Analysis of Factors For Incorporating Users Preferences in Air Traffic Management: A Users' Perspective

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This paper presents an analysis of factors that impact user flight schedules when users' preferences are integrated in the decision making process. The factors studied in this paper are a flight ranking function based on users' business models, the value of participation in a collaborative initiative, and the impact of the planning interval on the users' preference satisfaction. These factors were evaluated using the credit points concept published earlier. The study shows that the integration of user's preferences in the flight scheduling process may generate a trade-off between equity of the delay distribution and users' preference satisfaction. Results indicate that the planning interval can be used to reduce this trade-off and foster collaboration.

I. Introduction

Traditionally, decisions made to maintain or restore demand-capacity balance in the National Airspace System have sought to optimize a particular aggregate figure of merit, such as minimizing the maximum delay of flights or maximizing the utilization of the airspace. Unfortunately, this approach fails to recognize that balancing the air traffic demand involves the demands and objectives of airspace users. Thus, decisions seldom take into consideration airspace users' preferences, namely flight priority, departure time, route and altitude. A lack of mechanisms for incorporation of users' preferences in the decision making process leads the service provider to make decisions that may not be cost-effective and equitable for the users. This may translate to higher cost and passenger dissatisfaction. Since users have different economic impacts for individual flight delays, they are in the best position to suggest which flights can tolerate more delay, without revealing private cost information. This information can then be used by the air traffic service provider to seek more equitable and cost-effective solutions to restore the demand-capacity balance.

Early work on collaborative traffic flow management preserved the traffic flow management functions centralized with the service provider and only allowed the user's input in the initiative selection process.[1–4] Recent work on this area has proposed shifting some of the traffic flow management responsibilities to the users and allow the service provider to assume a supervisory role, intervening as needed.[5,6] This responsibility shift is proposed with certain limits as the service provider retains rationing and oversight capabilities. One of the advantages of this new perspective on collaboration is the ability of users to propose contingency plans for their flights, such as optional routes and departure times. Already, several studies have investigated the impact of flight priorities in the departure schedule decision making process.[7–9] These studies have shown that collaboration can reduce the overall delay in the system as long as users behave in an altruistic reciprocity fashion. That is, users are willing to absorb system-imposed delays as long as the service provider ensures equity of the system-imposed delay. Unfortunately, the collaboration among all participants can suffer if they perceive that the equity of the system-imposed delay is not preserved by the

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service provider. Consequently, modeling and analyzing users' behavior is necessary to design collaborative traffic flow management mechanisms that foster collaboration and yield acceptable delays to each one of the users.

In Ref. 10, the concept of credit points was presented for incorporating users' flight preferences in terms of flight priority, optional routes and intended departure time into the scheduling process that maintains air traffic demand below available capacity. An analysis of different factors for incorporating users' preferences in air traffic management from a system perspective using the credit-points concept was presented in Ref. 11. This paper presents an analysis from the users' perspective. The factors studied are: the credit assignment function based on each user's business model, the user participation level, and the planning interval. In addition, a delay cost is used to measure delay equity from the users' perspective. A concept of utility is used to gauge users' preference satisfaction.

A brief description of the credits concept is presented in Section II. The process of modeling and simulating user behavior using the credits concept is described in Section III. The simulation data, parameters of the model, and factors considered for analysis are described in Section IV. The analysis of the results are presented in Section V. The paper ends with concluding remarks on this study.

II. The Credit Points Concept

The concept of credit points is a mechanism capable of expressing user preferences, such as flight priority, in terms of credits. Credits are artificial currency that convey the users' preferences to the service provider,without disclosing company proprietary information. The service provider maintains air traffic demand below available capacity while trying to accommodate the users' preferences, as expressed by the number of credits assigned to each flight. This is accomplished by rerouting or by delaying flights on the ground. At the beginning of the day, users are allocated a fixed number of credits based on their departures and they expire at the end of the day. The total number of credits allocated for each user is five times their number of flights in a day. The allocated number of credits as well as the expiration period could be varied to study economical and operational implications of the concept, but their values remain fixed for the present study. Users then assign credits to flights based on their business model and credit assignment function (see Section III). The only restriction is that users cannot expend more credits than the total number of credits initially provided to them.

Typically, the service provider establishes a planning interval, which partitions the day into contiguous and non-overlapping time periods. For each time interval, users can submit their list of scheduled flights and corresponding credits, optional routes, and intended departure time to the service provider. After all submissions are completed, the service provider uses a simulation engine to iteratively fly all departing flights within that interval from origin to destination, and identifies capacity violations in the National Aerospace System (NAS). Whenever a capacity violation arises, flights creating the imbalance are ranked by their credits and the flight with the lowest credit assignment is selected for rerouting. If no optional route was submitted or selection of optional routes causes another capacity violation, a system-imposed departure delay is assigned to the flight. The value of the system-imposed departure delay varies depending on the capacity violation. For sector congestion, a 5-minute ground delay is given in this study, but a lower value may also be specified. For an airport capacity violation, a 15-minute delay or less is assigned. Given that airport capacities are evaluated every fifteen minutes, the assigned delay for an airport capacity violation is the necessary amount to reschedule the flight within the next 15-minute interval. This iterative process is continued until no capacity violations occur in the interval. Then, the credits corresponding to the granted flights are decremented from each user's total credit allocation.

III. Simulating User Behavior

The individual method used by users to encode the user's preferences in the credit points concept is known as the user behavior. In order to model the user's behavior, the following three functions need to be specified: An optional routes function, a credit assignment function, and a utility function. The optional routes function determines optional routes for a particular flight by receiving the flight plan, the aircraft type, and a list of overloaded sectors that cannot be present in the routes. Using this information, the optional routes function queries its internal routes database for routes that do not traverse any of the sectors contained in the overloaded sectors list. The query result is further refined to include only routes flown by the specified aircraft type and ranked by their frequency. Finally, the optional routes function returns the top three optional routes.

The credit assignment function assigns a numerical value to the importance of a particular flight based on the business model of the user. In a previous human-in-the-loop simulation, subject matter experts considered flight schedule, fuel consumption, aircraft type, crew legality, individual passenger connectivity, scheduled maintenance and load factors as the most relevant factors to determine the importance of a flight.[12] Since crew legality, passenger connectivity, scheduled maintenance, and load factors are considered proprietary information, their impact on flight priority cannot be properly modeled. However, flight schedule, flight path distance, and aircraft type are considered public information. Based on this public information, and the hubs and major cities information of each user, a credit assignment function, $C(f)$, for each flight, f, was developed as follows:

$$C(f) = \frac{1}{2}\left[\frac{D_f}{D_{max}} \times 10 + \frac{P_f}{P_{max}} \times 10 + H_f\right] \tag{1}$$

where D_f is the flight distance, D_{max} is the normalization flight distance constant (2000 nautical miles for US continental flights), P_f is the number of passengers that can be on that aircraft type, P_{max} is the normalization passenger constant (250 passengers) and H_f is the hub-connectivity factor for that flight, such that

$$H_f = \begin{cases} 10 & \text{if either the origin or destination is a hub,} \\ 7 & \text{if either the origin or destination is a major city and the other one is not a hub,} \\ 3 & \text{otherwise} \end{cases}$$

In the particular case that a user does not follow a hub-and-spoke model, the hub-connectivity of a flight is based on distance. A flight distance greater than 750 nautical miles is considered as a flight between major cities and assigned a hub-connectivity factor of 7. Similarly, a flight with a flight distance up to 750 nautical miles is assigned a hub-connectivity factor of 3.

The optional routes and credit assignment functions convey users' preferences to the service provider. Similarly, a utility function gauges the user's preference satisfaction by the service provider. Modeling an individual utility function is by itself a hard research problem as it contains both objective and subjective elements that are only known to the user. In this study, a utility function is defined with respect to a simulated baseline case, which mimics the current mode of air traffic operations. In particular, a utility function, $U(f)$, gauges the user's preference satisfaction by associating a numerical value to the associated cost of delaying a flight, f, with respect to the baseline as follows:

$$U(f) = \left[5 \times db_f\right] - \left[C(f) \times d_f\right] \tag{2}$$

where db_f and d_f are the system-imposed departure delays for the flight in the baseline case and in the credits concept case, respectively. The associated cost of delaying a flight, namely the delay cost, is the delay weighted by the credits assigned to the flight. Since the baseline case considers all flights equal, the delay cost of the baseline case is the delay weighted by the nominal credit value, which in this study is five. Given that the user's preference satisfaction is an aggregate measure of flights, and assuming additive separability, the utility of a user can be viewed as the sum of the utility of their flights.

IV. Traffic Data and Simulation Parameters

The traffic flight data used in the experiments was taken from historical records. Specifically, air traffic data from Wednesday, August 24^{th}, 2005 was obtained from the FAA's Enhanced Traffic Management System (ETMS). This represents dense weekday traffic with minimal weather impacts. The choice of a relatively clear weather day implies that the majority of flights were not delayed or rerouted by air traffic control due to weather. Once the air traffic data was validated, a four hour baseline scenario was generated using the heavy traffic volume from 3 to 7 pm Eastern Daylight Time (EDT). The baseline scenario contained 18,668 flights, representing 427 users. The top 40 users encompassed 10,514 flights, whereas there were 5,000 general aviation (GA) flights. It is noteworthy that the top 40 users plus GA users accounted for 83% of the flights in the baseline scenario, roughly the same percentage distribution for the entire day. The international users and domestic non-top users accounted for the remaining 17% of the flights.

As far as NAS capacity constraints are concerned, any sector or airport that was used by any flight in the system was included in the NAS capacity data set. This data set represents the universe of resources whose capacity constraints must be strictly satisfied. For this study, the data set contained 974 sectors, and 905 airports. The FAA's Aviation System Performance Metrics (ASPM) and the Operations Network (OPSNET) data were used to obtain the maximum departure and arrival values for each of the top 70 airports. Since the airport capacity statistics are available in 15-minute intervals only, and some airports reconfigure their runways to increase their departure or arrival rates, the observed maximum values are an estimate of the operational capacity of the top 70 airports. Airports outside of this set were assumed to have a default value of 13 departures and arrivals every 15 minutes. Similarly, the default sector capacities known as Monitor Alert Parameters (MAP) were taken from the Future ATM Concepts Evaluation Tool (FACET),[13] which also was selected as the simulation environment for this study.

IV.A. Simulation Cases

In today's air traffic operations, airport and sector capacity constraints may be violated.[14] In contrast, all resource capacity constraints are strictly satisfied in this simulation. Thus, a simulated baseline case of one filed route and equally prioritized flights was taken as the representation of the current air traffic operations. In addition, the following four case scenarios were used for the simulation: A user-centric case, a flat-case, a distance-based case, and an opt-out case. For all these cases, only the top 40 users were considered collaborative participants and their optional routes data bases were created by selecting routes from historical ETMS filed flight plans.

For the user-centric case, the credits for each flight were assigned based on the user-centric assignment function, $C(f)$, described in Equation 1. However, domestic flights with origin and destination outside the top 70 airports as well as all non-participant users were assigned five credits and given no alternate routes. Similarly, international flights were assigned ten credits with no alternate routes. For the flat case, each flight was assigned five credits and three alternate routes. This case encompasses the optional routes approach that is currently being investigated by the FAA. In the distance-based case, the credits for a flight were assigned based on the flight's path length as follows: three credits for a flight with a flight distance up to 500 nautical miles. From there on, a credit is added for any additional 250 nautical miles up to 10 credits. This case represents the ration-by-distance approach that has been used for ground delay programs.[15] The opt-out case is a tailor-made scenario designed to analyze the case of a participant user that does not collaborate anymore. In this special case, the user with the greatest delay cost was switched to the baseline option and the remaining top 39 users were left unchanged with respect to the user-centric case.

IV.B. Simulating User Participation

Users try to reduce their system-imposed departure delays by modifying the optional routes or credit assignment functions of their flights. In the absence of real users, this behavior is modeled by allowing simulated users to review and analyze past results, usually known as experiences. Simulated users analyze experiences in order to guess or gain information about other players' preferences. By analyzing previous utility values, and comparing previous flight schedules with planned flight schedules, a simulated user may chose to switch back to the baseline option and see what happens. This withdraw behavior is modeled by decrementing the user participation in all the above cases from the top 40 users to the top 28, the top 20 and the top 12 users. This accounts for a 30%, 50% and 70% reduction in participation, respectively.

IV.C. Planning Interval

In a model where all resource constraints are strictly enforced, a longer planning interval implies a lower aggregate system delay. That is, a long planning interval reduces the uncertainty of airborne flights entering the continental US, which cannot be delayed. This awareness of future airborne flights allows the service provider to efficiently distribute system-imposed departure delays to flights. However reducing the aggregated system delay may not be in the best interest of the users, since some flights may have to absorb more system-imposed departure delay than the absorbed system-imposed departure delay in a shorter planning interval. This extra absorbed delay might be considered unfair, because users were not able to adjust their preferences to cope with airborne flights. Similarly, a very short planning interval may create the perception of unfair system-imposed departure delay assignment due to the partial awareness of airborne flights, which can force the service provider to grant system-imposed departure delays to important flights in order to keep the demand-capacity balance in the NAS. In both cases, the users feel unfairly treated and they may not be willing to participate in the future. Therefore, the planning interval plays a role in the perception of the users' satisfaction and equity of the system.

In order to analyze the impact of the planning interval on the users' utilities, the planning interval for each one of the credit assignment and user participation cases were set to one hour, two hours and four hours. For example, in the one-hour case, the user preferences were submitted four times, one per hour and each submission only accounted for flights departing within that hour. Similarly, for the two-hours case, two submissions were done.

V. Results

One way to measure the benefits of collaboration is to study the equitable distribution of delays between users. A metric of equity for a distribution is the Gini coefficient, G,[16] which is defined as:

$$G = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} |x_i - x_j|}{2n^2\mu} \tag{3}$$

where n is the total number of flights, μ is the mean value of the distribution, and x_i or x_j is the total delay for the i^{th} or j^{th} user (from all users' perspective), or the maximum delay for the i^{th} flight (from a single user's perspective).

The Gini coefficient ranges from a minimum value of zero, when all flights for each user were assigned exactly the same amount of delay, to a theoretical maximum of one, when only one flight was assigned all the delay. However, the assumption that a delay minute has the same cost to any flight was removed when the service provider incorporated the users' preferences in the assignment of delays. Consequently, a lower Gini value does not directly translate to a higher utility for all the users. Similarly, aggregated utility maximization may be achieved at the expense of less important flights, which will increase the Gini value. Since equity and utility maximization are equally important in any collaborative initiative, the service provider may need to modify parameter values, such as the system-imposed departure delay or the planning interval, in order to achieve an acceptable compromise.

Table 1 shows the Gini, the total utility values, and the total delay (in minutes) for the top 40 users for the user-centric case, the flat case, the distance-based case, and the opt-out case for the one-hour, two-hour and four-hour planning intervals. The effect of utility maximization at the expense of equity can be observed in the user-centric case with a two-hour planning interval, where the total utility and Gini values achieve their maximum values, and the total delay is minimized. A more interesting case is the user-centric case with a four-hour planning interval, where the Gini value is minimized and the total utility value is the maximum value of all cases for the four-hour planning interval. From the service provider perspective, the four-hour planning interval is the best possible outcome. However, the two-hour planning interval is the best option from the users' perspective. For comparison purposes, the Gini and delay values for the baseline case were computed. Since the baseline case is the representation of the current air traffic operations, the Gini and delay values are estimates of the equity and delay in the current system. For the one-hour planning interval, the Gini value is 0.469 and the delay is 2,800 minutes. Similarly, for the two-hour planning interval, the Gini value is 0.42 and the delay is 2,980 minutes. Finally, for the four-hour planning interval, the Gini value is 0.48 and the delay is 1,990 minutes.

Table 1. Comparison of Gini values representing the overall delay distribution equity, the aggregated utility, and the delay in minutes of the top 40 users for different simulation cases and planning intervals.

Planning	**User-centric**			**Flat**			**Opt-out**			**Distance**		
Interval	Gini	Utility	Delay	Gini	Utility	Delay	Gini	Utility	Delay	Gini	Utility	Delay
1-hour	0.4362	5203	1750	0.4690	5700	1720	0.4667	5700	1730	0.4650	4584	1947
2-hour	0.5108	7117	1604	0.4593	5090	2011	0.4766	4698	2072	0.4810	2729	2463
4-hour	0.4063	3612	1816	0.4782	1500	1697	0.4271	3485	1795	0.4472	3236	2014

Figure 1 shows the delay cost comparison between the user-centric case and the opt-out case with a four-hour planning interval. The delay cost distribution of the top 40 users is ordered by the number of operations, with the left most as the top user. By ordering the delay cost of the top 40 users based on their number of operations, it can be observed that the distribution is right-skewed. That is, the tail on the right side of the distribution is longer than the left side and the bulk of the values lie to the left of the mean. The individual delay cost values for the top 40 users revealed that low-medium priority flights belonging to the top user (SWA) absorbed between 2 to 4 minutes more than lower-medium priority flights from other users. Given that the top user accounts for 10% of the participant flights, the extra delay absorption was consistent with the principle of proportional fairness[17] present in the credit points concept. Unfortunately, the accumulated extra delay increases the delay cost for the user substantially. Therefore, it is very likely that the top user will switch back to the baseline option in an attempt to increase the utility. This is the situation modeled by the opt-out case.

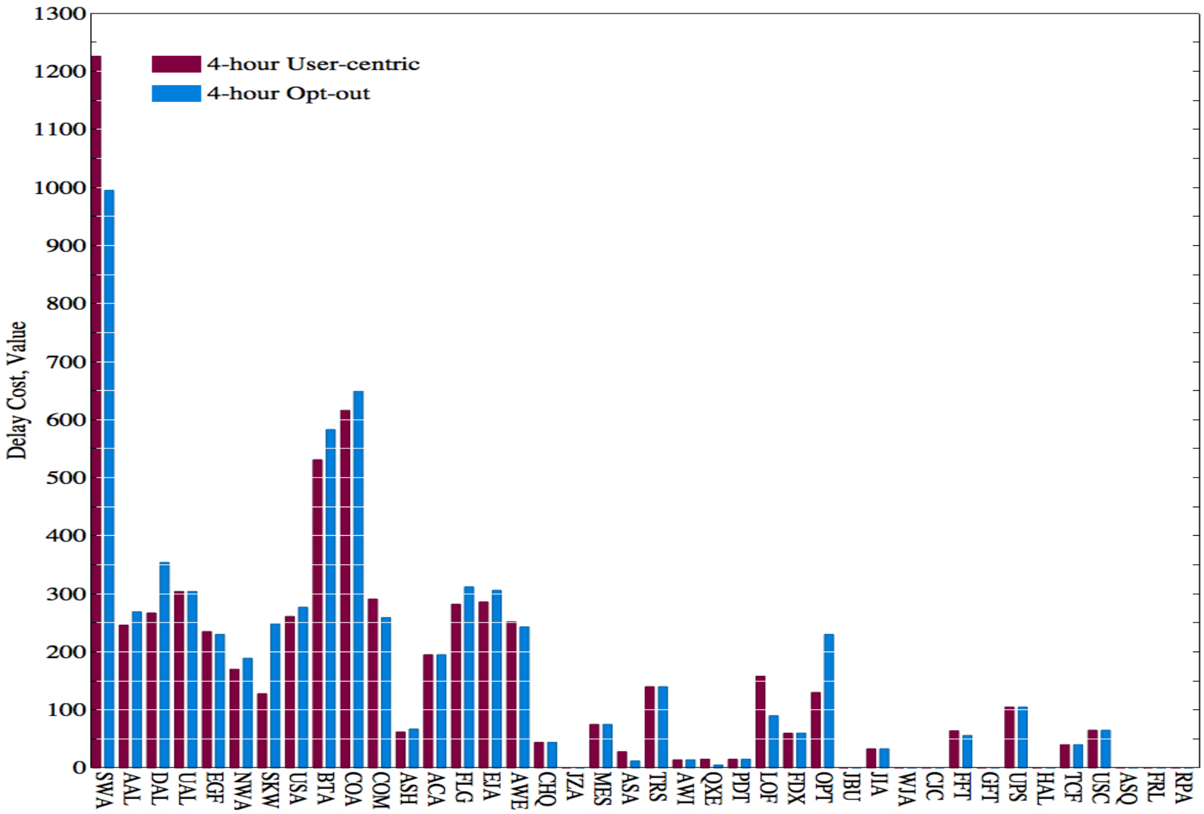


Figure 1. Individual delay cost values ordered by number of operations for the top 40 users in the user-centric and opt-out cases for a four-hour planning interval.

Figure 2 shows the delay distribution for the top 40 users in lexicographical order for both the user-centric case (light blue bars) and the opt-out case (maroon bars). It can be seen that by switching back to the baseline option, the total delay of the top user (SWA) was reduced substantially. In addition, the redistribution of the delay difference was well distributed among the remaining top 39 users.

V.A. Impact of Planning Interval on the Utility of Users

Given that the traffic data is four hours long, the four-hour planning interval represents the scenario where the service provider has complete knowledge of the users' preferences, possible NAS constraints, absolute control over all scheduled flights, and total awareness of airborne flights (international flights entering the US). This scenario is used to obtain a lower bound on the system delay. In contrast, the one-hour planning interval represents the scenario where the knowledge of the users' preferences, possible NAS constraints and airborne flights are revealed every hour to the service provider. Given that all resource capacity constraints are strictly satisfied, the service provider is forced to make conservative and short term decisions in the one-hour planning interval. Due to the partial knowledge and the scheduling decisions made in the past, these decisions may restrict the throughput of the NAS. The two-hour planning interval, used in current day operations, represents an acceptable compromise between the previous planning intervals.

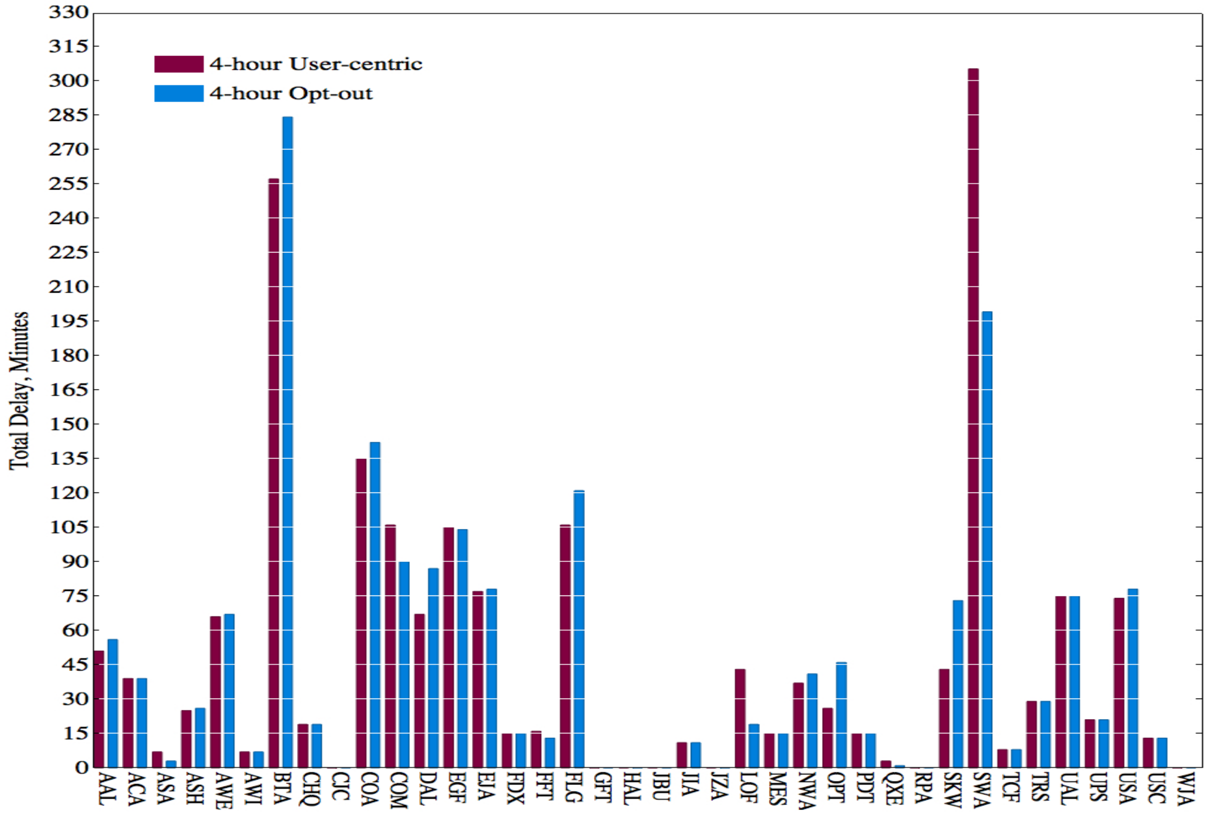


Figure 2. Delay distribution for the top 40 users, lexicographically ordered, in the user-centric and opt-out cases for a four-hour planning interval.

Table 2 shows the comparison of planning interval variations for the user-centric case. The top 40 participant users were grouped in the top 40 category, while all general aviation users were aggregated in the GA category. All remaining users were lumped together in the other category. Then, for each planning interval, the total delay, maximum delay and total utility were calculated for each user category. Finally, the total is simply the aggregated value of the user categories.

Table 2. Impact of planning interval on delay metrics and utilities for the participating users (Top 40), the general aviation users (GA) and the remaining non-participant users (Other) in the user-centric case.

Users	**1-hour Interval**			**2-hour Interval**			**4-hour Interval**		
	Total Delay	Max Delay	Total Utility	Total Delay	Max Delay	Total Utility	Total Delay	Max Delay	Total Utility
Top 40	1750	30	5203	1604	30	7117	1816	41	3612
GA	720	50	725	566	30	1695	119	20	1205
Other	270	35	-25	278	29	135	154	28	900
Total	2740	50	5903	2448	30	8947	2089	41	5717

Intuitively, the system delay should go down as the planning interval increases from one to four hours. This intuition is confirmed by observing a 11% reduction in delay when switching from the one-hour to the two-hour planning interval, and another 15% delay reduction when switching to the four-hour planning interval. However, system delay reduction does not imply overall delay reduction, as the total and maximum delay for the top 40 users peak in the four-hour planning interval. This can be explained by looking at the individual delay distribution of the top 40 users in Figure 3. For each of the top 40 users three bars are shown. The left bar in gray is the total delay for the user in the one-hour planning interval. Similarly, the middle bar in light blue and the right bar in maroon are the delays for the two-hour planning interval and four-hour planning interval, respectively. It can be seen that two users (BTA and FLG) accumulated a large delay in the four-hour planning interval in comparison with the other planning intervals.

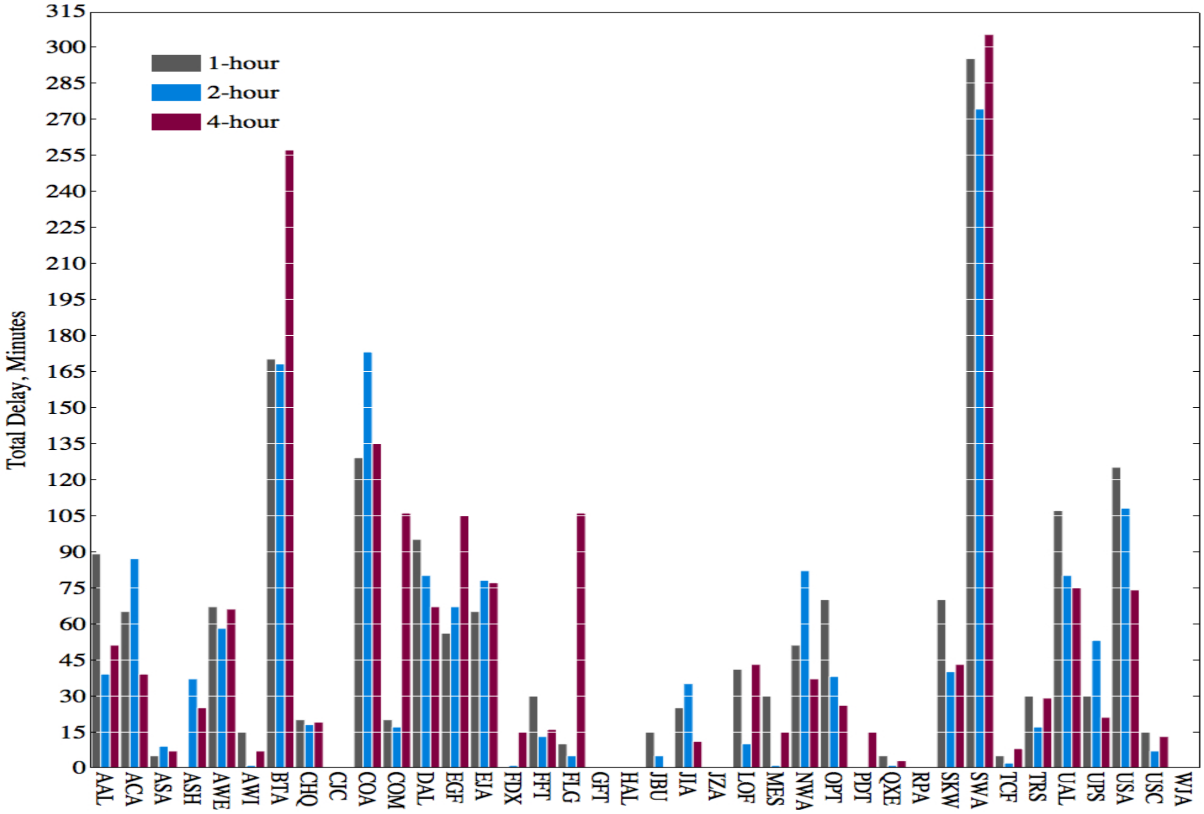


Figure 3. Distribution of delays for the top 40 users in the user-centric case for different planning intervals.

In order to unravel the origin of these delays, the delays for the top 40 users in the user-centric case with four-hour planning interval were plotted as a function of the assigned credits to individual flights in Figure 4. Each marker represents several flights. The number of flights for each marker is as follows. The four colored markers of light blue, light pink, pink and salmon represent 1-5, 6-10, 11-20 and more than 20 flights, respectively. It can be seen that several non-important flights (11 out of 444 from BTA and 9 out of 264 from FLG) were submitted with either two or three credits to the service provider and as a result, they were given at least 15 minutes of system-imposed departure delay. In the other planning intervals, most of these low priority flights were able to depart with less than 10 minutes of system-imposed departure delay due to the lack of NAS constraints knowledge and flights planned for the next one-hour or two-hour planning interval. Given that constraints must be strictly satisfied, the departure of these low priority flights force the service provider to give system-imposed departure delays to later flights, which may not be all low priority. Therefore, allowing for low priority flights to leave in short planning horizons may decrease the utilities of the users.

The two-hour planning interval has a total utility of 8,947, whereas the one-hour planning interval has a utility of 5,903. The two-hour planning interval improves by 52% the utility of the one-hour planning interval. Similarly, the two-hour planning interval improves the utility of the four-hour planning interval by 57%. To understand how this substantial improvement is achieved, Table 3 shows the utility statistics for he top 40 users. The minimum value represents the smallest utility, the lower quartile represents the lowest 25% of the utility values, the median divides the utility values in half, the upper quartile represents the highest 25% of the utility values and the maximum value represents the highest utility value. A negative utility implies that at least one user either accumulated more delay than the assigned delay in the baseline case, or had the same accumulated delay with a higher delay cost than the delay cost of the baseline case. The minimum values are of the former situation; whereas the latter can be observed in the negative total utility of other users in the one-hour planning interval in Table 2. The high utility numbers in the upper quartile and the median of the two-hour planning interval indicate that most of the users' delays were assigned to low priority flights,

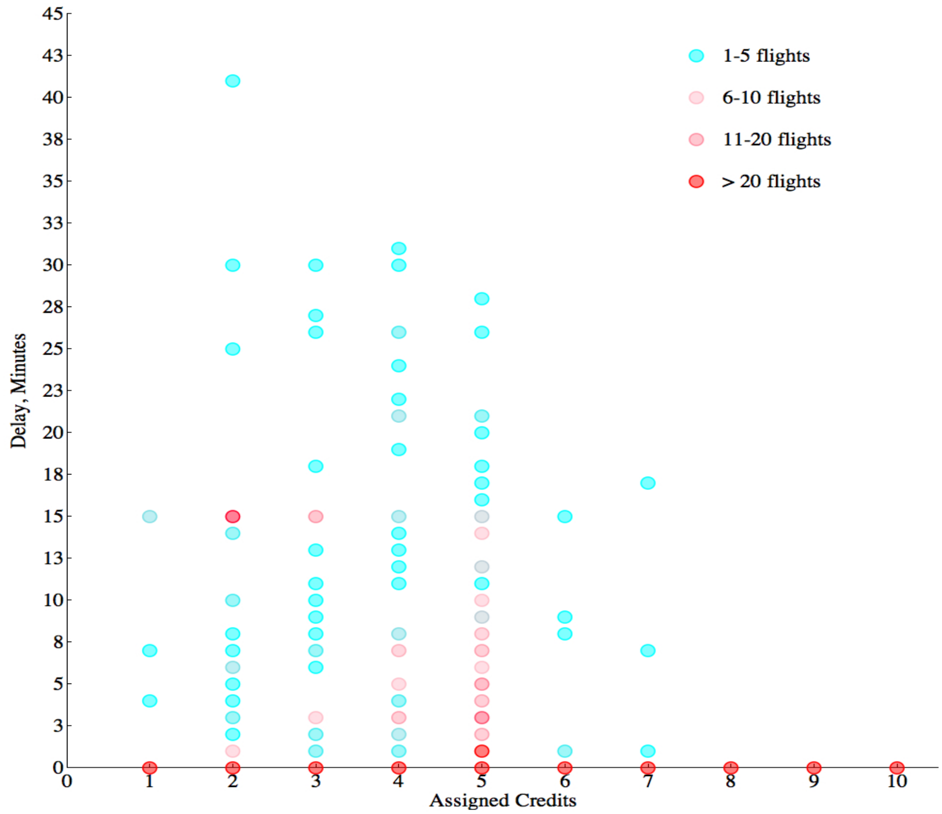


Figure 4. Credit-delay distribution for the top 40 users in the user-centric case using the four-hour planning interval.

some of which were able to depart within the two-hour planning interval, but were held on the ground in the four-hour planning interval. That is, a shorter planning interval reduces system-imposed departure delays to low priority flights without a substantial impact on the equity, due to the partial knowledge of future NAS constraints and flights.

Table 3. Comparison of the utility statistics for the top 40 users in the user-centric case for different planning intervals.

Interval	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
1-hour	−115	0.0	57.5	178.25	1034
2-hour	−148	18.25	93.5	251.25	1300
4-hour	−182	−3.75	12.5	127.25	740

V.B. The Value and Impact of User Participation

The equity-utility trade-off may affect the user's decision to participate in the credit point concept. In order to analyze the impact of user participation, a value of participation, $VoP(s)$, for user, s, is defined as the relative difference between the individual utility obtained from participating in the credit points concept, $U(s)$, and the utility received as a result of taking the baseline option, $B(s)$, assuming that all others users continue to participate, as follows:

$$VoP(s) = \begin{cases} -B(s) & \text{if } U(s) = 0 \\ \frac{U(s)-B(s)}{U(s)} & \text{Otherwise} \end{cases} \tag{4}$$

Note that the value of participation is a positive number when the user either gains utility by participating or loses utility by not participating. Similarly, the value of participation is a negative number in exactly the opposite situations. In addition, the value of participation is zero only if the user is insensitive to any variation. Obviously, the value of participation is dependent on non-deterministic factors outside of the user's control such as the impact of the decisions made by other users, and the selection of system parameter values made by the service provider, such as planning interval, system-imposed delay, type and level of equity in the schedule allocation. However, it is a useful construct to measure the impact of withdrawing or joining participants on the individual utility of users. For example, the value of participation for each of the top 40 users was used to determine the stability of the user-centric, and opt-out cases with a four-hour planning interval. Table 4 shows the value of participation statistics for the user-centric, and opt-out cases for a four-hour planning interval. The value of participation of the top user (SWA) in the user-centric case was the minimum, and only negative value of -1.41. The opt-out case was considered as a direct consequence of the negative value of participation obtained by the top user in the user-centric case. By switching to the baseline option, the value of participation for the top user became the positive value of 0.97, while the remaining 39 users maintained a non-negative value of participation. Therefore, the user-centric case with a four-hour planning interval is considered to be unstable, because it evolves to the opt-out case due to the negative value of participation of the top user. In contrast, the opt-out case with a four-hour planning interval is considered stable due to the non-negative values of participation of the top 40 users.

Table 4. The value of participation statistics for the top 40 users in the user-centric, and Opt-out cases for a four-hour planning interval.

Simulation Case	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
4-hour User-centric	-1.41	0	0.76	1	3.22
4-hour Opt-out	0	0	0.47	1	3.22

From the service provider point of view, parameters such as the planning interval and the system-imposed delay value can be used as incentives for user collaboration. By modifying these parameters as a response to a user participation withdrawal, the service provider can push the value of participation values from participant users towards the non-negative range. Given that users always try to increase their utility, parameter tuning may even stimulate users to participate again in the collaborative initiative. However, parameter tuning has to be done sporadically because parameter changes produce a short period of instability in the system that may discourage user participation. In order to determine when is it cost-effective to modify the planning interval, the user-centric case with varying planning intervals and four levels of user participation were simulated.

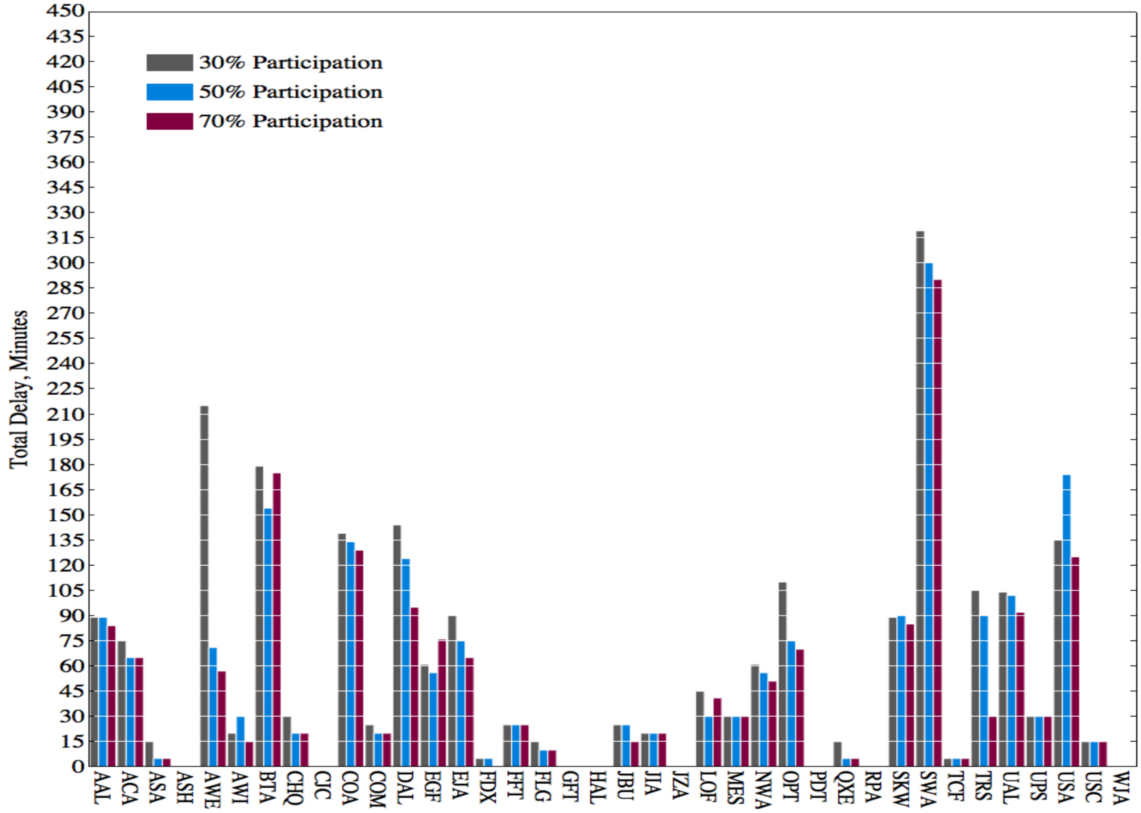
Table 5. Impact of user participation percentage on the delay metrics and utilities for the top 40 users (top 40), the general aviation users (GA) and the remaining non-participant users (Other) in the user-centric case using a one-hour planning interval (1-hour), two-hour planning interval (2-hour) and four-hour planning interval (4-hour).

Participation:	**100%**		**70%**		**50%**		**30%**	
Interval, Users	Total Delay	Total Utility	Total Delay	Total Utility	Total Delay	Total Utility	Total Delay	Total Utility
1-hour, Top 40	1750	5203	1745	5223	1930	4266	2235	2746
1-hour, GA	720	725	765	500	855	50	1015	-750
1-hour, Other	270	-25	275	-50	300	-175	280	-75
1-hour Total	2740	5903	2785	5673	3085	4141	3530	1921
2-hour, Top 40	1604	7117	2473	3954	2568	3835	2630	1632
2-hour, GA	566	1695	825	400	805	500	880	125
2-hour, Other	278	135	305	0	300	25	355	-250
2-hour Total	2448	8947	3603	4354	3673	4360	3865	1507
4-hour, Top 40	1816	3612	1826	3542	1898	3215	1942	2733
4-hour, GA	119	1205	126	1170	158	1010	167	965
4-hour, Other	154	900	154	900	155	895	196	690
4-hour Total	2089	5717	2106	5612	2211	5120	2305	4388

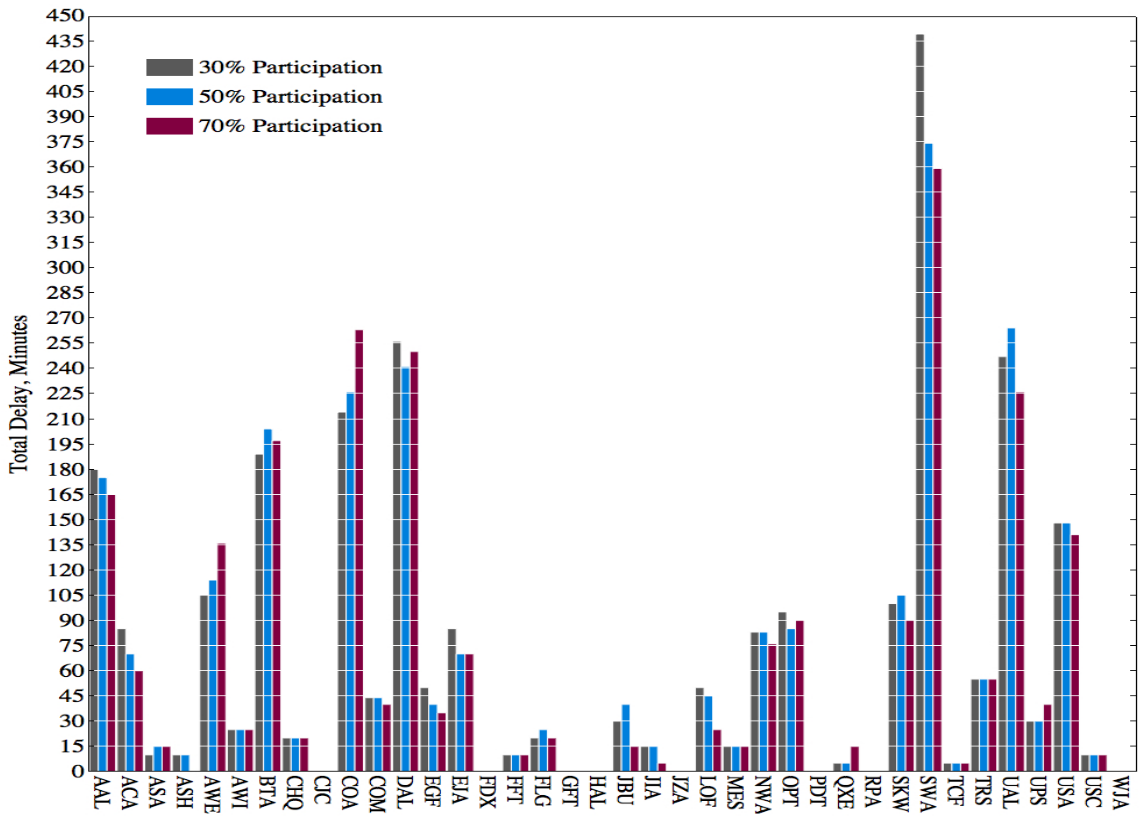
Table 5 shows the comparison of the total delay and utility values for the user-centric case with 100%, 70%, 50% and 30% user participation for the one-hour, two-hour and four-hour planning intervals. The top 40 users were ordered by their number of operations and then divided in four groups. The first group contained the top 12 users, which were assumed to always be participants. The second group included the top 13-20 users and the third group contained the top 21-28 users. Finally, the fourth group included the top 28-40 users. To simulate a seventy percent participation, users from the fourth group were switched to the baseline option. Similarly for a fifty percent participation, users belonging to the third and fourth groups were switched to the baseline option. For the final thirty percent participation, only the top 12 users were considered as participants.

Based on the data shown in Table 5, the two-hour planning interval has the best overall delay-utility ratio (blue numbers in the 100% participation column), but it also seems to be very sensitive to user participation. A thirty percent reduction in participation leads to a 51% utility reduction (from 8,947 to 4,354) and a 47% delay increase (from 2,448 to 3,603 minutes). Therefore, the service provider has the option to switch to either a one-hour or four-hour planning interval (maroon and green numbers in the 70% participation column, respectively). By switching to a four-hour planing interval, the service provider can reduce the total delay in the system from 3,603 to 2,106 minutes. However, this delay reduction is achieved at the expense of the top 28 users' utilities, which may cause a further drop of participation. If the service provider switches to a one-hour interval instead, the sudden boost of the top 40 user utilities from 3,954 to 5,223 may stimulate users to participate again. As soon as the drop in participation reaches the fifty percent threshold, the service provider is better off by switching permanently to a four-hour planning interval, where the overall delay is lower than the one-hour and two-hour planning intervals (maroon numbers in the 50% and 30% participation columns).

In addition, Figure 5 shows the individual delay distributions of different user participation cases with a one-hour planning interval in the top part and a two-hour planning interval in the bottom part of the figure. Three bars are shown for each of the top 40 users in both top and bottom graphs. The left bar in gray is the delay for the user in case of 30% participation. Similarly, the middle bar in light blue and the right bar in maroon show the delay for the 50% and 70% participation, respectively.



(a) one-hour planning interval delay distribution



(b) two-hour planning interval delay distribution

Figure 5. Individual delay distribution for varying user participation of the top 40 users for a one-hour and two-hour planning intervals.

VI. Concluding Remarks

The factors of user participation and planning interval were studied for incorporating users' preferences in air traffic management. Four different simulation cases were used. User utility and value of participation were used to gauge user satisfaction and simulate the case stability of the opt-out case, respectively. Finally, the impact of planning interval modification on the users' utility was analyzed. The study demonstrated that the integration of user's preferences in the flight scheduling process generates a trade-off between equity of the delay distribution and users' preference satisfaction. This can be extended to say that global delay minimization is not inherently equitable from the user's point of view. A second finding was that the two-hour planning interval seems to have the best delay-utility performance for the top 40 users and the general aviation users. This result seems to indicate that some degree of uncertainty (as in the two-hour case) is helpful in the search for a successful compromise between delay distribution equity, users' utility, and system stability. Finally, results indicate that the issue of participation is complex. Users may collaborate intermittently based on their own expectations and utility values. Therefore, a possible direction for future research includes an in-depth analysis and formalization of the credit points concept using a game theoretical framework.

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