

Simulations of Credits Concept with User Input for Collaborative Air Traffic Management

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This paper describes the procedure and outcome of a human-in-the-loop simulation experiment. The purpose of the simulation was to study feasibility of incorporating user flight preferences in air traffic demand and capacity management. Five airline dispatchers specified flight priorities for multiple routes. These priorities were used for airspace constraint management by creating a new credit ranked flight departure schedule. One air traffic manager prescribed and managed the airspace constraints. The dispatchers were trained on the system using different traffic scenarios. A realistic data set with convective weather was used for generating final results. Based on the experiment results, the credits concept allowed users to prioritize their flights and to distribute delays as per their preference. It was also observed that the delays could be reduced and better distributed among users with respect to a first-come-first served schedule, without violating airspace constraints. The study elicited several factors for prioritizing flights from the users' perspective, which could be used in future fast-time simulations.

I. Introduction

IN current air traffic operations, it is difficult for users of airspace (e.g. airlines, cargo operators, General Aviation, Etc.) to convey their flight planning preferences. This is due to unavailability of electronic data exchange and negotiation mechanisms. In general, the FAA or the air traffic management community does not know these preferences due to their proprietary nature. During times of congestion and airport constraints, traffic managers often impose changes to flight plans which do not incorporate users' preferences.^{1,2}

The FAA is working with the users to develop technology and new software that would allow users to provide their preferences of flight priority, routes and schedule. One of the technologies allows users to specify alternate route options in addition to the primary route used in current operations. Automation supported by the FAA would evaluate how each of the route options satisfy local airspace and airport capacity constraints.³ This technology would provide flexibility for users to fly their planes based on their individual business models. However, this approach solves the problem in a small region of airspace but may create congestion elsewhere. It could lead to additional constraints, which may be difficult to manage.⁴ In addition, market-based approaches have been studied to explore the incorporation of user preferences. In Ref. 5, optimization of a market mechanism is studied for airlines competing for airspace resources and an equilibrium solution is investigated. Ball, et al.⁶ present the need for including user priorities in an efficient future air traffic management system. The unavailability of user preferences is a significant obstacle in computing equitable schedules for the current air traffic system.^{7,8}

This paper presents the process and results of human-in-the-loop simulations to incorporate user preferences in pre-departure flight planning. The experiments were conducted at NASA Ames Research Center during Jan. 26-28, 2010. The participants were certified dispatchers working at major airlines. The experiments utilized a flight prioritization scheme for multiple routes. The credits-based concept used for prioritization was proposed in Refs. 9,10. Various scenarios were presented to dispatchers who provided a number of credits (a measure of importance of

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their flights), which were used pre-departure to schedule and route their flights. Metrics of delay, fuel consumption, credit balance, and equity were computed.

In Section II, the credits concept is described. The air traffic data used and the scenarios used to elicit dispatcher input are described in Section III. The roles and responsibilities of the air traffic management coordinator and the flight dispatcher are presented there as well. The metrics and results are presented in Sections V and VI, respectively. The paper ends with a few concluding remarks. The questionnaire presented to each participant in the experiments is included in the Appendix.

II. Credits Concept and Simulation Architecture

In order to analyze the feasibility and benefits of the credits concept, a new software architecture was developed. The Future ATM Concepts Evaluation Tool (FACET) software,¹¹ developed at NASA Ames Research Center, was used as the National Airspace System (NAS) simulation environment. Utilizing the FACET Application Programming Interface¹², a client-server architecture called the equitable Credit-based User Preference System (e-CUPS) was developed for conducting the experiments. The credits concept, FACET and e-CUPS are described next.

A. Credits Concept

Credits¹⁰ are a form of artificial currency and are used for specifying users' flight planning preferences. The purpose is to incorporate users' flight priorities, multiple route options, cruise altitude, and departure time during the pre-departure route filing process. The concept could be applied in a 15-minute, two-hour or day long traffic scenario. At the beginning of each planning scenario, the users are provided a fixed number of credits based on the size of their operations. The credits expire at the end of each scenario. The total number of credits allocated for each user is five times the number of flights planned to depart during the scenario. There is not a limit on the number of credits a user can assign to a given flight other than the airline's available credit balance. Each user ranks flights using his or her own utility function. The user utility function could depend on flight distance, number of passengers, type of aircraft, load factor, crew connection, etc. Users are allowed to assign different credit values across several route choices for a given flight.

Once the users assign credits for each route choice of each flight, the credits and routes are submitted to an automated server. Presumably, this server would reside with the FAA or an impartial entity. The server simulation process flies all flights from origin to destination and identifies regions of excess demand over capacity. Wherever there is excess demand, say in a sector, a credit ranking of all flights using that sector is done. The sector is utilized to capacity by the higher credit flights. The lowest credit flights over capacity are assigned their next route preference, and the entire simulation is run again. If no additional route options are available for any flight, it is held on the ground at the origin airport by a fixed amount of time (typically, 15 minutes). The credits corresponding to the granted route are decremented from the user's total allocation of credits. This iterative process is continued until there are no regions with excess demand. The credit assignments of each user are submitted to the server process and are not known to other users.

B. NAS Simulation Environment

FACET is a nation-wide air traffic simulation environment. Airport and airspace capacity constraints can be simulated for thousands of aircraft flying in the NAS. The capacities of airspace sectors and airport arrival/departure rates are obtained from the FAA's Enhanced Traffic Management System (ETMS)¹³. Aircraft can be simulated flying through (if permissible) or around the constraints. Pre-departure, the aircraft are rerouted if alternate routes are available. The flights can also be rerouted in the air or delays can be imposed on the ground by delaying a flight's departure time. A snapshot of FACET's display is shown in Fig. 1 with air traffic, convective weather and some special user airspaces.

C. Client-Server Architecture

The equitable Credit-based User Preference System (e-CUPS) architecture is designed as a client/server application, which is built on an asynchronous messaging framework. The server is able to support dozens of clients. The clients only connect to a single server. In general, the system is event-driven with clients responding to

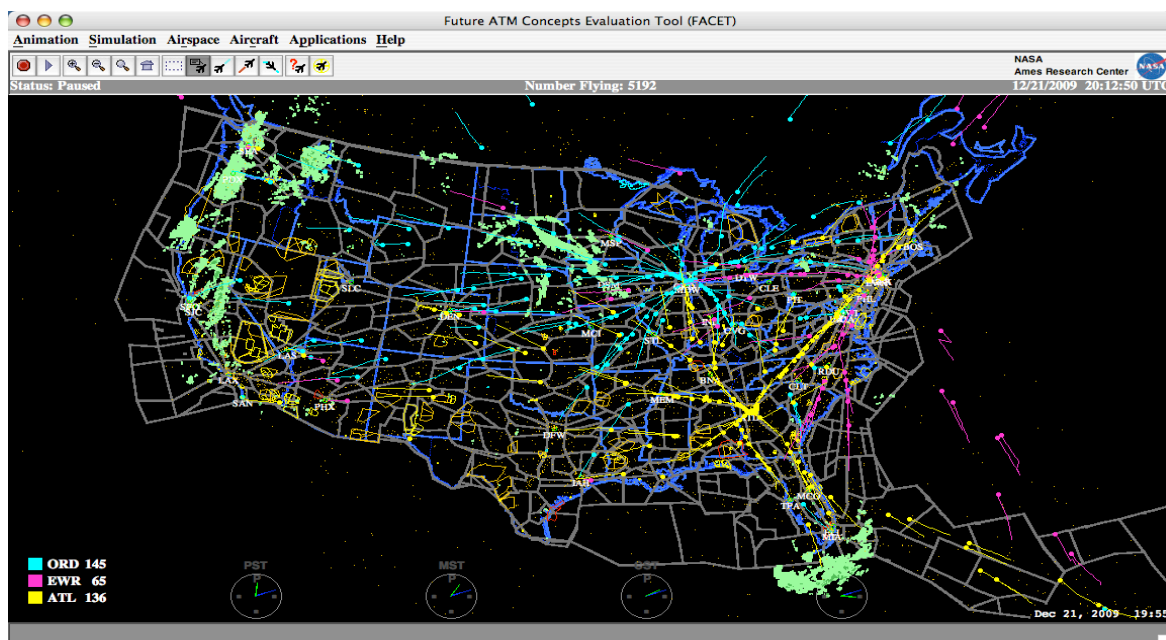


Figure 1. A snapshot of FACET simulation environment.

events generated by the server and the server reacting asynchronously to responses from clients. The client and server are both Java applications using a Swing user interface. All clients and the server embed their own distinct copy of FACET. The clients use FACET to plan routes between origin/destination airport pairs, to provide the server with a set of optional routes that it can consider when scheduling a flight, and to specify their priorities using credits. The server uses FACET to determine which flights are scheduled to depart during a scenario, as well as any sector and airport constraints that may lead to delays.

Additionally, all clients and the server are backed by a MySQL database, which is used to retrieve alternative routes for various origin/destination airport pairs and to store all the metrics that get captured during the simulation. The metrics data are read and processed post execution to study the user's performance and the overall behavior of the system.

III. Scenario and Experiment Description

This section describes the air traffic data and the scenarios presented to the participants for conducting the simulation experiments. The experiment scenarios with number of flights and the associated constraints are presented first. The roles and responsibilities of the traffic manager and the dispatchers are described next.

A. Scenarios

Air traffic data from Aug. 24, 2005 was obtained from ETMS and simulated in FACET. Heavy traffic volume during the hours of 3 to 7 pm Eastern Daylight Time (EDT) was used to create the experiment scenarios. A traffic scenario consisted of one through four 15-minute periods. In each scenario, the number of participating users and number of flights per user per period were varied. As shown in Table 1, five different air traffic scenarios were created based on number of flights for the top five users in the NAS. These scenarios were derived from the baseline Aug. 24, 2005 traffic data by selecting the corresponding number of total flights (last column in Table 1.)

Table 1. Description of air traffic scenarios.

Scenario number	Periods	Users	Flights per User per Period	Total flights
1	1	5	2	10
2	2	5	4	40
3	4	5	5	100
4	4	5	114, 105, 86, 159, 66	530
5	4	63 (5 participating)	Varying, with flights in air at start and including background traffic	3026

B. Experiment Runs

Scenarios 1 through 3 were used to familiarize the users with the communication interfaces and displays for preference submission. Scenarios 4 through 5 were used to conduct the experiments, as described in Table 2 below. The constraints imposed on all airspace sectors are shown as Sector capacities (column 2). For scenarios 1 through 4, the constraints were imposed on all sectors. For example, in scenario 4, only 30% of sector nominal capacities were allowed. The last scenario (number 5) contained flights in the air at the beginning and sector constraints were imposed based on presence of weather. In that scenario, only sectors with any weather present had their capacity reduced to 60% of the nominal value. In future, the sector capacities would be incorporated from other weather translation models available in literature.⁴ The number of credits made available were based on the number of departures in each 15-minute period or in lump-sum at the beginning. Lastly, the departure delay imposed on flights was either 5- or 15-minutes, as shown in the last column of Table 2.

Table 2. Description of experiment runs.

Experiment	Scenario	Sector capacities	Credits availability	Delay imposed
1	1	100%	Each period	15 minutes
2	2	100%	Each period	15 minutes
3	3	15%	Each period	15 minutes
4	3	15%	Entire scenario	15 minutes
5	3	15%	Each period	5 minutes
6	4	30%	Each period	15 minutes
7	5	60%	Each period	15 minutes

The experiments did not additionally constrain airport arrival and departure rates. Therefore, the users had reduced capacity airspace sectors but 100% of nominal airport capacities. Another limitation of the experiments was the absence of uncertainty in weather data. The experiments were run with actual weather as it occurred on that day. Uncertainty plays a key role in flight route decision-making. However, for the current simulations, the goal was to assess the feasibility of the credits concept and to elicit user preferences. Handling of uncertainty was considered beyond the scope of these experiments. Additional simulations are planned in which weather forecasts will be included, instead of the current weather data.

C. Roles and Responsibilities of Participants

NASA researchers developed the traffic scenarios. They provided the traffic manager with a set of sector capacities to apply so that the dispatchers had increasing workload as experiments progressed. For example, for scenario 3, capacities of 10%, 15% and 20% were suggested, with the proposed impact on traffic and dispatcher workload. The air traffic manager was responsible for selecting airspace capacities from this set and specifying to the dispatchers. The final selected values are shown under ‘Sector capacities’ column in Table 2. In the future, these capacities would be suggested to the manager from weather translation models⁴. The manager presented the traffic scenarios, and imposed delay parameters, as shown in the last column of Table 2. He also decided on when to start and end each period of each scenario. The display used by the manager is shown in Fig. 2. The upper panel (under “Session Configuration Parameters”) has comments for the scenario and database file names. The periods are shown

in the bottom table (under “Period Configuration Parameters”) with period times, total number of departures and corresponding number of flights. It also provides delays in previous periods and causes for those delays.

Session Configuration Parameters

Session ID: _____

SCREENSHOT

Session TRX File: /cupscot-0.9.5/cupscot/server/src/test/resources/TRX_scenario5_5

Session Comment: SCREENSHOT

When done, evaluate this session against these previous sessions: _____

Period Configuration Parameters

airport departure: 100% airport arrival: 100% Edit Sector Capacities

Periods:

Departure Window	Departures	Flights	Delays	Deferrals	Congestion Del...	Airport Delays	State
18:59 UTC to 19:14 UTC	264	1,843	0	0	0	0	closed
19:14 UTC to 19:29 UTC	316	1,796	0	0	0	0	closed
19:29 UTC to 19:44 UTC	288	1,855	-	-	-	-	opened
19:44 UTC to 19:59 UTC	297	0	-	-	-	-	planned
19:59 UTC to 20:14 UTC	18	0	-	-	-	-	planned

New Period Close Period Start Session End Session

☐ enable automatic close of period Delay (seconds): 3

Figure 2. The traffic manager user interfaces for flights and constraint management.

The dispatchers, on the other hand, were responsible for filing flight plans and corresponding credits for all their flights. A scenario consisted of several periods of 15 minutes each. The dispatchers worked on a number of flights departing during each period. They had to account for location of congestion and number of credits to assign for each flight (and possibly, each optional route of each flight) for maximum throughput and minimum delay.

The displays used by the dispatchers are shown in Figs. 3 and 4 (below). The top graphic in Fig. 3 shows the details for all the periods, including the current period (with the “Submission Window Opened” displayed) shown with a blue box. The first two periods are closed and the user was able to fly all of their flights with no delays, as shown by the orange dashed box. The opening balance (number of credits available for each user) and credits charged in the previous two periods is shown. The credit balance for the current period is presented at the top right (140, in this case). The particular user shown (DAL, in this case) has 28 departures in this period, shown above the blue box in the center. This display shows an overview of most relevant information about all the flights handled by the dispatcher in this scenario.

The bottom graphic in Fig. 3 shows details of flights departing in the current period. The dispatcher had to provide their priorities through the assignment of credits for these flights. The user has 140 credits available and if the default assignments using a distance-based utility function were chosen, the dispatcher would use up 136 credits for the flights. By double-clicking any row corresponding to a flight, the user was able to view additional details of that flight, in a new pop-up window shown in Fig. 4. If the user checks the box on left of flight id, the user knows that that flight is expected to encounter congestion in the airspace. The user may then either increase the number of credits assigned to that flight or may provide additional route options until the submission window is “Closed.”

The top graphic in Fig. 4 shows flight plan details for a single and selected flight (blue in bottom graphic of Fig. 3). This graphic allowed the dispatchers to modify the route options filed for this flight, the number of credits assigned, departure time, and the cruising altitude, shown within the purple box. The ability to select alternate routes from a database (“Alternate Routes...” button) or to create new routes (by typing in the text field at the bottom) is available in this graphical interface. The users also had the ability to view the database routes or newly created routes by selecting the corresponding check box (under ‘Show’), displayed within the green dashed box. Once the check box is selected, FACET displays the checked routes. This is shown in the bottom graphic of Fig. 4.

The dispatcher would submit the preferences once the credits and flight plans are selected for each of the departing flights in the current period (shown by pink box in the bottom graphic of Fig. 3). This information for each dispatcher was made available to the server process. The traffic manager at this point would close the period and no

additional changes were allowed. The iterative simulation runs (see section II.A) would then begin until a convergent solution is obtained (within 5 seconds to five minutes, depending on the scenario). Then the next period submission would open, until all periods in the scenario are completed.

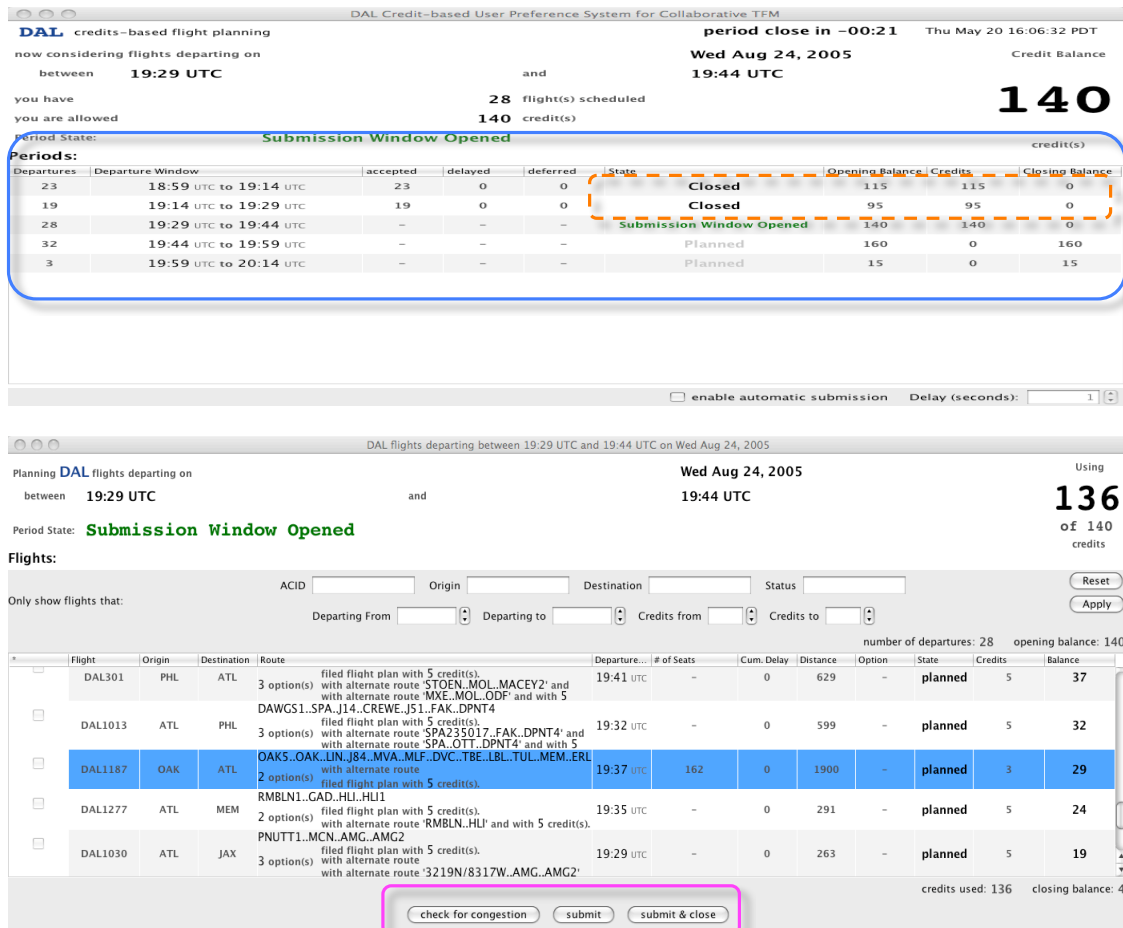


Figure 3. The dispatcher user interfaces for flights and constraint management. The top graphic shows the period details. The bottom graphic shows flight plan details for the selected flight (in blue in bottom window) along with all the flights in the current period.

IV. Metrics

To analyze the system and users' performance, several metrics were computed. Each of these metrics is presented in this Section. Some of the metrics were computed from a user perspective only, while others made sense from both user and operator perspectives. Each of the metrics described in Sections IV.A through IV.E was made available to the users at the end of each scenario. Even though the results are presented for the 'DAL' user, there was no participant from Delta Airlines.

A. Delay

The delays in the system were computed for all the flights and for each of the participating users. The total, mean and maximum delay values were recorded for participating users. The computed delays from system and user perspectives are presented in histograms (departure delays only) as well as numbers (departure delays and difference from originally filed route airborne delays) in top half of Fig. 5 below.

B. Fuel Consumption

For each of the participating users' flights, the fuel consumption required to reach destination was computed. The mean, maximum and difference from baseline (filed route) values of fuel consumption were recorded. The fuel consumption was computed based on the aircraft performance tables available within FACET. The fuel consumption values are presented from a user's fleet perspective only and are presented in the third panel from top on the left in Fig. 5.

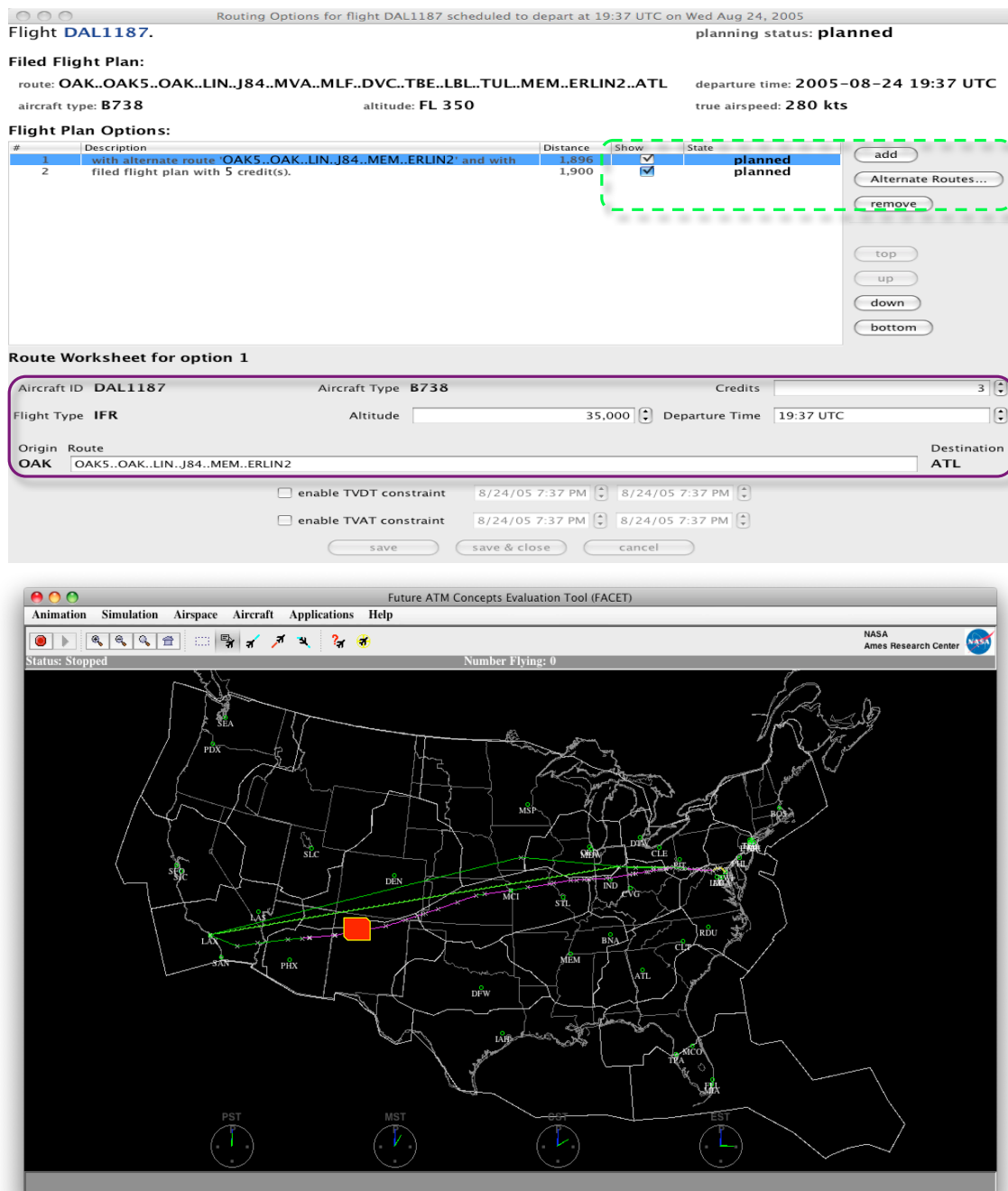


Figure 4. The dispatcher user interfaces for individual flight handling. The top graphic shows all the route details. The bottom graphic shows details of the alternate routes for a flight under consideration.

C. Equity

A coefficient for inequality in a distribution was used for computing equity of delay distribution. Gini coefficient¹⁴, G , was computed from a system perspective (for each user) and from a user perspective (for each flight in the fleet). It is defined as:

$$G = \frac{\sum_{i=1}^n \sum_{j=1}^n |x_i - x_j|}{2n^2\mu} \quad (1)$$

where, n = number of flights or users,
 x = maximum delay, and
 μ = mean of delays.

The Gini coefficient values vary from zero to one. Zero means that there were no differences between x s in the distribution, and one means there were high differences between x s in the distribution. For equitable delay distribution across all the users, the Gini coefficient for system delays should be closer to zero. On the other hand, a Gini coefficient closer to one is desired for a user's fleet. The goal is to unevenly distribute delays based on priorities between various flights for each user.

D. Credits

Due to the implementation details of the credits concept, it was conveyed to the users to use their credits wisely. The credits expired at the end of each scenario, however, the users can only assign from their allocated credit balance. A plot of credits used and available credit balance after each period was presented. This is shown in the bottom left graphic of Fig. 5.

E. Performance Index

The user performance index, S , was based solely on the delay incurred for the user compared to the system-wide delay of all users. This index is defined as follows:

$$S = \left[1 - \left(\frac{D_{user}}{D_{system}} \right) \right] * 100 \quad (2)$$

where, S is between 0 and 100%,
 D_{user} is the total delay incurred by each user, and
 D_{system} is the sum of delays of participating users.

The performance index, S , is shown in the Fig. 5 by a thermometer at the bottom right. Each of the users' performance was indicated at the end of a scenario by a color and a percent value. The colors of red, orange and green for $< 33\%$, $34-67\%$ and $> 68\%$, respectively, were used. It is acknowledged that S is not a satisfactory representation of the performance since it does not include the fuel consumption of users flights.

V. Results

All of the metrics described above were computed for the experiments. The scenarios one through four were more didactic and intended for concept understanding and system awareness for the participants. At the end of each scenario, a pictorial image of the results was presented to the participants. Figure 5 shows the reader this image for the more elaborate scenario 5 used in experiment 7. Table 3 reports results for all users in experiment 7. The results of the survey presented to the users are described in section B.

A. Experiment results

Figure 5 shows the image displayed to the dispatchers at the end of experiment 7 with scenario 5 (see Tables 1 and 2 for details.) This figure has three panels. The upper panel has two bar charts ('System Departure Delay' and DAL Departure Delay'), the middle panel has four tables with numbers 'System Delay Statistics', 'DAL Delay

Statistics', 'DAL Fuel Consumption', and 'Gini Coefficient'), and the bottom panel has a bar chart at left ('DAL Credits') and a thermometer ('Performance Index') at right.

The system-wide departure delay only for all participating users is shown in the upper left panel of Fig. 5. The x-axis shows periods one through five (as 200508...) The red bars indicate the results for experiment 7 (denoted 'This_session'). The blue bars show the results (previously computed) with all flights assigned five credits (denoted 'SCEN5_C5_S60_D15_UNI_1'). The green bars represent the performance with a distance-based utility function (denoted 'SCEN5_C5_S60_D15_DIST_1'). The departure delay (without the airborne delay) for one user (DAL) is shown in the top right panel. As mentioned earlier, even though the results are presented for the 'DAL' user, there was no participant from Delta Airlines. It is observed here that the delay is minimal (red bar) during all five periods (along x-axis) compared to the other two methods of credit assignment (blue and green bars).

For all tables in middle panel of Fig. 5, a comparison is provided with the previously computed five credits and distance-based credit assignments in rows 1 and 2, respectively. The results for experiment 7 are denoted with 'HITL_SCEN5_C5_SW60...'. The upper left table in the middle panel of Fig. 5 shows system delay statistics for departure delays as well as additional optional route airborne delays combined. For experiment 7, the system delays were larger (825 minutes) compared to the five credits (row 1) value of 780 minutes, but lower than the distance-based function (row 2) of 888 minutes. The upper right table shows those values for the individual user. Clearly, the DAL user was able to reduce delays significantly from 90 in row 1 and 133 in row 2 to 43 minutes for his fleet, in this experiment. Since the DAL user had 160 flights in the scenario, the mean value of delay is less than 1 (rounded to 0) under Mean delay column. The fuel consumption values are shown in the bottom left table in the middle panel of Fig. 5. The dispatcher was able to further reduce the fuel consumption from 1135 in row 1 and 363 in row 2 to 7150 lbs of savings in this experiment. The bottom right table shows the Gini coefficient values. Due to an error in the software, the system values in the image were subtracted from 1. Thus, the correct values for System-maximum and System-average should be 0.16 ($G=1.0-0.84$) and 0.15 ($G=1.0-0.85$) for rows 1 and 2, respectively. For experiment 7, these values should be 0.13 for System maximum and average both. From the values shown, it appears that system was able to distribute system (maximum and average) delays fairly well among users. The user, on the other hand, achieved a Gini coefficient of 0.99, which implies the delays among his fleet were very unevenly distributed. Both of these are desired outcomes.

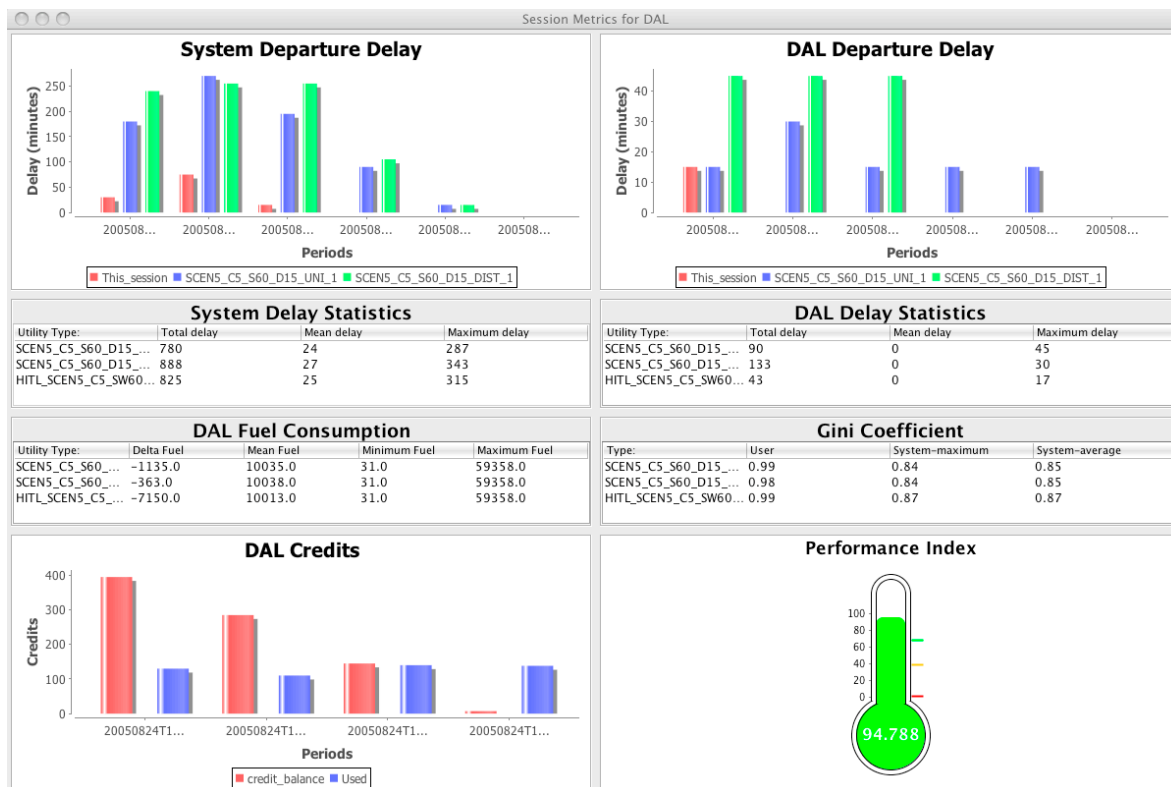


Fig. 5. Metrics display to users and traffic manager. The figure shows delays (system and individual, credits usage (for each user) and a satisfaction index.

The bar chart in lower panel shows the credits expenditure (blue bars) with the periods along the x-axis. The user chose to spend credits more evenly through the periods, even though more credits (red bars) were available (due to larger number of departures) earlier. For this experiment, the credits were allocated each period, and not lump-sum at the beginning of the scenario. The allocation of credits, lump-sum at the beginning or for each period, is an open question and is being considered in current research. The participants overall preferred a lump-sum allocation, which provided them with higher flexibility in prioritizing flights. The bottom right panel shows the user performance index. This user achieved a 95% value, which represents very low ‘DAL’ fleet delay compared to the system delay. There were very few runs where the individual users achieved between 50 and 65%, but once the concept of operations was clear to them, they were able to achieve 65% or higher value.

The results for all metrics for experiment 7 using scenario 5 are presented in Table 3. The DAL user shown in Fig. 5 is User 2 in Table 3. It is observed that User 1 incurred a significant portion of the delay. The reason is that

Table 3. All metrics computed for experiment 7 with scenario 5.

Participant	Total Delay	Maximum Delay	Delta Fuel	Mean Fuel	Maximum Fuel	Gini coefficient	Performance Index
User 1	315	47	15139	10162	54341	0.96	61.82
User 2	43	17	-7150	10013	59358	0.99	94.79
User 3	14	5	-12775	8181	37966	0.98	98.30
User 4	310	49	17696	5668	25295	0.96	62.43
User 5	128	20	4925	9935	54094	0.95	84.49

the user mostly assigned five credits to all flights for all routes. User 4 also incurred significant delays. The reason for this was that several of the users flights were competing for the same resources. Another important result is that two users were able to reduce their fuel consumption compared to the baseline filed routes. Lastly, each of the users was able to achieve a high Gini coefficient. This implies that they were able to distribute delays unevenly within their own fleet.

Another interesting result is shown in Fig. 6. The idea behind the credits concept is for users to be able to

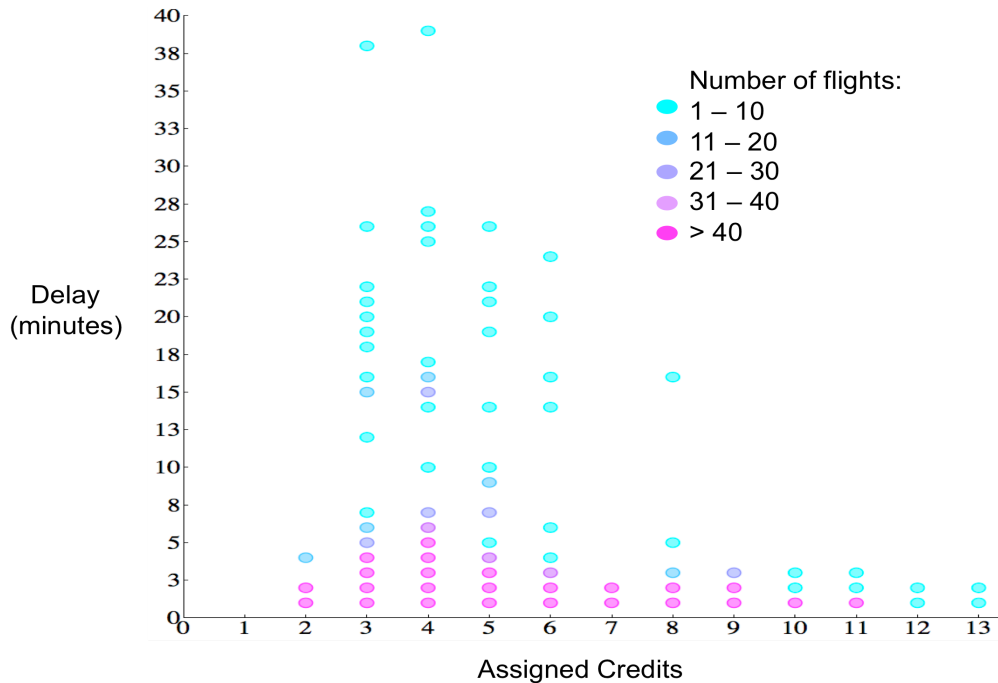


Fig. 6. Delay distribution for all the users as a function of number of credits assigned.

distribute the delays based on their priorities for individual flights. The benefit to the system is that a flight-prioritized schedule is available which satisfies the system constraints. In Fig. 6, delays are shown as a function of assigned credits to individual flights. Each marker represents several flights. The number of flights for each marker is described in the legend in Fig. 6 and is as follows. The five colored markers of light blue, darker blue, purple, light pink and dark pink represent 1-10, 11-20, 21-30, 31-40 and more than 40 flights, respectively. There are a total of 530 flight delays shown in Fig.6. It is seen that the delays were more for flights with lower credit assignments. It's observed that almost all flights with higher than six credits had less than 10 minutes of delay. Thus, the data in Fig. 6 conveys that the users were able to distribute the delays fairly well using the credit assignments in this concept.

B. Survey results

The users were provided with a survey at the end of each scenario. The survey questions are shown in the Appendix. The survey was Internet based, and had the ability to tabulate the results and provide statistics. Figures 7 and 8 show the results of the survey for overall satisfaction of flight utility parameters and overall experience with simulation parameters, respectively. The figures show the factors considered and the corresponding number of responses received (noted under the % value). Darker shading of boxes indicates higher number of responses received for that ranking. A ranking of 5 (in the column header) implies strongly agree, while a ranking of 3 and 1 implies neutral and strongly disagree, respectively. Since the number of responses were sparse, the average rating values are not statistically significant. However, schedule integrity with a score of 4.5 was the most important flight parameter out of 10 considered here. Crew connection was the next importance parameter. Figure 8 shows credit balancing with a score of 4.1 making it the most important simulation feature. Route search (for optional routes) and delay management were rated high for the simulation experience. Weather display was inadequate and needed additional information. Results presented in the figures are an aggregate of all the scenarios and across the five dispatchers.

Other than the questions 14 and 16, the dispatchers provided feedback on other questions in the Appendix as well. There was general consensus that the users were able to distribute delays as desired without incurring excessive delays (questions 9 and 10). They all learned more about the credits concept and its implementation with each new scenario. This led them to conclude that they preferred a lump-sum allocation of credits at the beginning of the scenario, instead of getting credits allocated at the beginning of each period of the scenario (questions 19 and 20). There was an undisputed positive agreement on the feasibility and benefits of the credits concept as a flight prioritization mechanism (questions 21 and 22), as applicable to their operations. There was generally agreed need

ITEM	5	4	3	2	1	Avg	Total
Number of credits remaining	23.5% 4	70.6% 12	5.9% 1	-	-	4.2	17
Delay of flights (more than 5 credits)	35.3% 6	52.9% 9	11.8% 2	-	-	4.2	17
Delay of flights (all)	23.5% 4	64.7% 11	11.8% 2	-	-	4.1	17
Fuel Consumption	35.3% 6	52.9% 9	11.8% 2	-	-	4.2	17
Wind Data	35.3% 6	29.4% 5	35.3% 6	-	-	4.0	17
PAX Connections	41.2% 7	41.2% 7	17.6% 3	-	-	4.2	17
Crew Connections	47.1% 8	35.3% 6	17.6% 3	-	-	4.3	17
Equipment connections	29.4% 5	47.1% 8	23.5% 4	-	-	4.1	17
Schedule integrity	58.8% 10	29.4% 5	11.8% 2	-	-	4.5	17
Avoiding TMs (Traffic Management Initiatives)	35.3% 6	52.9% 9	11.8% 2	-	-	4.2	17
Average %:	36.5%	47.6%	15.9%	0.0%	0.0%	4.2	170

Fig. 7. Results showing overall satisfaction index of flight utility parameter.

for incorporating airport arrival and departure rate constraints, uncertainty of weather forecasts and automation support for filing of alternate routes in the next set of human-in-the-loop simulation experiments.

ITEM	5	4	3	2	1	Avg	Total
Route Creation	29.4% 5	41.2% 7	11.8% 2	17.6% 3	-	3.8	17
Route Search	23.5% 4	52.9% 9	23.5% 4	-	-	4.0	17
Overall flight route	23.5% 4	52.9% 9	17.6% 3	5.9% 1	-	3.9	17
Credit Balancing	29.4% 5	47.1% 8	23.5% 4	-	-	4.1	17
Congestion display	29.4% 5	29.4% 5	17.6% 3	17.6% 3	5.9% 1	3.6	17
Weather display	11.8% 2	11.8% 2	70.6% 12	5.9% 1	-	3.3	17
TFM Controls	17.6% 3	23.5% 4	58.8% 10	-	-	3.6	17
Delay Management	23.5% 4	52.9% 9	23.5% 4	-	-	4.0	17
Average %:	23.5%	39.0%	30.9%	5.9%	0.7%	3.8	136

Fig. 8. Results displaying overall experience with simulation parameters.

VI. Concluding Remarks

A credit-based concept of operations for incorporating user preferences has been developed in earlier research. The assignment of credits provides a mechanism for users to define their flight delay distribution based on their business models. The concept was tested in a human-in-the-loop simulation environment at NASA. The objective was to gather airspace users' flight preferences while dealing with airspace congestion management. Five dispatchers currently employed at major airlines participated in the experiments and provided flight prioritization through the use of credits.

For the purpose of assessing the user and system performance, flight delays, fuel consumption and equity metrics were computed. From each of the metrics captured, it was clear that the user specified flight priorities performed better than the schedule-based (five credits each) utilities. The system was able to reach a solution within a reasonable time, while satisfying airspace constraints. The users were also able to distribute delays within their fleet by assigning credits based on their priorities. The users were able to keep flight delays below 10 minutes by assigning higher credits to more important flights. The importance of flights was largely dependent on ten factors, led by schedule integrity and flight connectivity. Users provided feedback that they preferred lump-sum allocation of credits for better flight operations. There was undisputed agreement that the concept of credits was feasible and beneficial, with the help of additional automation.

Appendix

An Internet-based survey system was used for this study. This website allows the survey results to be tabulated and graphed in a manner suitable for post-operations analysis. Several questions were yes/no type, others were categories of agreement and the rest required some explanation of their answers.

The survey questions presented to users are shown below.

1. Please enter the scenario number:

2. Please enter the user category (Traffic Manager, Dispatcher, Researcher):
3. Were the displays enough for you to file flights according to the credits concept? If no, please explain.
4. What additional components would you like to use to effectively manage flights? (e.g. Flight Schedule Monitor, Common Constraint Situation Display).
5. How did the convective weather forecast impact your decisions?
6. How did the congestion forecast impact your decisions?
7. What is a high priority flight? Please provide some examples of such flights.
8. What is a low priority flight? Please provide some examples of such flights.
9. Were you able to distribute delay among your flights?
10. Did you incur excessive delays?
11. Were you satisfied with the outcome?
12. Was the outcome fair/equitable?
13. Were you able to game the system?
14. Your Satisfaction index consists of: (See Fig. 7 for the table)
15. List and rate other factors not in previous question (1-5):
16. Your overall experience with: (See Fig. 8 for the table)
17. Was the credit concept clear to you?
18. Did you have enough information to plan the credit usage wisely? Please explain.
19. By running the scenarios repeatedly, did you learn about the credit system and its utility?
20. Credit Allocation should be given: (A) All at once, at the beginning. (B) In 15-minute intervals (C) other, please explain.
21. Do you think the credit-based concept is feasible (applicable to current operations)?
22. Do you think the Credit-Based concept is beneficial from your perspective?
23. Was the delay outcome with credits better than baseline scenarios?
24. Would you use e-CUPS over FCFS system? Why?
25. Should market-mechanisms be used in today's operations?
26. Would the system work if a flight planning system automatically submitted priorities (credits) for individual flights?

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