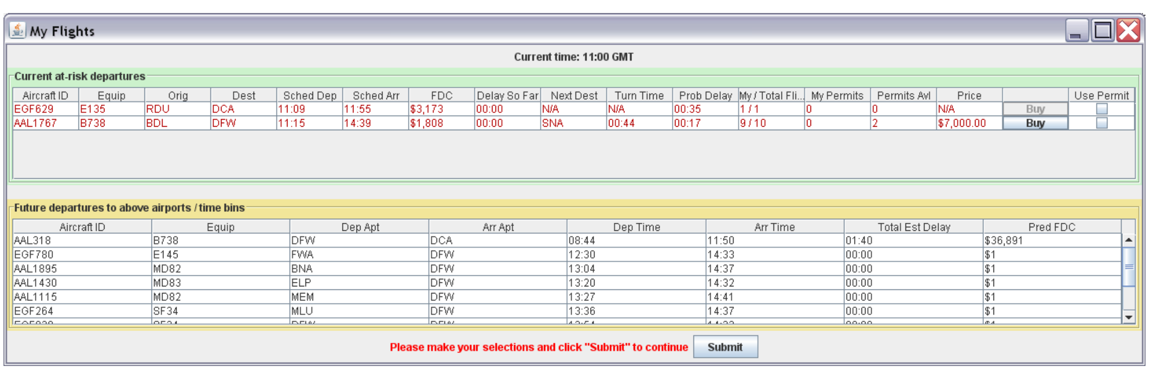

Figure 6.1: The My Flights window

The at-risk departures table contains fifteen columns of data providing information about each flight. In addition, each row contains a "Buy" button, which allows the user to purchase a permit for the flight, and a "Use Permit" checkbox, which allows a permit to be applied for the flight.

The columns of the table are described in Table 6.1.

Table 6.1: Columns in the at-risk departures table

Column Name	Description
Aircraft ID	The call sign of the flight
Equipage	The aircraft type
Origin	The departure airport ID
Destination	The arrival airport ID
Scheduled departure	The scheduled departure time of the flight
Scheduled arrival	The scheduled arrival time of the flight
FDC	The flight delay cost that will be incurred by the airline if the flight is delayed
Delay so far	The amount by which the flight has already been delayed
Next destination	The arrival airport of the next leg of the flight
Turn time	The amount of time the aircraft will spend at the gate of the arrival airport
Probable delay	The amount by which the flight will most likely be delayed if no permit is applied to it
My / Total flights	The number of additional flights departing to the same airport, and arriving at the same 15-minute time interval. This column is divided into two sections, separated by a slash (/). The first number indicates how many of the airline's flights will arrive at the airport/time bin combination, and the second number indicates how many flights belonging to other airlines fit those criteria.
My permits	The number of applicable permits held by the user's airline
Permits available	The number of applicable permits available for purchase on the permit market.
Permit price	The lowest price at which an applicable permit is available on the permit market.

<u>The Sell Permits window</u>

Another component of the airline user interface is the "Sell Permits" window, shown in Figure 6.2. This dialog allows the user to offer permits on the market.

Since each permit is applicable for a specific arrival airport and a specific arrival time period. The permits are thus ordered by these two parameters.

The "Sell Permits" window is comprised of two panes. One pane lists the permits held by the user and the other pane lists permits the user has placed on the market.

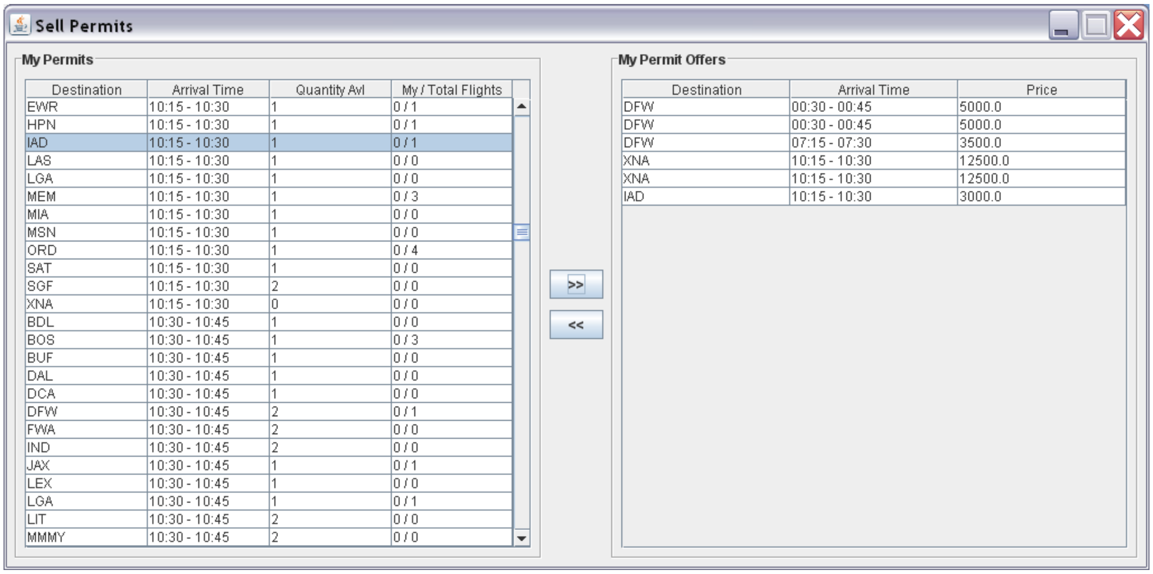

Figure 6.2: The Sell Permits window

The dialog contains two buttons, used for offering permits on the market, or for taking them off the market.

When the user makes a permit offer, another dialog appears which allows the user to specify an asking price for the permit and the quantity of that type of permit to offer on the market. Once those selections have been made, the permit is offered on the market, and becomes visible to other users who are in a position to buy the permit.

If the user later decides to keep a permit, rather than sell it, the user may take the permit off the market using the appropriate button on the GUI. This makes the permit unavailable for purchase for other users. There is a possibility, however, that another user might purchase the permit before the offering user attempts to remove it from the market. In that case, the permit will not be returned to the user.

<u>The scorecard</u>

The AOC GUI also contains a scorecard. This dialog contains running totals of several key metrics indicating the results of the user's actions throughout the simulation. These metrics include information on flight delays, flight delay costs incurred or saved, and permit trading activity.

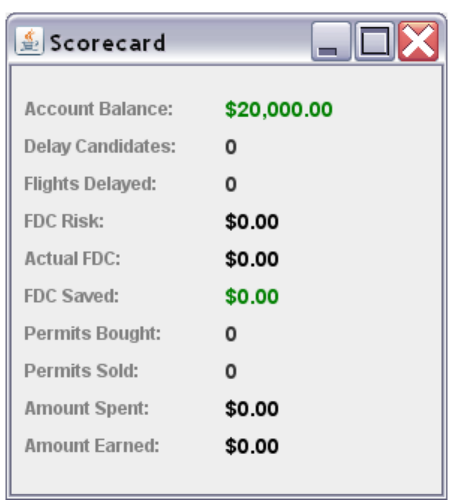

Figure 6.3: The scorecard window

To measure whether there was an improvement in the system, we measured whether the overall system delays were decreased, whether passenger delays were decreased, and whether an airlines' total delays were decreased. These delays were converted into costs of delay where the cost of delay is a non-linear function based on calculations provided in a EuroControl report [EuroControl, 2004].

For our experiments we benefitted from the participation of eight industry professionals. Three of the participants (Lance Sherry, Frank Berardino, Karla Hoffman) were from our development team and five were external participants. We were able to brief and train the participants prior to the experiments via phone conversations and direct access to the software via remote internet access. Table 6.2 summarizes the qualifications of the seven participants.

Table 6.2: Summary of HITL participants.

Name	Airline	Background
Michael Wambsganss	USA	Senior Associate, Booz Allen Hamilton; Previous Chief Executive Officer at Metron Aviation; Originator of much of the FAA Collaborative Decision Making (CDM) tools.
Ben Rich	AAL	Principal Subject Matter Expert, Cockpit Procedures, Metron Aviation; Former Captain, Boeing 777, Emirates Airline; Chairman, APA Accident Investigation Committee; FAA licensed Dispatcher.
Giles O'Keeffe	NWA	Principal Subject Matter Expert, Airline Operational Control, Metron Aviation; Past President of Airline Dispatcher Federation; Aircraft Dispatcher, Chief Dispatcher, Air Traffic Coordinator at Northwest Airlines.
Ira Gershkoff	UAL	President and CEO of SlipStream Aviation Software, Inc; 25+ years, strategic and operational information systems in the airline industry.
Roger Beatty	JBU	Airline Operations Coordinator at American Airlines; FAA Examiner for Aircraft Dispatcher Certificate.
Lance Sherry	DAL	Associate Professor, Systems Engineering and Operations Research, GMU; Executive director for the Center for Air Transportation Systems Research (CATSR).
Frank Berardino	COA	President of GRA Inc.; airline consultant.
Karla Hoffman	SWA	Professor GMU; Internationally recognized expert on market-based economics.

In summary, the participants were experienced, insightful industry professionals and in both HITL experiments the use of the permits resulted in substantial flight delay cost (FDC) savings. Some user strategies began to emerge, but these strategies undoubtedly would evolve with more practice. Not surprisingly, our analysis of the results reveals that user performance has several components that interact, sometimes in subtle ways. Finally, our HITL experiment results well complement the earlier fast-time results. Together these experiments tell us much, but many questions remain.

As the fast time simulation experiments showed (Section 5) the free-pass permit concept has the potential for FDC savings in excess of $1.1M per day in heavy congestion scenarios. Even with limited experience, our participants improved their overall delay costs substantially. The simulations began at 7am and continued for eight simulated hours (2 hours of time for our participants) and improved the overall savings by $256,000. This is a substantial since we had not yet arrived at the heaviest congestion period when the simulation ended due to time constraints and where users could apply permits to their own flights but could not trade permits with other airlines.

On Day 2 of the experiment, when permits could be bought and sold, the permit offer-prices ranged from as low as $200 to as high as $10,000, although the permits that sold were mostly priced between $500 and $2000, with only two permits selling above $5,000. It was clear from the actions of the participants that they considered permits to have substantial value and that they needed time to ascertain how to price permits and when to purchase permits.

We therefore do not provide any quantitative evaluations of the simulation but rather present the general feedback that we received from the participants through a survey after the completion of the HITL. [Hunter, 2010] provides the complete survey results. Here we present some general comments:

- "I think you have something worth pursuing here"
- "Benefits analysis performed by Nextor some years back showed that expanding our present, limited trading capability, is the surest way to generating discernible benefits to the operators."
- "It would improve the CDM system …"
- "I really enjoyed the exercise and I think the concept has some promise. But it needs to incorporate essential characteristics of today's system (rapidly changing, lots of uncertainty, slot swapping as an essential network management tool) or it probably won't go very far."
- "I would recommend that the air carriers create a new job position that combines business acumen with airline operational control expertise and have that person parked next to whoever is doing the air traffic coordination for the company. A sort of 'day-trader' in permits."
- "It would improve CDM, because it creates other options that weren't there before. How could it make the system worse off? Yes, I think a trading system is a good idea."
- "Yes!" [there is value to the priority permit concept]
- "As we saw in the tests, the learning curve and proficiency in the process were important."
- "Today's TFM system [allows] some limited trading through a mechanism known as "slot credit substitutions (SCS)." Any new process, such as the permit concept, would have to support enough trading to perceive as not resulting in less capability."
- "And I will absolutely attempt to harm my competitors under this type of system, whereas under the current GDP system, I concentrate on helping myself, and am not as concerned with trying to harm the competitors."
- "Priority permits would help considerably once the airlines get faster on their feet. Until that time, they will still help, but mostly on a tactical, one-at-a-time basis."
- "You need to allow players to offer a bid (buy) price, instead of simply relying on the ask (sell) price."

7. Conclusions

Our fast-time simulation results indicate that market-based TFM concepts can improve participating AOC performance significantly. They reduce participating airlines' total flight delay cost substantially even though, at times, delays may increase slightly.

All of the market-based TFM concepts we investigated have advantages and disadvantages. The free-pass flight permit concept is the closest to the current system where delay assignment is executed through the Ground Delay Program using a ration by schedule rule. The free-pass concept is also easy to implement and execute. A key aspect of this concept is that trading the permits on a secondary market enhances the utilization rate.

The day-of-flight tolling concept enables the participating airlines to cut their delay and total operating cost. The TFM service provider under the tolling mechanism has more options to resolve the congestion problem. This concept imposes higher workload on the service provider's side, however. Users will likely view a tolling concept, like any user fee, unfavorably. To overcome such sentiment, it will be important to convey and demonstrate that this tolling concept is a net positive for users as the tolls need only be used when their cost is more than offset by direct operating cost savings.

For our real-time HITL experiments, we benefited from our experienced, insightful participants and our survey produced excellent participant comments. In these experiments, the permit transactions resulted in additional FDC savings. Some strategies emerged, but they undoubtedly would evolve with more practice. We observed that user performance has several components that interact, sometimes in subtle ways.

The fast-time and HITL simulations complement each other well and tell us much, but many questions remain. Additional research is needed to experiment with different concepts and parameter settings over a collection of different weather and traffic schedule scenarios. In addition, there are several software display and capability enhancements needed to confirm our results and support more realistic HITL simulations. The next step should also include extended HITL experiments to evaluate user learning and evolution of performance.

7.1. Lessons learned

In this section we summarize the lessons learned in this research project. We also present possible next steps for refining market approaches to day of flight access to the NAS. In making this list, it is important to focus on the primary objective of a market-based allocation system: to provide an efficient way to allocate access to the NAS among competing users. Efficient in this context means two things: First, whatever market system is adopted should be easy to implement without great cost to operators or the TFM provider, and second, the resulting reallocation of resources should result in more benefits to operators and passengers than the costs imposed, meaning the outcome would be desirable (from society's point of view). With this in mind, the following are some of the prominent lessons or findings of our research.

7.2. Market-based TFM design considerations

In the US, where there are few limits to the number of flight plans, the day of flight imbalances between capacity and demand are larger than elsewhere in the world. Other policies taken prior to the day of flight, such as cost-based user fees (in lieu of taxes), implementation of slots at more congested airports and other policies, could pay substantial dividends and reduce imbalances on the day of flight. One fruitful area for future research would examine the optimal level of planned activity that balances the benefits of desired operations with probable delays. We have termed this a "service standard" for the NAS, essentially a promise of a minimum level of expected service.

The research in this project has focused on designing day of flight markets for access to the NAS. Several design features became prominent in the alternative market designs:

Product Definition. Any market has to have a well-defined product that can be transferred from one party to another. The product being traded in a day of flight market is best defined in a sector/ time bin framework. All flight plans can easily be translated into this format and used to define demand on the system in each time bin.

Initial Ownership. Another important design feature is determining who owns the initial access rights in a market. If the TFM provider owns the access rights, it can explicitly design a congestion pricing or auction system (reserve prices) that charges users the estimated delay costs each imposes on the NAS, for any given schedule. For example, in a multi-step congestion-pricing format, the most-delay causing flights would be charged first and given the opportunity to accept delay or pay the toll. The process would continue until demand-capacity balance was restored. When TFM providers own the access rights, they logically would be the ones that would collect funds from selling them.

If, on the other hand, the operators own the access rights, then any market system will be based on their willingness to pay to avoid delays, which is bounded by their private costs. Thus, in an auction or congestion pricing system, operators would pay to avoid their own consequential costs of delays, but not be concerned about the costs they impose on others. When operators own access rights, the sellers would collect funds from the buyers (other operators).

The ownership of access rights therefore has a direct effect on the allocation among operators. In cases where the TFM provider owns the rights, we would expect that those flights imposing the most costs on the system would incur more of the delays, unless they were so valuable that operators would be willing to pay to offset the costs they would impose on everyone else. The minimum number of flights needed to restore demand-capacity balance would tend to be delayed in this format. When operators own the access rights, we would expect larger and/or long haul aircraft to be advantaged since their consequential costs of delay would be higher than smaller aircraft, all other things equal.

Time. Demand-capacity imbalances occur in sectors at specific times, but operators and the TFM provider may have to make decisions about specific flights at very different times. Two flights scheduled to transit Cleveland Center at 1600 might have two very different departure times, thus different times when decisions would have to made about whether to accept a delay or pay to fly. A flight from SFO might depart at 1100 Cleveland time, while a flight from Chicago would leave at 1500. Thus any market solution will need to operate continuously over a significant portion of the day, to provide options for both long haul and shorter haul operators.

Quantity of Access Rights on Offer. The amount of capacity available in a sector/time bin is unknown in advance of the day of flight. To be useful, a market solution would facilitate the sale of priority during times when demand exceeded capacity. Since the size of the imbalance will be unknown for any given day, the priority rights would have to a substantial minority of total available capacity. At the same time, enough of the access rights should potentially be available in the market to be of interest to operators and to facilitate the distribution of priority rights among them. This is an important area for further research.

Comprehensible Market. There are more than 100,000 sector/time bins each day in the NAS. Obviously, both the TFM provider and operators will need a means to identify flights potentially subject to delay and then have time to decide which among them to prioritize and/or acquire additional rights to operate during demand-capacity imbalances. In the HITL for this work program, a significant effort was undertaken to provide operators with useful information on potential delays for specific flights, the characteristics of those flights, and the availability of priority rights in a market environment. At the same time, the HITL also provided a mechanism for operators to identify priority rights that would not be needed and thus potentially available for exchange or sale. More work on these software tools should be undertaken to facilitate exchanges and sales among operators managing in a highly complex and changing network environment.

Fit with Existing CDM Institutions. There are important precedents already established in the allocation of scarce NAS capacity on the day of flight. A market allocation system could be designed to completely replace these precedents, but it is more likely that any new market system would have to fit comfortably with CDM and ration by schedule in order to be accepted by the user community.

Incentive Compatibility. There is a very large literature on the ways to design markets to insure that the incentives created are compatible with the intent of the market. In this case, we are interested in improving the allocation of scarce NAS access on the day of flight. Creating a market in access rights means creating a product definition and a means of exchange that are not abused by participants. There is a very large auction literature on this subject that can be applied to any type of market.

7.3. Selection of permit concept for HITL experiment

After identifying over 3400 market options (including changes to both the before day of flight and day of flight conditions), we focused our efforts in the HITL on a relatively simple market design. About 10% of NAS capacity in the form of priority permits would be distributed among operators in proportion to their schedules. These permits would allow users to arrive at a specific congested airport in a specific time slot. Operators could choose to operate their own flight with the permit or put it up for sale at an asking price. Other users could acquire the permit via a central exchange by paying the asking price. This design had several advantages in terms of the design criteria just enumerated:

- The product description was relatively simple and thus easy to understand and trade.
- The initial ownership was established with the operator, who could use the permit or sell it, as it wanted
- Operators were free to sell their permits at any time, including very early in the day; this made it possible for long haul operators (needing to make operational decisions early in the day) to have access to needed priority permits in time to act on them.
- Because permits would represent a small percentage of total capacity in a time bin, it is likely that the TFM provider would have sufficient capacity available to give holders priority regardless of the size of the demand-capacity imbalance.
- By limiting the product definition to access rights at a congested airport, the permit concept reduced the potential complexity of the problem for operators by several factors. The definition also is consistent with current CDM policies. Because the permits represent a small percentage of capacity at congested terminals, the TFM provider should be able to provide capacity in time bins required to complete priority flights, much in the way this is accomplished today. However, the HITL did not explicitly confirm this and some work in this regard would be welcome in order to examine the range of capacity that could feasibly be offered in this market design.
- The market design included an exchange where operators could offer permits for sale without identifying themselves; the seller was free to withdraw the offer at any time, perhaps to use it instead when no offers were forthcoming, or to adjust the price to attract a buyer. At the same time, other operators could buy the permits at the stated asking price without revealing their

identities. This blind feature of the market would provide some assurance against adverse behavior by participants, but more work would need to be done to insure incentive compatibility of the design.

7.4. Positive results

Perhaps the most surprising result of our research is that a day of flight permit market would stand a good chance to operate efficiently – that is,it would not impose undue costs on participants and would likely improve the allocation of resources. (This conclusion is of course preliminary, given the limited number of HITL runs that were possible with the resources available.) We say that this is surprising because it was not obvious that a market could work in such a complex network environment subject to the uncertainties created by weather and wind conditions. But the permit market we examined fits so snugly within the current CDM framework that it or something like it might actually work and be accepted by operators.

Today, operators in a CDM environment are given priority rights in proportion to their schedules and allocate these rights to their operations as they see fit. Only when they cannot use one of their rights (because of logistical issues) do operators have incentives to turn them in to be exchanged with rights later in the day when the logistics of their flights do work.

With the permit market, operators would have the additional choice to use some of their "priority" rights or sell them to others at a price they determine (the asking price). Any operator may choose to buy permits voluntarily made available in the market. Operators initially would have the same amount of rights to the available capacity as they do today, with the additional features that some of the rights would be given priority (be delay free) and could be sold. Thus, operators would in the worst case be just as well off with the permit market as they are today, but might be better off, if they either sold or acquired permits.

The terms of trade among operators would be substantially expanded in this market design because money would be used to facilitate trading, instead of requiring that operators swap permits. This finding is not surprising once we recognize that markets with pecuniary exchange always create more opportunities for trade than is available with barter alone.

One important question, not addressed in the HITL, is whether the market should have both bid and ask sides. In the HITL, only operators selling permits provided price information. The transaction took place when a buyer was willing to satisfy the asking price. The seller was blind to whether anyone would be interested in the offer, including what they might bid for the permit. A two sided design for the permit market would feature both bid and ask dimensions. Sellers would then have information from buyers on the sector/time bins where permits were designed and what the bid price was. Buyers would have information on availability and asking price. The two sides of the market could adjust accordingly and more exchanges might take place. An interesting question is whether in a bid-ask environment there would be a need for a market maker – someone that could intervene to buy or sell permits to insure a smooth running market. Another interesting question is whether the market would be liquid enough to justify having both bid and ask prices.

Finally, it is important to note that the permit market would also be compatible with enhanced trading (one for one) of access rights and/or enhanced re-filing capabilities to provide operators with alternative routings around congested sectors. These enhancements are complementary to the market designs discussed in this research.

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