COMPREHENSIVE ECONOMIC EVALUATION OF LARGE SCALE TRANSPORTATION INVESTMENTS SEEKING CONSENSUS THROUGH PARETO EFFICIENCY

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Abstract

The implementation of large-scale transportation system improvements results in a complex web of costs and benefits that impact many distinct user groups differently. Failure to take full accounting of the distributional effects in cost-benefit analysis can result in lost opportunities to implement programs that are potentially efficient economically after adequate distributional adjustments are made to alleviate the imbalance in the incidence of costs and benefits.

Air traffic management investments have often suffered from this problem and many programs that are otherwise cost-beneficial have languished in the political process of implementation due to opposition by one group or another. The purpose of this paper is to demonstrate how traffic management technology investments can result in wide variations of impacts among the different users. The concept of equity in queuing systems is introduced and used to assess the impact of storm-caused delays on different types of operations at a major airport hub. The differential impact of a weather prediction technology, currently being deployed at airports in North America, is evaluated by estimating delay to different airlines and flights. The results demonstrate that current methods of charging for such technologies, e.g. ticket taxes in the U.S., are not an efficient way of cost-recovery.

Keywords: Distributional effects in cost-benefit analysis; Technology investments; Equity in traffic management system; Air traffic control economics
Topic area: E1 Assessment and Appraisal Method w.r.t. Transport Infrastructure Projects and Transport Activities

1. Introduction

The implementation of large-scale transportation system improvements results in a complex web of costs and benefits that impact many distinct user groups differently. Government agencies responsible for such programs often use cost-benefit analysis to justify the necessary investment. In most cases this analysis does not account for the differential incidence of costs and benefits. The result is that programs that may be feasible in terms of aggregate cost-benefit analysis fail to be implemented because of political opposition by one or more of the impacted groups. Failure to take a full accounting of the distributional effects in cost-benefit analysis can result in lost opportunities to implement programs that are potentially efficient economically, even after adequate distributional adjustments are made to alleviate the imbalance in the incidence of costs and benefits.

The study discussed in this paper deals with evaluating the impact of investment in the specific case of air traffic management technologies. Air traffic management investments have often suffered from this problem and many program that are otherwise cost-beneficial have languished in the political process of implementation due to opposition by one group or another. Such opposition may be avoided if distributional effects are adequately considered in the cost-benefit analysis. Technologies that are aimed at enhancing air traffic flow oftentimes impact one subset of flights and airlines more than another, e.g. long haul versus short haul, hubbed versus non-hubbed. Yet when these technologies are implemented, their costs are charged uniformly to all airlines thereby creating an environment where one group of airlines is likely to oppose an investment while another is supportive of it. For another example, air traffic controllers may oppose a technology that is otherwise economically feasible because it increases workload in the control room. But if some of the net benefits from the investment are re-directed in the form of increased controller wages or modified work rules, then such opposition might be alleviated. In other words a major barrier to implementation can be overcome by instituting re-distribution mechanisms that aim to make Pareto-efficient investments.

The research reported in this paper illustrates the wide variation in impacts among airlines and flight types from a weather prediction technology named ITWS that is being implemented at some airports in the U.S. A conceptual framework is presented within which it is possible to take account of such wide variation and seek re-distribution mechanisms that can lead to a more equitable distribution of costs and benefits. In the context of air traffic management technology, these mechanisms can take on a variety of forms. Differential access priorities to systems and differential pricing and taxation schemes apply to agents that are users, such as different types of airlines. Differential subsidies, wage rates and work rules apply to agents that are suppliers, such as traffic controller or flight crews.

2. The state of the art

Cost-benefit analysis of air traffic management investments by government agencies in the U.S. often requires a total net social benefit evaluation. Costs and benefits are aggregated to derive a relatively simple set of final conclusions about the value of a project. However, cost benefit analysis as practiced by agencies such as the Federal Aviation Administration (FAA, 1999) does not insure equity, Pareto efficiency, and much less guarantees political consensus. Technology and policy choices are often made in the political arena and may come at the will of a powerful person or group. Negative effects on a subset of stakeholders can be outweighed by benefits to a majority in some cost-benefit analyses.

Standard cost-benefit analysis has expanded in an attempt to capture environmental effects and the value placed on access by different agents. It also tries to reconcile varying opportunity costs across income levels with a view toward equity. In aviation, the newest guidelines call for categorizing delay by where it occurs and to account for the effects of induced demand from better service (FAA, 1999). However, attention to the distributional impacts among the multitude of agents involved in air traffic management remains inadequate. In evaluating the cost of air traffic delay, a distinction is sometimes made between low-cost and full-cost carriers and two different multipliers are used to convert delay to monetary cost. But little work ca be found where attention is paid to the following three important issues in aviation cost-benefit analysis: 1) Aggregate delay is not shared equally among the players. Most aviation cost-benefit analysis hinges on how the change will effect delay (normally, the single largest benefit of a technology) and most use queuing theory to calculate the savings; 2) While carriers may be categorized into low-cost or high-cost, these categories do not capture the cost differences of varying fleet mixes, operating costs, flight types, and business strategy relating to schedule; and 3) There may be incentives to deviate from *First In-First Out* practices in managing traffic queues, which may skew delay to certain flights and passengers. Examples would be reordering the planes to prevent triggering reportable delay; maximizing runway usage; and prioritizing connecting flights or flights with higher passenger loads. A far more detailed queuing and delay analysis needs to be integrated into cost-benefit methods in order to address issues of this type. This paper presents an attempt at doing this.

3. Conceptual framework

Conceptually one can aim to calculate impacts of a project on a group of agents in such a way as to retain knowledge of individual preferences. If a project produces net social benefits to all, then with such knowledge one can invoke a compensation criterion to approach a Pareto efficient solution to the problem of differential impacts. Arguments for public investment are based in the idea that the funded project will have positive externalities that could not be internalized to trigger private expense. We are focusing on negative externalities that may prevent a project from being approved. Coase argued that "a Pareto optimum would be reached without government interference through Pigouvian taxes" given strong property rights and clear endowments (Page, 1973). However, by aggregating the detailed impacts one cannot reveal these externalities or, more correctly, hidden effects, one loses the information needed to apply Coase's principle.

3.1. Conceptual Model

We consider a system with many stakeholders, or *agents* $i \in \boldsymbol{I}$ and a project whose impacts are measured by $j \in \boldsymbol{J}$ metrics representing different measures of performance (cost, delay, etc.) We define a matrix

$\boldsymbol{M} = \{m_{ij}\}$

where m_{ij} represents the impact of the i^{th} measure of performance on agent j. We next define matrix, $\boldsymbol{U} = \{u_{ij}\}$ representing the valuation of metric i by agent j. This can be obtained from a study of the utility structure of agent j and, given sufficient knowledge about the behavior of the agent can be measured by j^{th} the compensating variations that would result from changes in the value of metric i. By combining the impact matrix $\boldsymbol{M}$ with the valuation matrix $\boldsymbol{U}$ we can obtain an effects, or evaluation, matrix $\boldsymbol{E} = \{e_{ij}\}$,

$$\boldsymbol{E} = \boldsymbol{M} \cdot \boldsymbol{U},$$

which represents the agent-specific utility changes due to the project in question. $\boldsymbol{E}$ can form a basis for defining redistribution mechanisms (pricing, taxes, etc.) that are necessary to ensure a Pareto efficient solution and to correct any inequities that may result from the implementation of the project.

The impact matrix, $\boldsymbol{M}$, (measuring how a project or a policy affects each agent) requires a detailed model or simulation of the system operating under the project in question. Considerable capabilities exist in the current state of the art for detailed simulations of aviation systems. Much of their results however are aggregated prior to applying them to cost benefit analysis. The Valuation Matrix, $\boldsymbol{U}$, can be measured by observing agent behavior in order to understand how the different metrics are valued. Ultimately, it is a mechanism for converting as many of the metrics as possible to monetary terms. For example, if a particular airline prefers to incur additional fuel consumption in order to reduce flight times, then that should be reflected in that airline's internal cost structure. If a group of passengers prefer reliability (reduced cancellations and missed schedules) to flexibility (more flight options) then that should be reflected in their demand function. The Effect Matrix, $\boldsymbol{E}$, can ultimately be obtained from the dot product of the two, if everything is well behaved and measured by the right scale. From $\boldsymbol{E}$ we obtain the total effect of a project or policy on each agent. From the effect matrix, we will be able to create a cost reallocation strategy.

4. Investment in air traffic management technology

We apply the conceptual framework articulated above to investment analysis of technologies that enhance air traffic efficiency in the terminal airspace. To do this a few words on how improvement arise and are perceived by users in that environment are in order. Improvements in the terminal airspace can occur in two operating modes: *normal* operations and *degraded* operations. The model captures the differences in how technologies impact the system under both modes. Technologies designed to improve degraded operations are inherently designed to restore the system to normal operations, whereas those aimed at enhancing normal operations expand the capacity of the system even when it operates at it peak performance. Because airlines tend to schedule operations according to the capacity during normal modes, certain aircraft delays under normal operations are accepted as the cost of doing business. Changes to the normal operations can influence capacity and/or efficiency, and certain improvements that increase capacity under the normal mode may actually increase the differences between normal-operations capacity and degraded-operations capacity, further exacerbating the impact of degraded operations.

Degraded operations occur when one or more elements operate at less-than-normal operational capability or with one or more restrictions due to weather or equipment outages. The technologies that influence the degraded mode try to reduce the impacts to this minimum level where in a perfect world the minimum would be no disruption and the system would always be in "*normal mode*" regardless of the weather or outages. Many capacity enhancement programs are designed to reduce the severity and/or duration of the degraded operations mode.

Accounting for the state of the system sets the stage for understanding how stakeholders will react to the technology and gives a common basis for the comparison of alternative ATC system enhancements. Knowing how a technology will affect the state of the system also facilitates the identification of similar, potentially overlapping and competing technologies or projects, that are either duplicative, mutually exclusive, mutually supportive, independent, or some combination of the above. This approach can be applied to multiple projects to select the optimal combination of projects and technologies that provide the greatest system benefits at the least cost.

4.1. Key metrics for analysis

Efficiency: Because the system has been defined in terms of normal and degraded modes, the impacts of a technology such as weather prediction could depend on mode. An airline that has five flights a day at a given airport will view increased efficiency differently than one with 50 flights. An airline operating a major connecting hub will view increased efficiency differently than a point-to-point airline with no connecting flights at the airport in question. Efficiency, as well as the loss of efficiency due to mode degradation can be affected by a technology, but their economic impacts can vary widely depending on the nature of the operations involved. As uncertainty relates to a specific technology or technologies, cost-effectiveness can be determined by comparing the cost associated with reducing the uncertainty with the savings associated with the reduction in inefficiency. Under normal operations, there is inherent uncertainty because of imperfect information. Technology changes to normal operations seek to increase knowledge and reduce the uncertainty and thus decrease the inefficiency of the system.

Delay: This is an important metric of system performance and one that plays a central role in cost-benefit analysis. As mentioned earlier, most applications include fairly highly aggregated measures of delay that mask the true variations among agents and the real economic cost of delay. Aggregate delay analysis misses important distributional effects of a technology, especially when it shifts where delay occurs and how the delay burden is distributed. An important feature of delay analysis as applied in this model in the inclusion of schedule buffer. The buffer, results from the practice of what is called schedule *padding*, which airlines in order to maintain on-time performance while absorbing expected delays. Excessive buffer leads to inefficiencies, especially when airlines pay crew costs for the entire scheduled time even if a plane arrives early. Insufficient buffer, on the other hand causes on-time performance to decline, adversely affecting an airline's competitiveness position.

Table 1 shows the categories of delay per flight and the method for calculating the cost of each type of delay. The distinction between elements of delay is critical for it proper costing. For example, when a flight arrives before its scheduled arrival time, the crew does not earn over-time. However, the flight, possibly delayed an amount less than the buffer built into the schedule, may have incurred some extra flight time, which affects its direct operating cost. In such a case only the second element would enter into the costing of this '*delay*'.

Table 1: Calculations for Delay to Operators by Carrier and Aircraft from Aviation Daily

	On ground – engines off	On Ground - engines on	Airborne Delay
Less than buffer*	None	Direct Maintenance	Direct maintenance + Fuel/Oil
More than buffer**	Crew costs	Direct Maintenance + Crew costs	Direct maintenance + Fuel/Oil + Crew costs

* If the airborne time is less than the planned OAG flight schedule (minus buffer, taxi in/out times), then saved delay is multiplied by the crew costs to counterbalance the cost of the delay taken on the ground.

** If the delay is more than the connection time, an administrative cost is added per connecting passenger

4.2. Case Study weather enhancement technology, ITWS

The case study presented here deals with the evaluation of the impact of Integrated Terminal Weather Service, ITWS. This technology provides a weather preview capability that allows pilots and traffic controllers to manage traffic more effectively during convective weather events in the terminal airspace. ITWS has been deployed at a number of airports in the U.S. and is under consideration for wider deployments in the US National Airspace System. The focus of this study is on one class of metrics representing various elements of delay and on a group of agents representing different airlines, aircraft types, and type of flights (long haul vs. short haul).

A recent study by the MIT Lincoln Labs (2001) uses simulation to estimate the delay reduction that can be achieved from deploying ITWS. The study simulates the results for a variety of episodes that the technology mitigates. Using a specific day, May 24, 1999, the MIT study calculates the total delay savings by having five more departures an hour for ten hours to be approximately $2 million dollars. The study uses block hour values for cost of delay and, as is common practice, aggregates the totals for all agents. In an attempt to obtain a more comprehensive estimate of the benefits of the ***M*** matrix for ITWS, we have use data for this day from the ASQP database and model the total delay value for the day with and without ITWS. Beyond the method by which delay values are calculated, the analysis here also deals with how delay values could be affected by the state of the system. Additionally, increases in the efficiency of the system during degraded operations could lead to secondary benefits such as the reduction of buffers leading to more operations or less delay during normal operations.

4.3. Methodology for analytical example

On May 24, 1999, ITWS was used to mitigate the impacts of a major storm at the Newark Airport, EWR. Measuring the delay reduction due to ITWS requires estimating what the day would have been like without it. Using the time history of each individual aircraft that operated at EWR that day, one can trace the aircraft's progress, and measure delay incurred at various stages in the operation as the aircraft departed its upstream station, arrived at EWR, and eventually departed EWR to its downstream station. Using the Lincoln Lab simulation results that indicate a loss of 5 aircraft departure slots per hour in the absence of ITWS departure delays are estimated using a simple deterministic queuing model.

In the analytical example, we find a direct benefit of ITWS of $254,327 in delay savings to the ASQP reporting airlines on May 24, 1999. This value is significantly different from that of the $996,912 obtained by the 2001 study. The main source of difference is the dis-aggregation of delays and the introduction of schedule buffers that airlines use to absorb expected delays without affecting flight schedules. In the analysis presented here, delays are calculated separately for each airline based on that airline's operating costs for each aircraft type. Delays are also differentiated on what segment of the operation they are incurred prior to assigning a cost value to them. Thus cost values per minute of delay obtain depending on whether it occurs while the aircraft is in the air, parked, or taxiing on the ground. In Table 2, the delay costs in minutes and dollars are shown for each airline. From this table, we can see that there seem to be clusters (around 45, around 68, and around 75) of delay savings per flight in minutes due to ITWS. However, when they are translated into dollar values, some dispersion occurs because of the different operating costs of the carriers and the fleet mixes.

4.3.1. Differential incidence of delay cost

Table 2 shows the differential impact of delay on different airlines. For example, USAirways experienced more delay cost at Newark before ITWS on May 24, 1999 than any other carrier. This seems to be a function of its operating costs rather than actual delay experienced had ITWS not been deployed on that day. The initial "endowments" of delay can be tied back to the *Pareto* framework to determine if the technology implementation would meet the *Pareto* criterion or whether some compensation to that airline would be cal led for, at least in theory.

Table 2 reveals that ITWS does have varying effects on the airlines at Newark because of the number of flights that the airline had, their operating costs, and the time of day of their flights. Continental, the largest operator at Newark, benefits the most in total delay and total dollars. America West, one of the smaller carriers at Newark benefits the most per flight in minutes and in dollars. Delta saves the least per flight basis. While it is clear that all carriers benefit from the deployment of ITWS at Newark, there is no reason why all carriers should be willing to pay for it equally. It is far from obvious that the current scheme for paying for such investment, namely tickets taxes, is anywhere close to being an economically efficient pricing scheme.

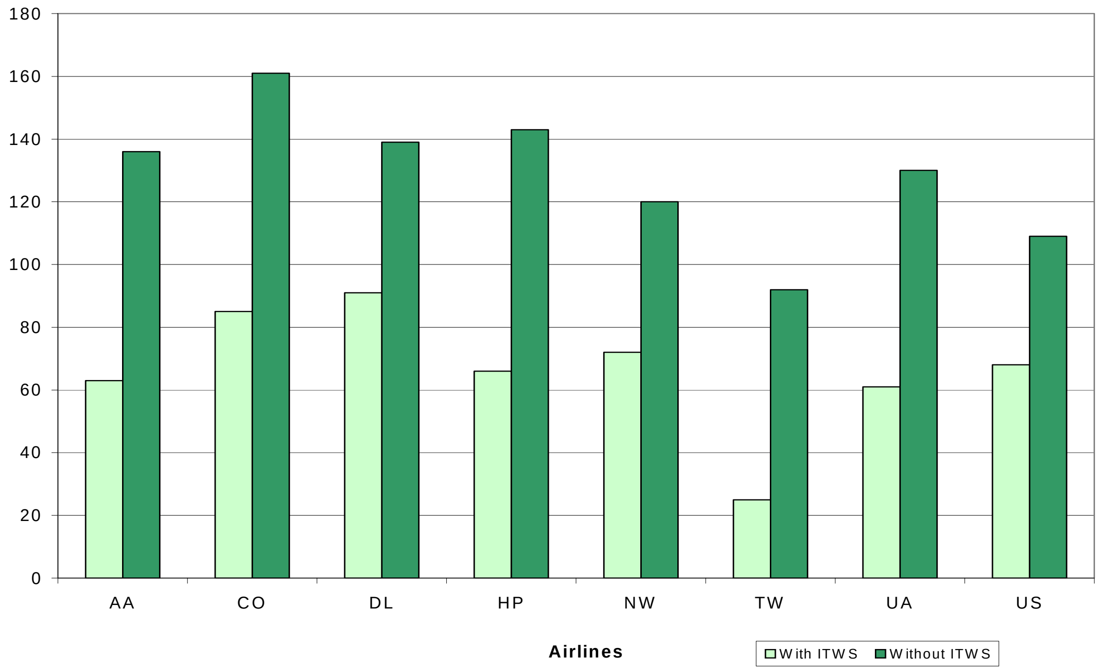

Figure 1: Average Delay Costs in Minutes per Flight, Newark Airport, May 24, 1999

Figures 1-2 illustrate the differential incidence of delay and delay cost among the different carriers. Fig. 1 shows the savings in average delay in minutes per flight due to the deployment of ITWS. Fig. 2 shows the same results in dollars per flight. Not only do the different airlines accrue different savings from the implementation of the technology, but they also incur different monetary costs and hence cost saving. This is because, depending on the types of flights and types of aircraft, and the nature of their schedule, different airlines will incur different money cost for the same minutes of delay. It is clear that they should be willing to pay differently for the technology, both in total and average delay.

4.3.2. Equity and the initial delay endowments

In addition to possibly yielding different benefits to different users, a technology can create inequity by altering the initial delay endowment as represented by the departure from the FIFO regime that it can cause in a queuing system. This arises in cases where technologies aimed at optimizing the overall operation of the system alter the initial order of arrivals to a service queue (e.g. a take-off or a landing). In the case of weather mitigation, preview capabilities of weather related closures of certain parts of the airspace may cause the controllers to process some aircraft ahead of others, or airline dispatchers to send some flights ahead of others.

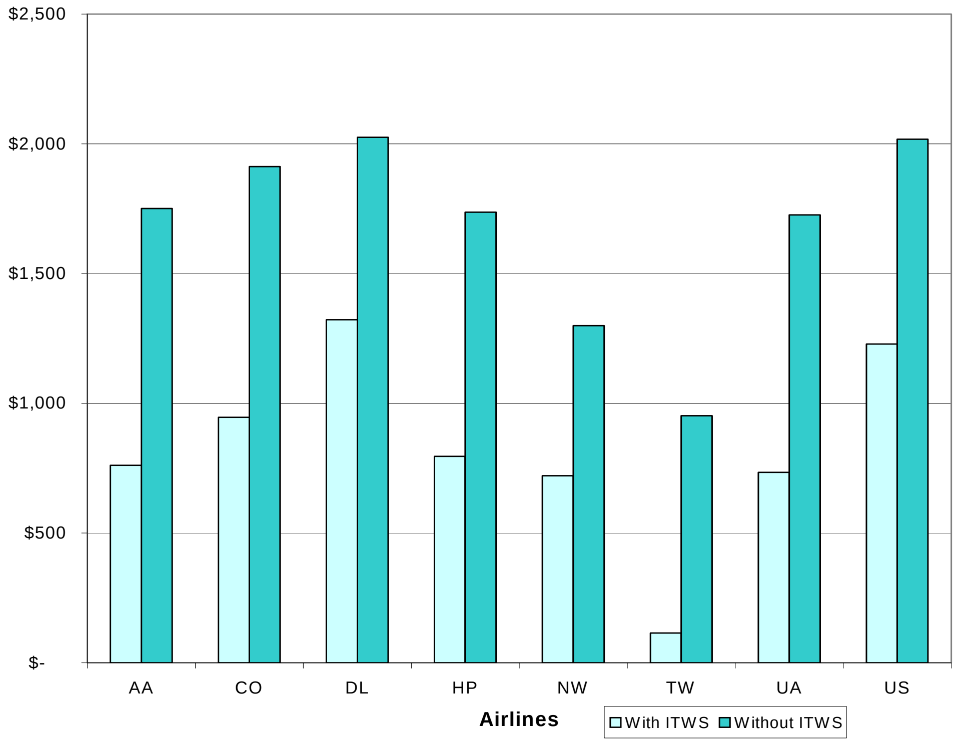

Figure 2: Average Delay Costs per Flight in Dollars, Newark Airport, May 24, 1999

One way to capture these equity implications is to look at the degree to which the queue regime adheres to the first-in-first-out (FIFO) principle. By observing the history of each aircraft in the system, we are able measure departure from FIFO and use that to quantify the degree to which delays are allocated differentially among flights. Different flights experienced very different delays on May 24, 1999. A metric that measures departure from FIFO can be use to quantify the equity implications of the traffic management scheme in effect. Understanding the reasons behind these differences will help understand the distribution of impacts among different flights, and the extent to which these differences are impacted by the operational behavior of different airlines in managing their traffic under degraded capacity modes.

To illustrate the queuing analysis we look at the departure process from EWR on two days, June 1, 1999 and May 24, 1999. The first was a date with good weather and visual conditions throughout, and the second was a day with severe convective weather storms and significantly reduce airport and airspace capacity. Three variables are defined for the purpose of this queuing analysis:

1. An aircraft's place in the departure queue NEWDEP is defined by:
   NEWDEP = *max.* {(ASQPARR+30) ; OAGDEP}
   where ASQPARR is the actual arrival time of the aircraft, and OAGDEP is the scheduled departure (pushback) time. By adding 30 minutes to the first term we represent an aircraft place in the departure queue either by its scheduled departure time, or if it arrives late, by the arrival time plus a 30-minute turn-around time.
2. An aircraft's actual pushback time, ASQPDEP.
3. An aircraft's actual wheels-off time, WHOFF.

Table 2: Costs of Delay to Reporting (ASQP) Airlines at Newark Airport on May 24, 1999

	American	Continental	Delta	America West	Northwest	TWA*	United Airlines	US Airways
Aggregate Cost of Delay								
In Dollars								
With ITWS	$ 19,015	$ 160,806	$ 25,119	$ 6,371	$ 8,653	$ 574	$ 20,539	$ 8,603
Without ITWS	$ 43,771	$ 325,081	$ 38,471	$ 13,889	$ 15,586	$ 4,762	$ 48,319	$ 14,128
Savings from ITWS	$ 24,756	$ 164,275	$ 13,352	$ 7,518	$ 6,933	$ 4,188	$ 27,780	$ 5,525
In Minutes								
With ITWS	1587	14510	1734	528	859	127	1713	475
Without ITWS	3399	27453	2638	1146	1438	462	3636	763
Savings from ITWS	1812	12943	904	618	579	335	1923	288
Cost of Delay per Flight								
In Dollars								
With ITWS	$ 761	$ 946	$ 1,322	$ 796	$ 721	$ 115	$ 734	$ 1,229
Without ITWS	$ 1,751	$ 1,912	$ 2,025	$ 1,736	$ 1,299	$ 952	$ 1,726	$ 2,018
Savings from ITWS	$ 990	$ 966	$ 703	$ 940	$ 578	$ 837	$ 992	$ 789
In Minutes								
With ITWS	63	85	91	66	72	25	61	68
Without ITWS	136	161	139	143	120	92	130	109
Savings from ITWS	73	76	48	77	48	67	69	41
Per Minute Costs								
$ per minute w/	$ 12.08	$ 11.13	$ 14.53	$ 12.06	$ 10.01	$ 4.60	$ 12.03	$ 18.07
$ per minute w/o	$ 12.88	$ 11.88	$ 14.57	$ 12.14	$ 10.83	$ 10.35	$ 13.28	$ 18.51
savings in $ per min	$ 13.56	$ 12.71	$ 14.65	$ 12.21	$ 12.04	$ 12.49	$ 14.38	$ 19.24

* TWA merged with American Airlines after this date.

These data are available from the ASQP data (http://www.faa.gov) for a sample of reporting airlines covering about 90% of all air traffic in the US. For each of the two days in the sample, two queuing diagrams are compared. One is based on the cumulative counts of the relevant variables, and gives the average delays and queuing behavior of the system as a whole, without regard to actual delay of individual aircraft. Such a cumulative queuing model describes a system in FIFO. The other diagram traces the history of individual aircraft and thus shows the actual delays experienced by individual aircraft. The difference between this pair of queuing diagrams describes the extent to which the system deviates from the FIFO regime.

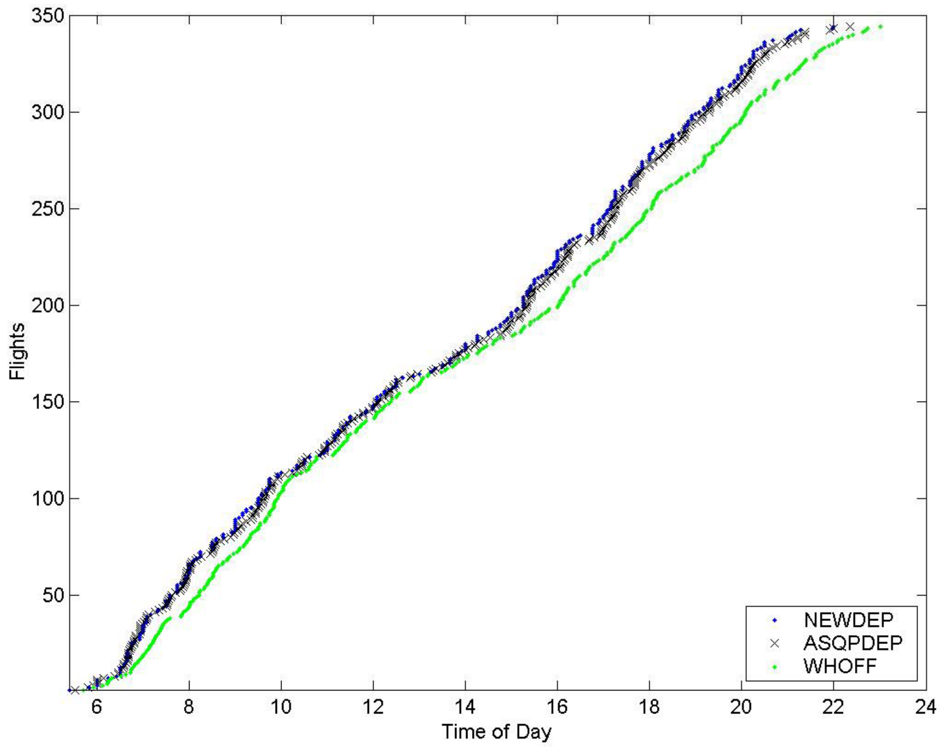

Figure 3: Newark ASQP Cumulative Departure Count Curve, June 1, 1999

Figure 3 and 4 show these queuing diagrams for June 1, 1999. As can be seen in Fig. 3, this day has very little delay in the system, except for a period in the afternoon when the rate of aircraft push backs (ASQPDEP) exceeds the runway capacity (WHEOFF), and the taxi-out queues build up. The aircraft specific queuing diagram in Fig. 4 shows very little reordering of aircraft and close similarity to the FIFO regime.

The picture is quite different when looking at April 24, 1999, a day with a significant loss of capacity due to weather, shown in Figs. 5 and 6. Figure 5 shows the aggregate delay values and the evolution of queue lengths with no distinction among aircraft, or under the hypothetical condition of a first-in-first-out regime. The horizontal difference between the OAGDEP curve and the ASQPDEP curve represents departure delay in leaving the gate (or on-time departure performance). The horizontal different between the ASQPDEP and the WHOFF curves represents the total actual taxi-out time, which includes departure queuing delay. This diagram shows the extent of delays on that particular day, when as mentioned earlier severe weather conditions were encountered.

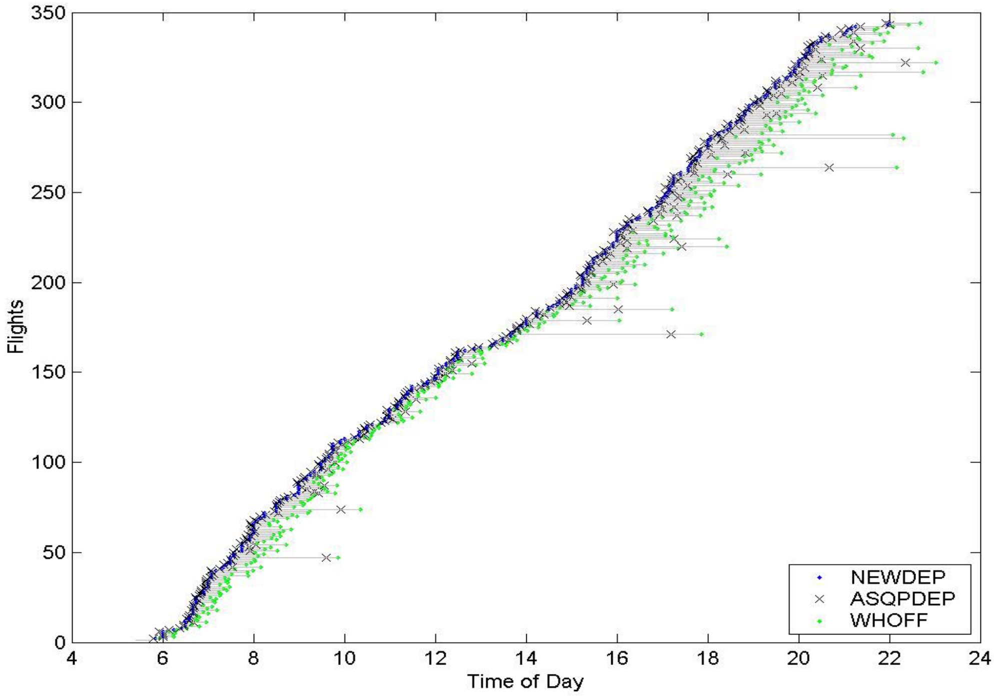

Figure 4: Newark ASQP Departure Delay (flight specific) on June 1, 1999.

Sequenced by scheduled departure time (Current NEWDEP).

Delays on the order of 2 hours or more are clearly visible in the diagram. But what is perhaps more interesting is the actual history of individual aircraft as shown in Fig. 6 where significant departures of FIFO are evident, and when many aircraft were taken out of their order in the service queue both in departure from the gate (ASQPDEP), and in actual take-off (WHOFF). Recall that ITWS was in operation on that day and it is reasonable to assume that traffic controllers, or airline dispatchers would take considerable liberties with the FIFO regime in order to use the technology to its fullest potential and get as many flights out as possible during the period of sever capacity degradation.

In order to quantify this departure from the system's initial endowment of delay as represented by the schedule we measure the departure from FIFO in the queuing system. A convenient measure of this departure can be derived from the fact that in as some flights are advanced ahead of others in the queue the total delay is not altered but its incidence is altered such that the advanced aircraft saves an amount of delay that is equal to that lost by the aircraft that is skipped. This means that when comparing FIFO and any other scheme that serves the same total number of aircraft the total and the average delay are the same, FIFO will have the minimum variance of delay. This property is used to characterize a queuing scheme *i* on the basis of the following variance ratio, R_i, defined as follows:

$$R_i =_{.} \tilde{\square}_i \square_f$$

where $\square_i$ is the delay variance in system *i* and $\square_f$ is the delay variance in the equivalent FIFO system. A larger value of R represents a queuing system with more deviation from the FIFO regime and a saving of delay to some aircraft at the expense of others in the same queuing systems.

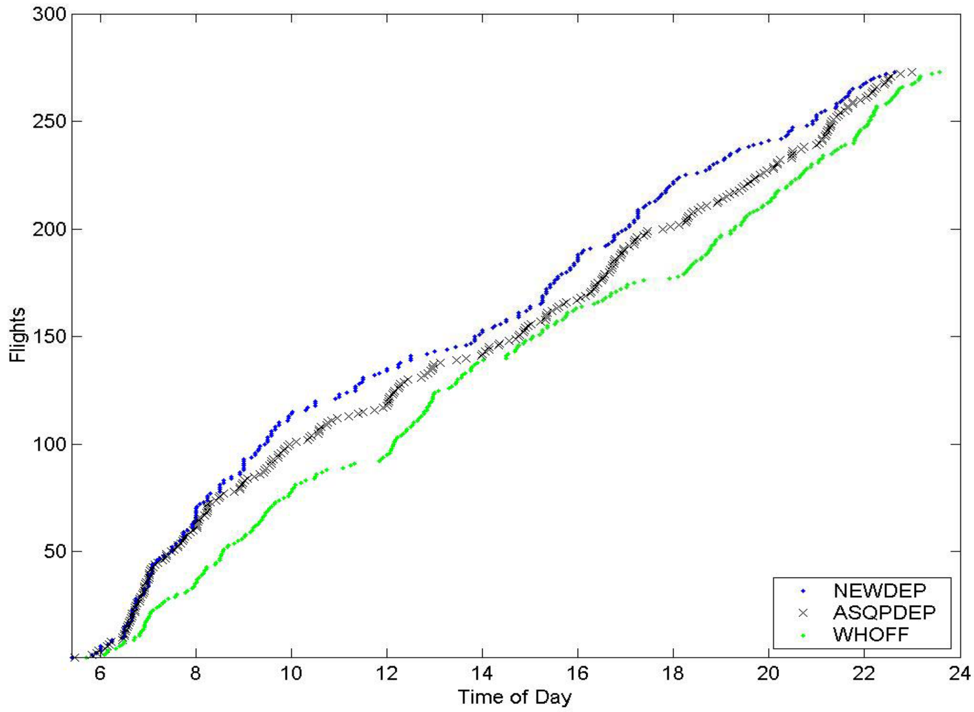

Figure 5: Newark ASQP Cumulative Departure Count Curves, May 24, 1999

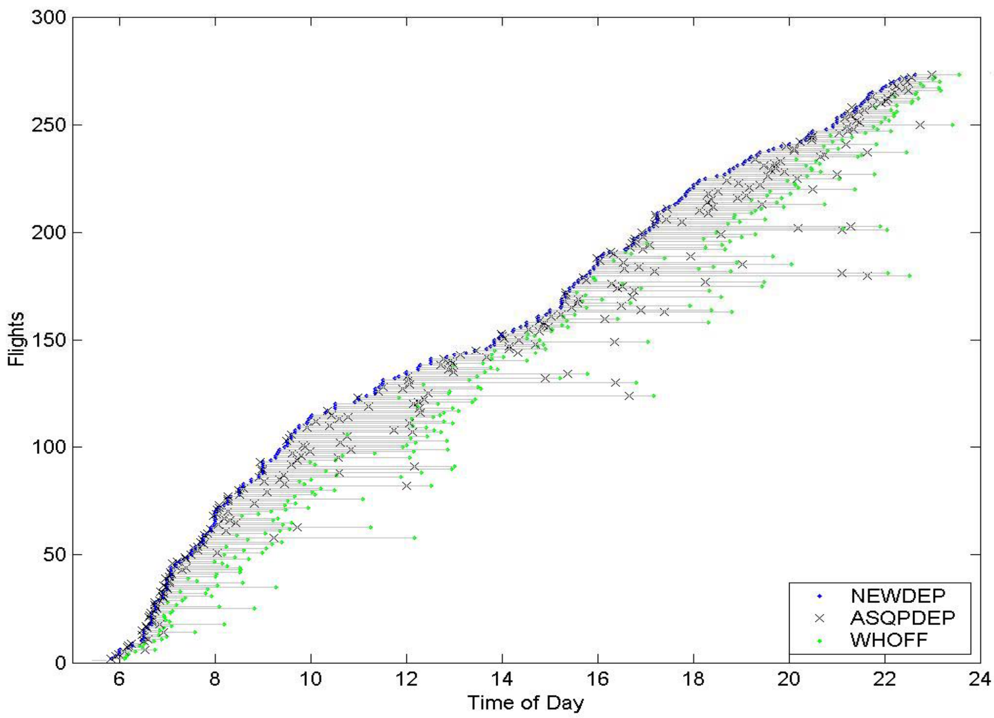

Figure 6: Newark ASQP Departure Delay (flight specific) on May 24, 1999.

Sequenced by scheduled departure time (Current NEWDEP).

The values of these queuing equity indices, R, are calculated for the systems displayed in Figures 3-6 representing the good weather days and the bad weather days with ITWS technology in effect. To further differentiate the equity index among types of flights, it is calculated separately for short haul flights (flights shorter than 2 hours) and long haul flights. Figure 7 shows the R-values for Newark for these flights calculated for the cases with high delays and no ITWS intervention, and lower delays with ITWS intervention. It is notable that the delay reduction attributable to the technology is accompanied with increased departure from the FIFO queuing regime, which means at a price in terms of equity among types of flights.

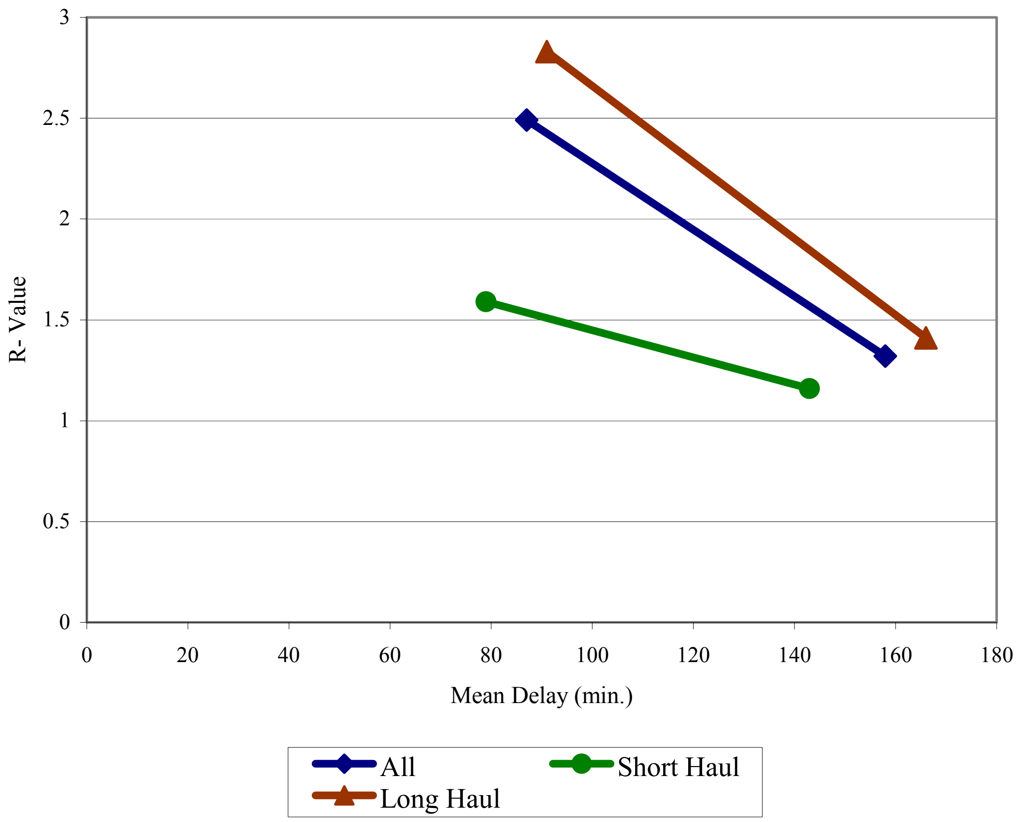

Figure 7: Efficiency and Queue Disruption – R-values for Newark Airport, May 24, 1999 (with and without ITWS)

These results, together with those shown in he previous section illustrate the differential impact of this technology on airlines and on flight types. Some thoughts on the implications of this on pricing for air traffic services follow in the next section.

4.4. Pricing and redistribution

Reallocation is necessary in two situations: cost recovery and finding a *Pareto* efficient solution to a technology change. The results in the previous section illustrate the importance of an airline's cost structure is to its value of a technology and consequently to its willingness to pay for it.

If the technology is priced correctly, it may provide for some cost recovery while providing a *Pareto* efficient solution. Given an investment decision in air traffic management, the aim is to determine an efficient pricing mechanism for Air Traffic Services (ATS) in that it maximizes net social benefits. This generally means maximizing the sum of consumer and producer surplus and results in a pricing mechanism that is based on the marginal cost responsibility of each user group. Such a scheme will work when marginal costs are above average costs.

However, ATS services generally belong to the category of public facilities with significant economies of scale, falling average costs, and with marginal costs that are below average costs. In such systems, the marginal-cost pricing scheme is generally revenue negative. Therefore, a pricing mechanism, such as Ramsey pricing must be sought that would recover costs and allocate prices efficiently. Under Ramsey pricing, prices are determined on the basis of maximizing net social benefit, but they are subject to the constraint that they must cover total costs. In particular, adjustments must be made in the form of marginal cost surcharges that are inversely proportional to the price elasticity of the demand by the various user groups (GRA, 1997).

In the case of a technology like ITWS, the measurable benefit is in terms of the delay savings. In the first part of the study we obtain the costs of different blocks of delay and use them as a basis for evaluating benefits to different users. On the basis of that evaluation, one could suggest fees or charging schedules for different users and also an organizational set up. For this study, we have not delved fully into a reallocation scheme for ITWS as everyone prefers having ITWS and therefore reallocation to find an efficient solution is not necessary. This does not mean that ITWS is equitable as our results shows a broad variety of benefit based on the airline and that significant reordering does occur.

5. Conclusions and application

This paper proposes an investment analysis framework that reveals possible *Pareto* efficient solutions by considering the distributional aspects of benefits and costs. With information about the initial endowments of different agents the analysis can reveal how a technology can affect the stakeholders individually, by using metrics that are specific to different agents (stakeholders). The case study applied to ITWS technology focuses on the distribution of delay impacts among agents (here airlines and flight types). The case study focuses on the departure process at Newark during a bad weather day. Current work extends this to the arrival process, where delay is taken in the air, or on the ground, when the ground delay program is in effect. This would permit a more disaggregate measurement of delay components and their monetary costs, leading to a more thorough cost accounting.

Other enhancements to the model that are underway include a more thorough analysis of buffers that are used to make the schedule robust to minor, expected delays. Additionally, we can move from using general averages of buffers, taxi times, and costs to user specific functions that will model “reality” even more closely

Acknowledgements

This work was supported by the Federal Aviation Administration Terminal Business Service (ATB) through NEXTOR, the National Center of Excellence for Aviation Operations Research.

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