Incorporating User Preferences in Collaborative Traffic Flow Management

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This paper presents a preferred route selection method that includes a concept of credit points for improving collaboration between participants in Traffic Flow Management. The notion of expending credit points by users to prioritize their flights is considered for selecting alternate flight routes. Starting with a simple scenario containing a few flights, the paper presents four route selection modes for each flight, a sequential approach and aggressive, moderate and conservative user behaviors. Flights were simulated based on selected routes, with an automated system monitoring airspace constraints. With the current fidelity of the experiments, adopting a moderate or conservative approach appears to provide more benefit than being an aggressive user when all flights depart at the same time. Additionally, two different traffic scenario data (current and three times the current traffic) were used in the dynamic case to assess the utility of such a concept with time-varying schedules. Results indicate that the current implementation with moderate user behavior handles these traffic scenarios in a reasonable time and satisfies the airspace constraints.

I. Introduction

THE National Airspace System (NAS) in the United States has been witnessing increasing delays due to severe weather and high traffic volume for the past six years,[1] and it is expected to get worse in the next couple of decades. Commercial users of the NAS are sustaining increased delays, which translate to higher costs and passenger dissatisfaction. To reduce delays, improvement is needed in the interaction between the FAA and the airspace users[2] in terms of common constraint identification and impact assessment. Flow planning by the users is difficult due to the lack of a mechanism for filing route options for their flights.[3] Insufficient collaboration in the Traffic Flow Management (TFM) area translates into additional delays and increased workload for operators.

About ten years ago, the FAA and the users (e.g., airlines, cargo operators, general aviation, etc.) collectively formed the Collaborative Decision-Making (CDM) group. This group and the corresponding CDM process are in charge of improving the Collaborative Traffic Flow Management (CTFM) in airspace operations. There have been many operational improvements due to contributions from this group. The Future Concepts Team (FCT) is a subgroup of CDM and is working on collaboration that can be accomplished in the near and far term future.[4] This subgroup focuses on two main issues of integrated collaborative routing and a system-wide concept to enhance electronic negotiation between the participants. The former addresses aspects of sharing constraint identification and impact assessment along with route availability for users during situations where the traffic flow is constrained due to events like severe weather and traffic congestion, while minimizing impact on FAA operators. The latter provides the basis for enhanced communication automation. The FCT is investigating how users can use automation to better identify and negotiate optimal routes for their flights, and is currently investigating how the interaction with the FAA can be improved by providing priorities of their individual flights. Along with the studies of the FCT, other research includes aspects of routing of aircraft around convective weather cells,[5,6] reduction in capacity of regions of airspace due to severe weather,[6-8] and assigning slots for arrival/departure aircraft for an airport metering fix.[9] Each of these studies point towards a need for optional routes for users to improve operations; however, methods to

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evaluate several routes and assess their impact on operations and system performance, while incorporating user preferences, have been limited in scope.[10]

A baseline concept of operations has been developed at NASA Ames Research Center for enhancing the collaboration between the FAA and airspace users.[2] The baseline concept outlines four primary steps in the collaboration process: constraint identification, impact assessment, flow planning and flight implementation. A recent study conducted the task analysis for feasibility of this baseline concept. [11] The current research addresses the flow planning aspect of collaboration. To strengthen the idea of users providing priorities of individual flights, a concept of using credit points is developed, which would help the FAA use the information for constraint management. It is assumed that users would have sufficient fidelity to specify their priorities of each route preference on a scale of zero to ten credits. Based on this scale, the users have five credits per flight on an average to specify their preferences. Thus, the users are allotted total credit points equaling five times their operations for each day. In this concept, the users specify between zero and ten credit points to each of the several route options to describe the importance of each flight flying on those particular routes. These credit points for each flight are then ranked in the evaluation process to assign a route to each flight and are decremented from the total allotted to the user. This provides a basis to assess performance of the system for different flight route prioritization schemes through different user behaviors. The present study considers only pre-departure flights; however, it can be extended to en route cases. As a first step, this study does not address trajectory uncertainties or the uncertainties of departure time delays, inaccurate weather forecasts or controller action during in-flight re-routes. [12]

The paper first describes a realistic simulation environment available for studying the flight paths of aircraft along prospective available routes in Section II. The overall process of flight route allocation for potential application by users is presented in Section III. The concept of credit points, how they are earned and expended by users are also defined there. Section IV describes the experiment design, along with several route selection modes and performance metrics for the two (static and dynamic) cases used. Preliminary results of the route allocation process for the two cases are shown in Section V, and a discussion of the advantages and limitations of this concept are presented in Section VI. Conclusions based on current work are presented at the end in Section VII.

II. Simulation Environment

To assess the use of optional routes with credit points, the Future ATM Concepts Evaluation Tool (FACET)[13] was used. FACET is a modeling and analysis system developed to explore advanced ATM concepts. It handles traffic information at various spatial levels in the NAS, from the Air Route Traffic Control Center, the sub-regions called Sectors, to the modeling of individual aircraft trajectories. FACET can be used as a playback, simulation or real-time data analysis system. The playback mode provides the user a capability to understand how the air traffic evolved on a past day by replaying prerecorded data from that day. The simulation mode allows the user to take initial conditions from a certain time and evolve the air traffic based on available intent, consisting of flight plans that provide origin, destination, route of flight, aircraft type, cruise speed, cruise altitude and take-off time. FACET uses aircraft performance tables with the equations of motion while incorporating winds aloft from the Rapid Update Cycle forecast model. FACET utilizes the FAA's Enhanced Traffic Management System[14] (ETMS) provided air traffic data. Figure 1 shows a snapshot of FACET with six highlighted routes (in blue) for aircraft (yellow triangles) traveling between Los Angeles International (LAX) airport and Boston Logan International (BOS) airport.

Using the simulation capabilities of FACET, aircraft were flown along assigned routes and at each minute, the sector congestion (where the number of aircraft in a sector are above a threshold value) or airspace impacted by weather was obtained. For this study, the National Weather Service published NEXRAD product was used to identify convective weather regions. FACET assesses the airspace constraint information by overlapping the convective weather cells on sectors and identifying those as sectors with a reduced capacity to handle aircraft. This reduced capacity is used to reassign flights on alternate routes. The next section describes this allocation process using a system of credit points.

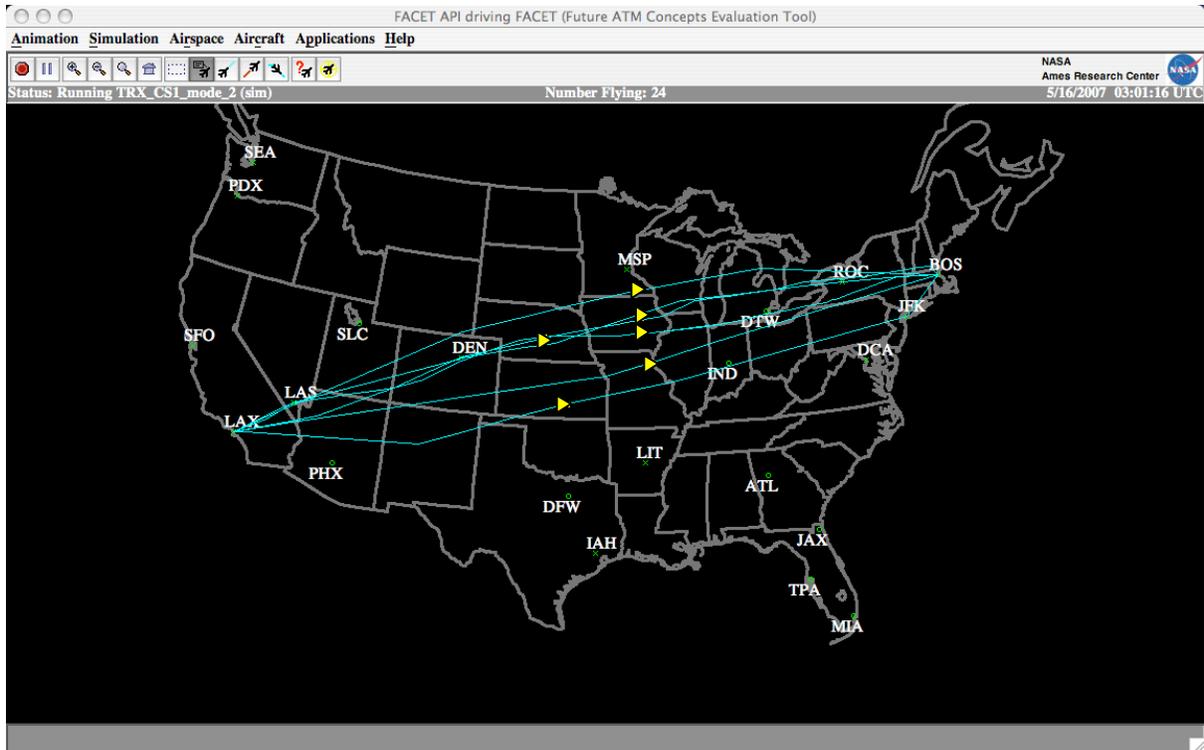American Institute of Aeronautics and Astronautics

Figure 1. Simulation of flight route preferences for flights between LAX and BOS in FACET. The triangles show aircraft and blue lines show their route options.

III. Flight Route Allocation Process

The route allocation process is described in this Section. Figure 2 provides a schematic of the flow of information. In the beginning, several flights belonging to multiple users are scheduled, assigned credit points (described below) and flown along a specific route in FACET. FACET evaluates the congestion (or constraints, like existence of weather) information at every minute. All sectors are evaluated for congestion, i.e., number of aircraft higher than the nominal capacity (e.g., monitor alert parameter or MAP, as defined by the FAA) or presence of weather in a sector, in which case the capacity of the sector is reduced to 70% of MAP. There is other ongoing research to determine the reduction in capacity due to existence of weather,[15] but since that is in progress, the capacity is reduced by a fixed number of 70%. Since this study only considers pre-departure flights, if a sector capacity is violated then the flights are reallocated on different routes, rather than considering the option of in-flight rerouting. It should be noted that only the number of flights that are in excess of available capacity are considered for route modification. The excess flights are the flights with lowest credit points from a credit-based ranking of flights passing through that sector at that time. This method differs from the current operations where the flights are assigned slots on a first come first served basis (where user preference is not explicitly accounted for), whereas this method gives a preference to higher credit point flights. Once the excess flights have been reallocated to alternate routes (from a predefined list generated for this research and in an automated manner), another run is executed to compute sector counts and the next iteration is performed. This process continues until convergence is achieved when all flights are assigned routes for reaching their destination such that no constraint is violated. In this process, convergence is guaranteed since a flight is cancelled in the static case (described in section IV.A1) after delaying four 15-minute blocks. In the dynamic case (described in IV.A2) with time varying and realistic schedules, convergence is not a problem and flights are simply delayed in 15-minute blocks. At the end, metrics are computed and computation time is recorded.

A concept of credit points is used for this research during the reallocation process. The idea is to incorporate users' preferences and intent during the pre-departure route filing process. The users, at the beginning, are assigned a fixed number of credits based on the size of their operations. In this research, the total number of credits allotted to each user is five times their number of operations in a day and expire at the end of each day. The number of allotted

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credits, as well as duration of validity of credits, could be varied to study other operational and economic implications of this concept. For the concept proposed here, the users typically expend between zero to ten credits based on the importance of each flight, to be used for each route of each flight. Even though there are ten maximum credit points assigned by any user in this research, the method does not have that as a limitation. Whichever route the user is assigned, the corresponding number of credits is decremented from the user's total credits. This scheme implies that if a user with only two flights files a certain route with eight credits for one flight, the second flight for the same user will have a maximum of two credits to file for all routes. Alternatively, if a user does not get the first choice route, the difference in the number of credits (if any) between the assigned route and the first choice route are available to the user to use with other flight routes. This process impresses upon the user to be cautious about assigning credits to routes based on their genuine need. Since this process of reallocation is completely automated by the service provider, each user should not have concerns about other users getting a competitive advantage. The concept of credits for each route is used here, in contrast to simply prioritizing flights to improve predictability of the system (because the exact assigned route is known) and users' preferences (because only the users have information on criticality of flights). It is granted that currently the concept has limited advantage of predictability since it does not account for uncertainties faced after departure.

IV. Experiment Design

A. Experimental Cases

This section describes the cases studied and the corresponding scenarios, the route selection modes for users and the metrics computed for performance comparison of various runs.

In this study, all the flights are considered for the allocation process before they depart from the origin airport. There are two cases considered. First is a static case, created to understand various user behaviors and the flexibility of the credit-based concept for a worst-case traffic scenario. In the static case, all the flights depart at the same time from a list of origin airports to all the other airports in the list. The second is a dynamic case where an actual day's data were used. The static case examines how well the concept handles unrealistically heavy traffic, whereas the dynamic case examines realistic traffic and schedules.

1. Static Case

The static case with non-varying departure schedules, is implemented to understand abstraction of the route reallocation process employing the credit point concept for a worst-case scenario consisting of an unrealistic number of flights. To understand this, each experiment was started with twenty-four flights, all departing at the same time. A dozen flights going from Los Angeles International (LAX) airport to Boston Logan International (BOS) airport and the other half going from BOS to LAX. Among the twelve flights considered each way, there are three flights each for four (airline) users, called ALA, ALB, ALC and ALD. For a scenario with a fixed number of flights, the number of available routes was fixed at three or six (shown in Fig. 1) between each origin and destination for the reported experiments (but is not a limitation of the method). The flights also have their number of credits to expend assigned for the corresponding route before departure. In this case of six flights (three flights each way), each of the four users get 6*5, or 30, credit points allotted initially. It should be noted that users assign credits for each route of each flight, and not just for each flight. The latter would mimic a priority for each flight without regard to importance of the route of flight. For this static case, the credits were assigned manually (in the absence of real users providing this data) by ranking the (three or six) route choices based on FACET computed fuel consumption for each origin-destination pair. The three route choices were assigned 7, 4 and 1 credit points, respectively, whereas the six route options were assigned 7, 7, 4, 4, 1 and 1, respectively. It is acknowledged that optimal assignment of credits is a research issue; however, in the future it should be provided by an automated process accounting for more complex user preferences through a flight planning system. For this research, all flights going from the same origin to the same destination, file the same flight plan to initialize the reallocation process.

As the flights are flown in the simulation, there may be constrained sectors that are at, say, 90% of their capacity (referred to as the constraints in Fig. 2) and the excess flights (from 91 to 100%) are drawn into the reallocation process. The excess flights, picked from the bottom of the list after sorting for credits specified, have their flight plans modified based on one of the four selection modes (described in the next subsection IV.B). For a particular scenario, the selection mode is held constant throughout the run. It should be noted that if a flight exhausts all the route options or if a user keeps insisting on a particular route, after four iterations, it is given a 15-minute delay; and after one-hour of delay, it is removed from the simulation as if it was cancelled. Also, as a measure of goodwill, if a flight is delayed 15 minutes, it is awarded one credit point back. Using this process, the largest static case studied for this research consisted of six flights for eight users each (instead of four mentioned above) and 20 origin-destination

pairs (instead of one mentioned above). This scenario has 48 flights (8 users times 6 flights/user) going from each origin to the 19 other airports and in opposite direction, consisting a total of 1920 flights departing simultaneously at the beginning. This makes it an academic example and considered the worst-case scenario for this research. Table 1 shows the various scenarios considered for this study and which figures show individual results.

Table 1: Various scenarios used with the number of routes, users, origin-destination pairs, resulting number of flights and where the results are provided.

Routes (R)	Flights/User/OD (F)	Users (U)	Origin-Destination Pair (OD)	Total flights (N=U*OD*2*F)	Results
3	3	4	1	24	Fig. 4
6	3	4	1	24	Fig. 5
3	3	4	12	288	Fig. 6
3	3	8	1	48	Fig. 7
3	6	8	20	1920	Section V.A

2. Dynamic Case

The dynamic case demonstrates the ability of this credit-based concept to handle actual traffic schedules. The experiment starts with Enhanced Traffic Management System (ETMS) data for August 24, 2005. A list of top 20 airports and three alternate routes were created for each of the 20*19 origin-destination (OD) pairs. (Note that the flight routes from origin airport (e.g., SFO) to destination airport (e.g., JFK) are usually not the same as the reverse routes to fly from origin JFK to destination SFO due to winds, etc.) For this dynamic case, the credits were assigned by computing the origin-destination distance. Depending on each OD pair flight distance (greater than 2000 nm, between 1000 and 2000 nm and less than 1000 nm), the first route choice was assigned either 7, 4 or 1 credit points e.g., LAX-BOS (>2000 nm) =7 credits, LAX-DFW=4 credits and LAX-SFO (<1000 nm) =1 credit (see Fig. 1 for airport locations). The credit points are assigned based on distance, because it is presumed that longer distance flights would be more important for users in general. For the dynamic case, the top ten (airline) users are considered participants in this credit point reallocation and collaboration process. In the beginning and at each subsequent instant in time, the selected OD pair flights for the ten users are flown along the route choice. All the other (non-selected-OD pair) flights for all users are simulated along their nominal flight plans with five credits, since that's what each user is assigned initially for each flight. If at any instant either sector congestion (number of aircraft greater than monitor alert parameter) or a sector impacted by weather (where the capacity is reduced to 70% of MAP) is encountered by a flight, then it is considered for reallocation if the number of credits used for that route are lower compared to other flights in that sector.

To study the feasibility of this concept of credit points for incorporating user preferences in a future traffic environment, a three times (3X) the current traffic (1X) scenario was used as initial data, instead of the August 24, 2005 data. The method developed in Ref. 16 is used for this research where the FAA-provided airport growth rates were extrapolated to generate a three times the current traffic data. The same process described above for current traffic scenario is employed to study the utility of credit points based reallocation of flight routes.

One exception in the dynamic case (both 1X and 3X) is that the flights are not cancelled but are allowed to delay in 15-minute blocks for as long as it takes for a convergent solution. In the static case, due to the exceedingly large number of flights, the computation time would increase enormously if flights are not cancelled; however, in the dynamic case with a reasonable departure schedules, computation time is not an issue. The results for these cases are described in section V.B.

B. Route Selection Modes

Once the scenario is developed, the users that are required to modify their flight routes employ one of the four selection modes in the static case. These are a sequential mode and three behavioral modes. In each of these modes, the number of flights with the origin-destination (OD) pair and the number of route options specified remain the same, and the credits assigned by users to each flight route varies. The first route selection mode is the sequential mode. In this mode all the flights, when apportioned for reallocating the flight route, go to the next route in the list of available options with the corresponding number of credits (nominally, 7 for route 1, 4 for route 2 and 1 for route 3), until all route options are exhausted. The next behavioral mode implements strategies based on the user being aggressive, moderate or conservative.[10] An aggressive user insists on the same first route and files it again with the same number of credits. It is presumed that the aggressive user is willing to take a 15-minute delay to get the first choice route. The moderate user goes to the next route in the list of available options with four credits (similar to the

sequential mode). The conservative user, on the other hand, immediately goes to the last route and is charged one credit point. For the behavioral mode, four users are considered. These are named ALA, ALB and ALC, which are always modeled as aggressive (A), moderate (M) and conservative (C), respectively, while ALD takes each of these roles (A, M, C) in the three runs. As the reallocation process continues, the system-level manager continues to assess routes based on these selection modes and to evaluate constraints.

Based on lessons learned from the static case results, for the dynamic cases, each user was considered to be a moderate or conservative behavior user who chooses to go to the next route option for the reallocation process. Although it is pedantic to assume that each user would demonstrate the same behavior for all its (critical and not-so-critical) flights, this study was limited in this regard.

C. Performance Metrics

For the static and dynamic cases, the amount of time utilized for computation is recorded for a convergent solution. This is helpful from the air traffic service provider's perspective, since it provides an estimate of time taken for the planning interval of the route filing decision process. It is also beneficial to compare strategies from a user's perspective in terms of the delay specified to each flight along with the fuel consumed on the granted routes compared to the first choice route. Thus, total delay is the additional time taken to fly on the assigned route along with a sum of the fifteen-minute blocks of delay assigned. The number of credits expended by each user provides a metric for the users to assess their operations for the period of the scenario. Future research will explore whether this system of credits can help define optimal solutions for the user and the FAA, since it is a common parameter to monitor.

V. Results

A. Static Case

For all the static case results presented, modes 1 through 4 refer to the sequential, and three behavioral route selection modes with airlines ALA, ALB, ALC as aggressive, moderate and conservative, respectively; and airline ALD cycling through aggressive, moderate and conservative behaviors in three runs, respectively. Figure 3 shows the computation time needed for convergence as a function of the number of origin-destination (OD) pairs when three versus six route options (R) are available and three versus six flights per user per OD pair (F) are considered in the reallocation process. In the case of 8 users, the additional users, ALE, ALF, ALG and ALH, follow behavior of the first four users in the same order. Therefore, ALD and ALH are the users that cycle through the A, M and C behavioral modes. The use of additional four users tests the flexibility of this concept to more users. As expected, the computational time is higher as more iterations are needed to converge for larger number of flights and OD pairs. However, the time needed for larger number of flights (R3F6) is more than the time needed for increased number of route options (R6F3) as the number of users is doubled from four to eight in the 20 OD pairs case. This is because the R6 case tends to spread flights out (in turn better utilizing the airspace) and reduce congestion. Each of these times are for a total of three runs; initial checking of constraints, reallocation process and final run for verification of allotment and metric computation (with all sectors at full capacity). It should be noted that the case with three route options (R3) and three flights per user per OD pair (F3) with one OD pair consisting of 24 flights represents the nominal traffic load situation in individual sectors of current day.

To describe the details for individual flights at convergence, results are presented in Figs. 4 through 6. The top left (a), top right (b), bottom left (c) and bottom right (d) images of each figure show, (a) the number of credits left over, (b) accumulated delay in minutes, (c) additional fuel consumed in pounds with respect to the first choice route and (d) final number of flights on non-nominal (not first choice) route, respectively. In each of those images, results are presented for four runs for each user ALA, ALB, ALC and ALD. The four runs correspond to the four selection modes. The first considers each user subscribing to sequential mode (Seq-dark blue in Figs. 4 through 8). The second through fourth runs have ALA as aggressive (A), ALB as moderate (M), ALC as conservative (C) and ALD cycles through A (AMCA-light blue), M (AMCM-yellow) and C (AMCC-red) behaviors, as described in the legend. Fig. 4 shows histograms of the case with one OD pair, four users, three route options and three flights/user/OD pair (24 flights in all, described in row 1 of Table 1). Fig. 5 shows the results for the same case as Fig. 4 but with six route options (second row of Table 1). To contrast the results for a larger number of OD pairs, Fig. 6 shows same case as in Fig. 4 but with twelve OD pairs (three flights/user/OD pair, four users and 12 OD pairs both ways give 288 flights, mentioned in row 3 of Table 1). Taking a look at four colors for ALD in Fig. 4b, one sees that user ALD incurs more delays compared to the other three users whether it selects sequential (dark blue), aggressive (light blue), moderate (yellow) or conservative (red) behavior. However, in this very small scenario, ALD accumulates more delay when it's moderate, while ALA, ALB and ALC are aggressive, moderate and conservative, respectively.
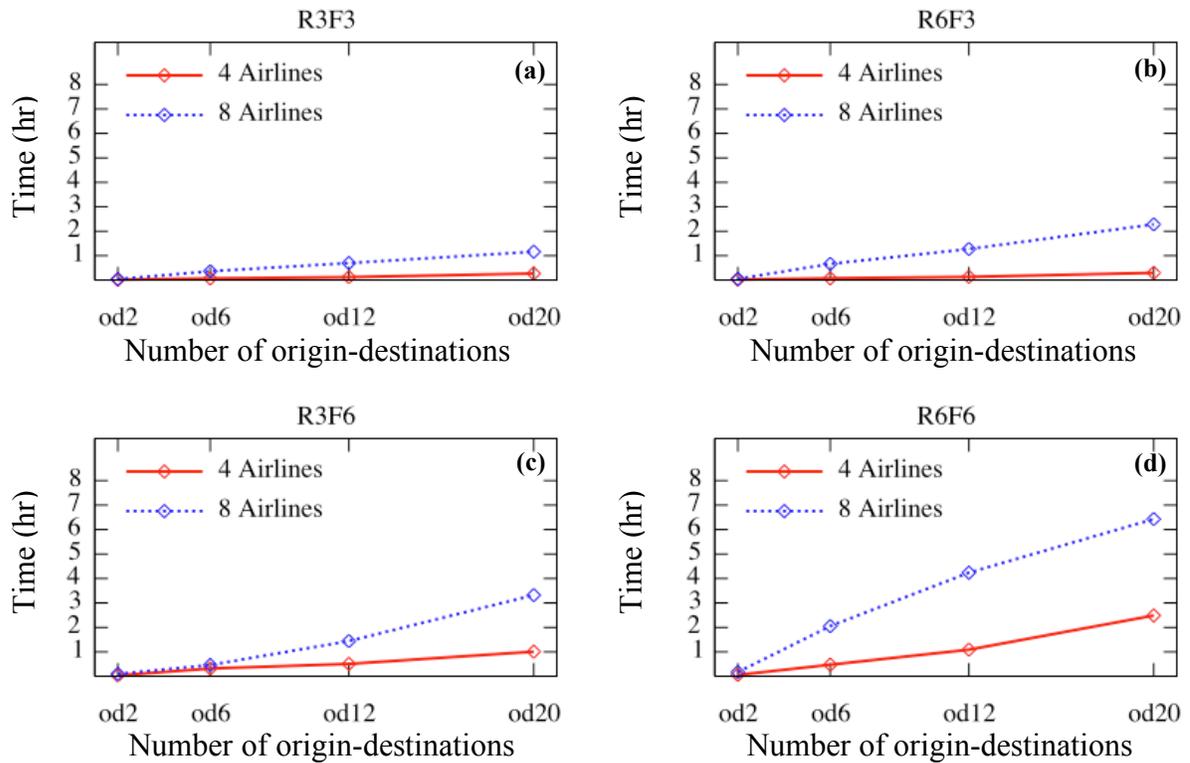
Figure 3. Computational time needed for convergence as a function of origin-destination (OD) pairs for four and eight users with (a) 3 route options (R) and three (F) flights per user per OD pair, (b) 6 R and 3 F, (c) 3 R and 6 F, and (d) 6 R and 6 F scenarios.
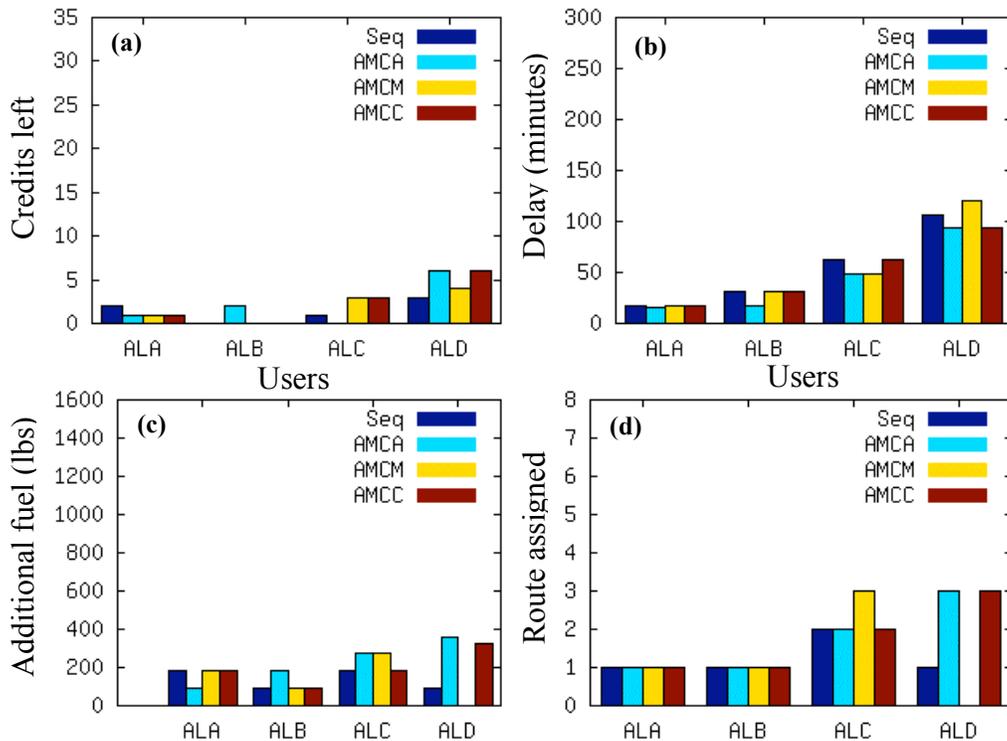

Figure 4. Number of credits remaining (a), delay (b), additional fuel (c) and allocated route (d) shown for one OD pair, four users with three route options and 24 flights in all employing the four selection modes.
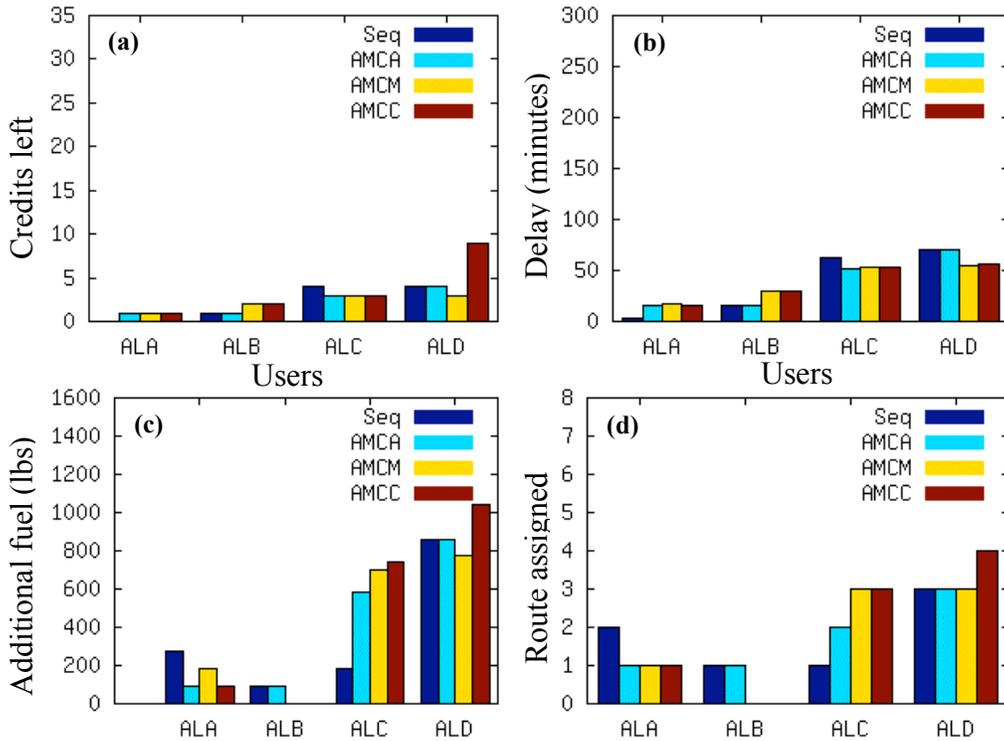
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Figure 5. Number of credits remaining (a), delay (b), additional fuel (c) and allocated route (d) shown for one OD pair, four users with six route options and 24 flights in all employing the four selection modes.
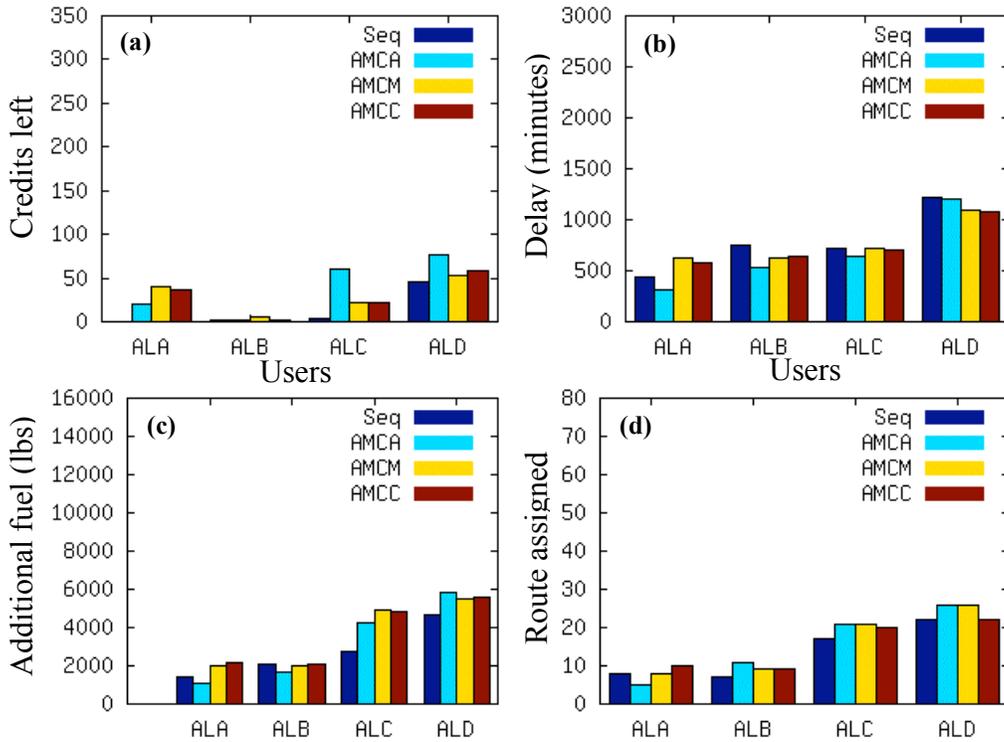

Figure 6. Number of credits remaining (a), delay (b), additional fuel (c) and allocated route (d) shown for twelve OD pairs, four users with three route options and 288 flights in all employing the four selection modes.
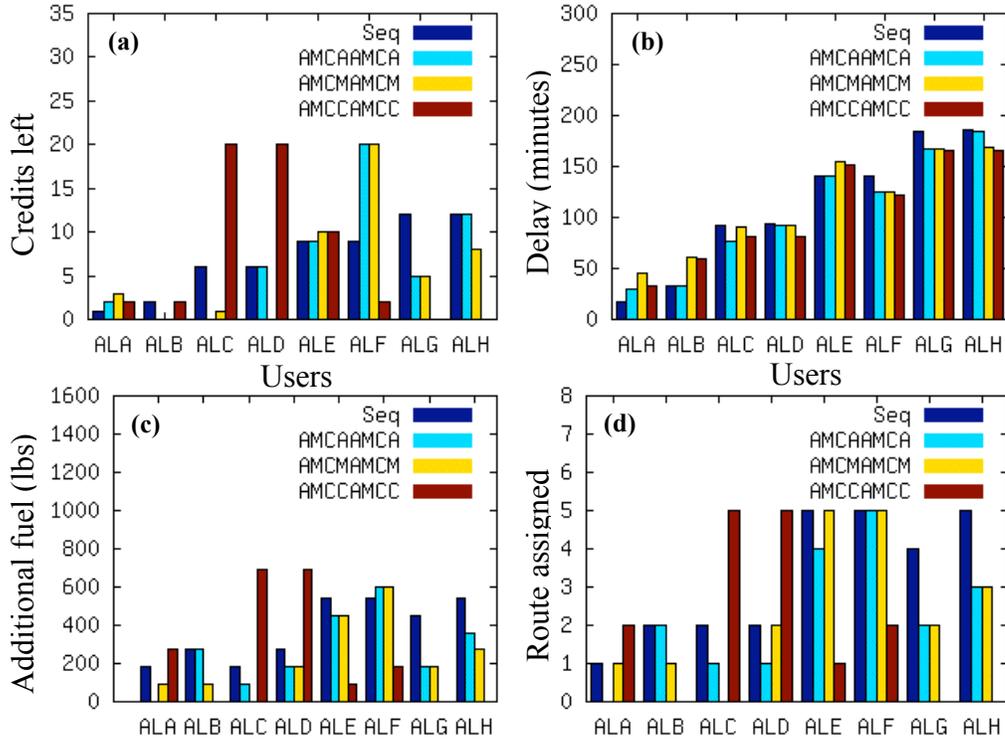
Figure 7. Number of credits remaining (a), delay (b), additional fuel (c) and allocated route (d) shown for one OD pair, eight users with three route options and 48 flights in all employing the four selection modes.

On the other hand, looking at Fig. 4d and Fig. 4c, ALD was allotted the first choice routes and so did not incur any additional fuel consumption when it was moderate. It had three flights from LAX to JFK (as shown in Fig. 1) and three flights from JFK to LAX, and it had 6*5 or 30 credits assigned initially, and from Fig. 4a it is seen that ALD still has three credits left over (yellow).

Fig. 5 shows similar results as in Fig. 4 but for twice the number of route options for the same number of flights. Now observing Fig. 5b, one sees that being moderate (yellow) for ALD gives lesser delay compared to all other behaviors when more route options are available. It also has lesser fuel difference (Fig. 5c) and same number or more flights compared to other behaviors on the preferred route choice. The number of credits left over is less than in other modes though, which in general is better. Unless it is known from predicted data that there would be severe weather in the latter part of the day, or there are critical flights for individual users later in the day, it does not make sense for users to save up on credits as they expire at the end of the day. Fig. 6 shows these results for a larger case of 288 flights with twelve OD pairs (described in fourth row of Table 1). Increasing the number of airports does not seem to vary the observed behavior significantly, and being moderate or conservative is better than aggressive for ALD, which is similar to the finding in Ref. 10. The computation time for this case was less than 10 minutes (Fig. 3). Also, observing ALB from all three Figs. 4, 5 and 6 and ALF from Fig. 6, who demonstrate moderate behavior, perform well overall except when others are being aggressive. Another interesting feature was that, in all the cases shown here in the three figures, none of the users had any flights cancelled. It was recorded during the runs that once the number of flights exceeded approximately 300, the number of cancellations grew. In the worst-case and unrealistic scenario of 1920 flights with three route options, about 58% of the flights were cancelled but with six route options (more spreading of demand), about 35% of the flights were cancelled. This behavior is anticipated, since these academic scenarios are being run with today's sector capacity parameters. However, the reallocation method captures the large demand presented to it. It was also a starting point to investigate whether this credit point concept is viable for actual data and how it would work with a futuristic air traffic scenario.

B. Dynamic Case

To understand how the credit points based concept functions with real data, the dynamic case is employed. One day's worth of actual traffic data were used for August 24, 2005 in this dynamic case. As opposed to the static case, where all the flights take off at the same time, the scheduled departure times were obtained from the ETMS data and

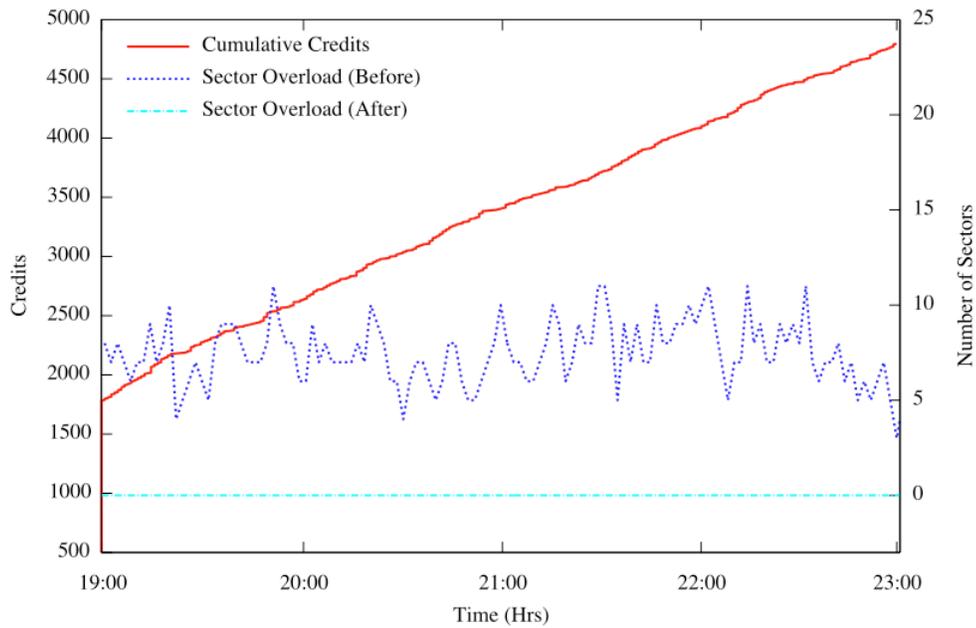American Institute of Aeronautics and Astronautics

Figure 8. Number of credits used and number of congested sectors as a function of time. Note that none of the sectors are congested after the reallocation process is complete.
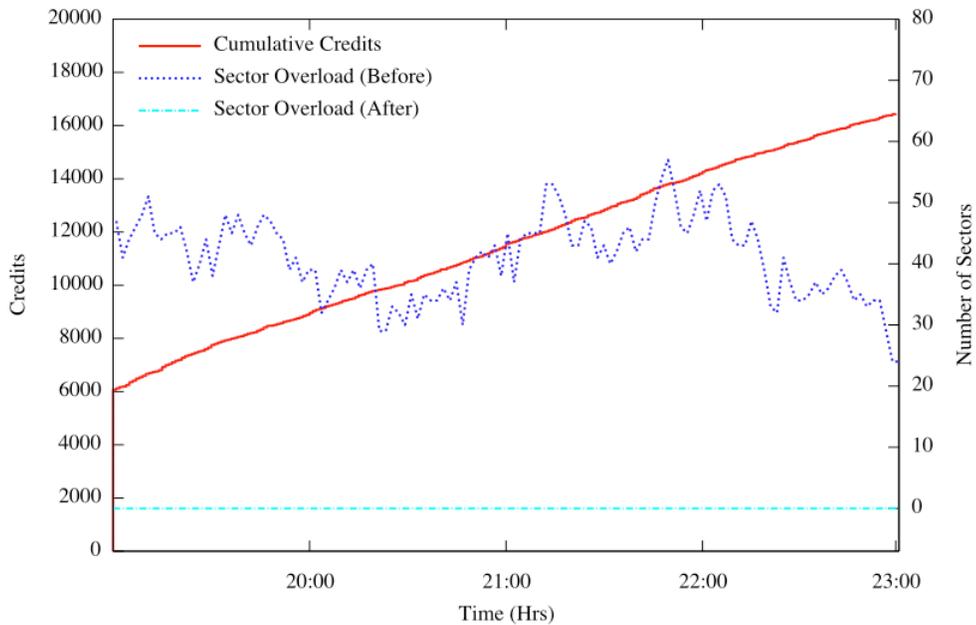

Figure 9. Number of credits used and number of congested sectors as a function of time. Note that none of the sectors are congested after the reallocation process is complete.

used in FACET for the dynamic case. The flights for ten (airline) users were then flown and constraints evaluated with each user getting three route options on pre-selected airports (20 OD pairs) with largest flight operations. For sector volume congestion, the FAA-provided monitor alert parameter (MAP) values were used for each sector and only traffic above 18,000 ft was considered. In order to check for weather-impacted sectors, the NEXRAD weather

data were used. The NEXRAD data were synchronized in FACET and MAP values of any sectors were reduced to 70% of the nominal value if and when weather was present in those sectors. With these constraints, the reallocation process was conducted as described in section III, with each of the users demonstrating moderate behavior. For the period of 19 through 23 UTC (3 through 7 pm EDT), the statistics for each of the ten users were computed. The results for one user with 865 flights are shown in Fig. 8. It should be noted that for all sectors at 100% capacity case, none of the users had any delays and the additional fuel consumed was negligible. Thus, by equitably and predictably distributing flights on available routes, this concept resolves flight routing issues and sector overload by better utilizing available capacity. For the same case but with weather impacting a number of sectors, four out of the ten users had less than 0.5% of their flights delayed by not more than 30 minutes.

To test out this concept of credit points for a future environment with three times the current traffic scenario, the traffic data for such a set[16] were used in FACET with the MAP values doubled, i.e., the airspace capacity was assumed to be twice as much as the current capacity. The number of flights considered was 44,472, and the ten users combined have 16,415 flights with five users accounting for more than 2,000 flights each. As mentioned earlier in the 1X case, all the background traffic not belonging to the participants and not in the pre-selected OD pair list flew with five credits each. Also, at the beginning of simulation, the flights that were en route were allowed to fly without reallocation (with ten credits), since this concept is only applied to pre-departure flights. For the same period as in Fig. 8 (19 through 23 UTC) and for the same user considered in Fig. 8 (now with 2969 flights), the number of credits used and impacted sectors are presented in Fig. 9. Similar to the current traffic scenario results presented in Fig. 8, the three times current traffic scenario handles sector volume congestion and sector weather impact well with the current credit points concept. Each user had less than 1% of flights that were delayed. As can be seen, the mechanism of route reallocation with credit points is able to handle the schedules and sector impact for large scenarios extremely well.

VI. Discussion

The first drawback in the current approach is that this method involves additional workload for dispatchers at Airline Operations Centers or other users' sites due to the credit assignment as the initial condition, but in the future that could be accomplished through additional automation in the flight planning systems. In the present version for the dynamic cases, a set of routes had to be generated *a priori* for a selected set of origin-destination pairs. That would be additional work for the dispatchers during filing of flight routes; however, even the current day flight planning systems have a large number of alternate routes database available. In the dynamic cases, due to the diversity of traffic and users, the background traffic was not properly accounted for but was observed to absorb more delay compared to participants in the process. While this is inappropriate, it would encourage users to participate in the concept, keeping in accordance with the Collaborative Decision-Making (CDM) philosophy.

Three other important issues of implementation are encountered during this study. First, the results are based on the manual credit assignment by researchers and do not necessarily reflect the user preferences. In the future, it is planned to conduct human-in-the-loop simulations with experts to alleviate this concern. Second, users would generally not behave in the same manner all the time, i.e., being aggressive or conservative for all their flights. This could smear the understanding gained from the static case scenarios; however, this behavior also can be captured during expert simulations. The last issue discovered during this research is that a negotiation process, to provide additional flexibility, would make this concept more acceptable by the users. A simple hierarchical rule-based negotiation process has already been developed. It is being tested and will be the topic of next report.

On the other hand, the benefits indicate that the credit-based concept seems to handle large cases well. Based on the observed performance, it tends to better utilize the capacity (under nominal and off-nominal conditions), provide limited but enhanced predictability (known pre-departure takeoff times and overall schedules, no tactical reroutes, and better resource assessment for service provider), a measure of performance for the users (number of credits expended versus amount of delay, choice of assigned route versus first choice and additional fuel consumed) and lower air traffic service provider workload (low or no overloaded sectors). It is also scalable to larger number of users and larger number of origin-destination airport pairs, as would be required for nationwide use.

VII. Conclusions

The air traffic management system can significantly benefit from collaboration between users of airspace (airlines, general aviation, etc.) and the FAA. Over the years as traffic increased, it has been identified that during traffic constraining events, a common assessment of the system constraints between users and the FAA, and specifying multiple flight route options, would be beneficial. This study presents a method of assessing the performance of the system when such user route preferences are incorporated in operations with a credit point

assignment mechanism under different route selection mode in worst-case traffic (static) and actual traffic (dynamic) cases. This research concludes that allowing users to present several pre-departure route options to a system-level automation, along with specification of number of credits for each route option of each flight can help improve management of airspace and traffic during constrained operation times. A worst-case traffic scenario tested the flexibility of the concept with a large number of flights and assessed user behaviors (e.g., aggressive, moderate and conservative). Demonstrating moderate or conservative behavior was better than being aggressive. A real traffic scenario was used to study whether the concept can manage airspace congestion and weather impact. The concept of credit points and the route allocation process handled all the airspace constraints completely with little or no delay for participating users. This method also contributes towards better predictability of the system (not accounting for post-departure uncertainties), provides users with a measure of their performance (number of credits expended with choice of routes made available), and helps the airspace provider with a means to assess resource requirements (airspace constraints evaluation).

Acknowledgments

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