



Subject Matter Expert Evaluation of Multi-Flight Common Route Advisories

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Flights often experience large delays when they are routed around weather. Multi-flight common route advisories provide time-saving re-routes for groups of flights whose current weather-avoidance routes have become outdated because the weather has dissipated and/or moved away. A laboratory evaluation of these advisories was conducted by five subject matter experts having extensive experience in traffic flow management operations. These experts provided a total of 200 data sets in the airspace of Fort Worth Center and Houston Center. The tool identifies time-saving route changes taking into account flight plans, wind fields, and the spatial-temporal evolution of predicted convective weather. The tool is not designed to account for complex operational factors such as non-standard sector traversal, and hence a relatively low percentage of advisories initially generated by the tool were rated as acceptable (55% for Fort Worth Center and 22% for Houston Center). However, a high percentage of advisories were rated as acceptable (86% for Fort Worth Center and 75% for Houston Center) after the subject matter experts used the tool's user interface to make route modifications that accounted for relevant operational factors. The workload associated with using the tool was rated as low for 80% of Fort Worth Center advisories and 56% of Houston Center advisories. On average, Houston Center advisories provided larger time savings but were more complex, hence they were more challenging to evaluate and received less favorable ratings. The results of this evaluation make a good case for human-automation teaming to design weather re-routes for delay recovery.

Introduction

Traffic flow management [1] seeks to balance the demand for National Airspace System (NAS) flight resources, such as airspace and airports, with the available supply. When weather blocks normal air traffic routes, traffic flow managers must re-route affected flights for weather avoidance. Depending on the nature and scope of the weather, traffic flow managers may use pre-coordinated re-routes such as Playbook Routes or Coded Departure Routes [1], or may design *ad hoc* local re-routes. The routes of affected flights are modified accordingly, and the weather avoidance routes of these flights will, of course, be less efficient than their nominal routes due to increased flight time and fuel burn. In current traffic flow management operations, the transition into a weather avoidance re-routing initiative is typically implemented more aggressively than the transition out of that initiative as the weather dissipates or moves away. For example, strategic large-scale Playbook re-routes are sometimes left in place for many hours as initially implemented, even though the weather has changed significantly. There is an opportunity to periodically modify the re-routing plan as weather evolves, thereby attenuating its adverse impact on flight time and fuel consumption; this is called delay recovery.

Multi-Flight Common Routes (MFCR) is a NASA-developed operational concept for delay recovery, designed to assist traffic flow managers in efficiently updating weather avoidance traffic routes after the original routes have become outdated due to subsequent evolution of the convective weather system. In order to reduce the number of advisories that need to be evaluated and (possibly) implemented, MFCR is designed to group multiple flights and merge them on a common route segment to provide an orderly flow of re-routed traffic.

The MFCR concept of operations can be summarized as follows. A re-route advisory is presented to the appropriate Traffic Management Coordinator (TMC) who evaluates it and has the option to modify it using the

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MFCR tool's graphical user interface (GUI). If the TMC finds the advisory to be operationally appropriate, he/she would coordinate with the Area Supervisor(s) of the sectors that currently control the flights in the advisory as well as TMCs in other facilities that would be affected by the advisory; coordination with the Air Traffic Control System Command Center (ATCSCC) may also be necessary. When the TMC accepts the MFCR advisory via the GUI, the corresponding flight plan amendments would be sent to the air traffic displays of the appropriate sector controllers, using the AirBorne ReRoute (ABRR) capability; ABRR is scheduled for nationwide operation in 2017. The sector controllers would then offer time-saving route modifications to the pilots of the affected flights via datalink or voice, and then implement the corresponding flight plan amendment if the pilots accept it after consultation with their dispatcher if necessary.

MFCR is implemented as an application in the software environment of the Future Air traffic management Concepts Evaluation Tool (FACET) [2]. This application is the NAS Constraint Evaluation and Notification Tool (NASCENT). An assessment of NASCENT's single-flight re-routing functionality is presented in [3]. An analysis of a preliminary version of NASCENT's multi-flight functionality is presented in [4]. The present paper focuses on a subject matter expert (SME) evaluation of MFCR, covering the operational concept, algorithm, and GUI. The next section provides an overview of MFCR's multi-flight re-routing functionality. This is followed by a description of the SME evaluation, and presentation of major results. The final section summarizes conclusions drawn from this SME evaluation.

Overview of MFCR Advisories

MFCR suggests wind-adjusted time-saving weather-avoidance routes for groups of flights that are currently within the same Air Route Traffic Control Center and have on their current flight plan a common downstream waypoint, called the Return Capture Fix, in a nearby Center. The routes of multiple flights are merged at a waypoint called the Merge Point, and the flights then fly along a common route segment to the Return Capture Fix after which they resume their original routing.

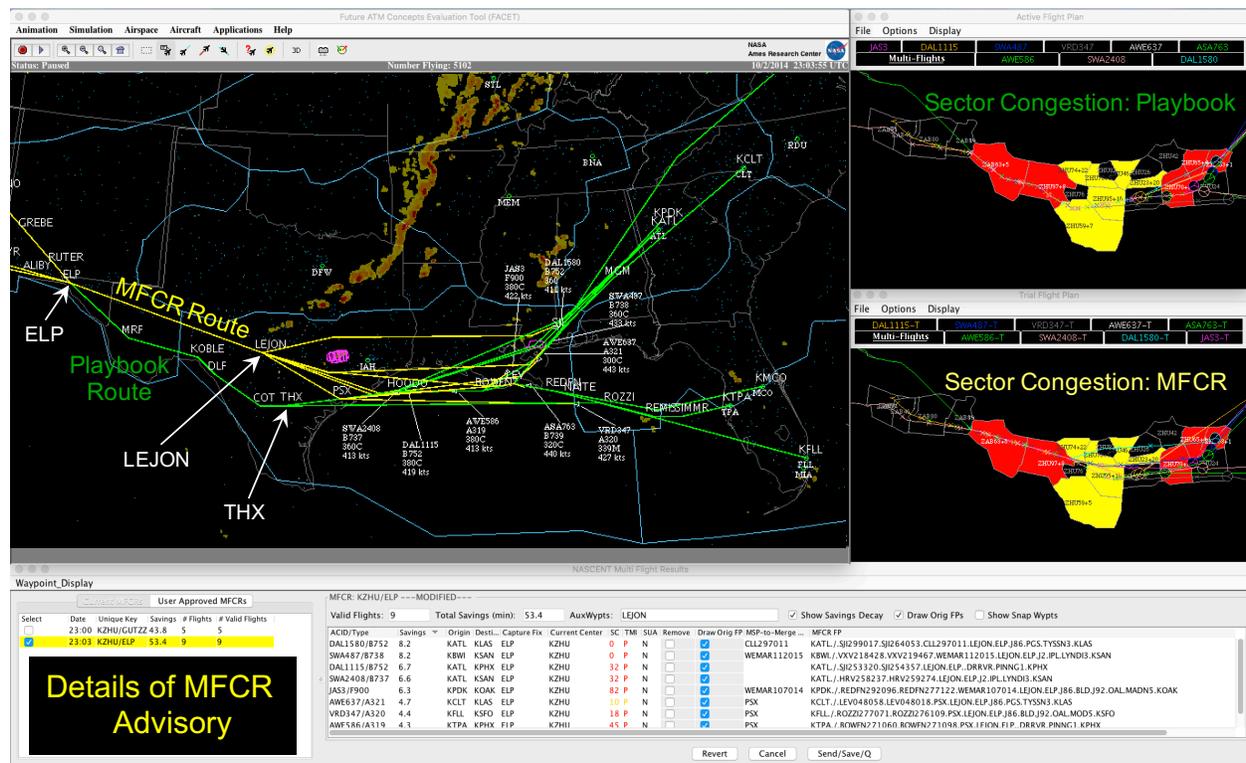


Fig. 1. Example MFCR advisory

Figure 1 presents an example MFCR advisory in the airspace of Houston Center. The green routes depict the current flight plan which corresponds to an implementation of Playbook “LEV West Partial” which is typically used when a large weather system in the south-central U.S. blocks transcontinental traffic. This Playbook re-route merges west-bound traffic from the southeastern U.S. at fix THX (Three Rivers, TX) and sends the traffic via some intermediate waypoints to the fix ELP (El Paso, TX), after which traffic follows standard jet routes to their destinations in the western U.S. In Fig. 1 this Playbook routing is still in effect even though the weather (depicted by yellow, orange, and red contours in the large map on the left) has moved to the north. This presents an opportunity for MFCR to advise an updated set of time-saving weather-avoidance routes, shown by yellow lines.

The MFCR advisory shown in Fig. 1 identifies nine flights in Houston Center that are advised to be merged at fix LEJON (the Merge Point) and then sent direct to ELP (the Return Capture Fix). The new routes of these nine flights are estimated to provide a total time savings of 53 min (an average of about 6 min per flight). Also, these flights have been organized into a new flow along the common route segment from LEJON to ELP. If this new flow continues to be free of weather, there is also an opportunity to update the existing Playbook routing and provide time savings to other aircraft that are currently upstream of this route modification. This would provide a beneficial intermediate routing solution prior to entirely lifting the Playbook restriction when the weather dissipates fully.

The MFCR tool’s algorithm routes traffic around weather-blocked airspace as well as Special Use Airspace (SUA), although SUA was not activated in this study. The re-routing algorithm does not take into account other operational factors such as sector loading, sector traversal features (e.g., crossing arrival/departure sectors, proximity to sector boundaries), fix-crossing restrictions, and letters of agreement. These complex factors are very specific to local airspace, and are hence difficult to accurately and comprehensively implement in a software tool. The approach taken in the MFCR tool design is to provide the user with good situational awareness to evaluate these factors, and provide functionality via the GUI to quickly and easily make route modifications that account for these factors if necessary. The GUI enables user modification of relevant route segments via mouse and keyboard inputs. As the trial plan modifications are made, the displays of all relevant data (flight time savings, weather proximity cues, sector loading) are updated accordingly. The GUI enhances situational awareness by providing functionality to display sector boundaries and representations of current and forecast weather at user-selected altitudes and times. The GUI also provides sector loading data: the panels on the right-hand side of Fig. 1 show sector loads for the current (Playbook) routing as well as the MFCR-advised routing. Red or yellow sectors indicate a prediction of traffic demand in excess of sector capacity, with red indicating a higher level of confidence in the prediction of sector overload. Although the MFCR algorithm does not utilize sector loading information to compute re-route advisories, it is presented to the TMC for situational awareness. The TMC may use any of the GUI-provided information to modify MFCR advisories for operational acceptability as needed.

SME Evaluation

An SME evaluation of MFCR was conducted 1–4 November 2016 in the Air Traffic Control Laboratory of the Aviation Systems Division at NASA Ames Research Center. Five participants, recent FAA retirees (under two years on average) with extensive operational experience in traffic flow management, served as SMEs for this MFCR evaluation. Immediately prior to retirement, two SMEs were at Fort Worth Center (ZFW), two at Houston Center (ZHU), and one at the ATCSCC. These SMEs had an average of 13.4 years of experience in traffic flow management operations.

Evaluation Schedule

All SMEs went through all stages of the evaluation at the same time. On the morning of the first day, the SMEs received a comprehensive briefing on MFCR, including its concept of operations, algorithm, and GUI. This briefing was followed by a demonstration of the re-routing tool and a tutorial on its various functionalities. On the afternoon of the first day, the SMEs participated in a hands-on training activity to exercise all relevant functionalities of the re-routing tool using a variety of traffic scenarios selected for the practice session. The second and third days were devoted entirely to data collection where each SME was presented with 40 MFCR re-route advisories for evaluation and possible modification using the tool’s trial planning functionality; the SMEs conducted their evaluations independently. Each data collection run focused on the SME evaluation of a single MFCR re-route advisory. After each advisory evaluation was completed, the SMEs filled out a detailed post-run questionnaire for that advisory. On the morning of the fourth day, the SMEs filled out a comprehensive post-study questionnaire and then participated in an extensive debrief session with the researchers, discussing various aspects of MFCR’s operational concept, algorithm, and GUI.

MFCR Advisories

MFCR advisories normally change over time: some flights may be dropped from the group and/or new flights may be added to the group. In this SME evaluation of MFCR advisories, the dynamic aspect was suppressed and the SMEs were presented with a traffic scenario that was effectively frozen in time. All traffic, including flights in the MFCR advisory, remained static. However, the SMEs were given the ability to modify the MFCR advisory and immediately see the effects of their trial plans without their modifications being confounded by the dynamics of the advisory. This enabled the evaluation of an advisory at a single pre-determined instant of time, with the goal of providing some fundamental insights appropriate for an initial evaluation of MFCR advisories.

The MFCR advisories used in this evaluation were constructed using data for a set of bad-weather days in 2014 and 2015. Traffic data were obtained from the FAA's Aircraft Situation Display to Industry (ASDI) feed, wind data were obtained from the National Oceanic and Atmospheric Administration, and Corridor Integrated Weather System (CIWS) data were obtained from the Massachusetts Institute of Technology – Lincoln Laboratory. The CIWS data were used to build the Convective Weather Avoidance Model (CWAM) [5] which provided horizontal polygons for weather avoidance as a function of altitude and time. Using these data, MFCR software was run in batch mode to generate re-route advisories in ZFW and ZHU airspace. The following requirements were imposed: a minimum of two flights per advisory, a minimum of 3 min time savings per flight, and a minimum of 10 min time savings summed over all flights in the advisory. Relevant data were output for an offline analysis that resulted in the selection of the static advisories used in the evaluation. Traffic and weather data files associated with these advisories were saved to create a collection of scenarios used in the evaluation.

A total of 100 scenarios were generated for use in this SME evaluation, 50 each in ZFW and ZHU airspace. Ten of the ZFW/ZHU scenarios were used for SME training, and the other 40 were used for data collection. Figure 2 shows two characteristic parameters, the number of flights and flight time savings, for the data-collection advisories (with a ZHU outlier removed to enhance clarity). It can be seen that the distributions of these parameters are quite different across ZFW and ZHU advisories, with the latter typically having more flights per advisory and larger time savings per advisory. The average per-advisory time savings were 33 min for ZFW and 61 min for ZHU. These differences are attributed to variances in the nature of the weather relative to the traffic flow patterns, on the days for which these advisories were generated; additionally, since every Center is unique, there are differences in the traffic flow patterns across ZFW and ZHU. Hence, in this evaluation, the ZFW advisories are considered to be representative of low-complexity advisories with modest time savings, while the ZHU advisories are considered to be representative of high-complexity advisories with large time savings. For this reason, results are reported separately for the two Centers.

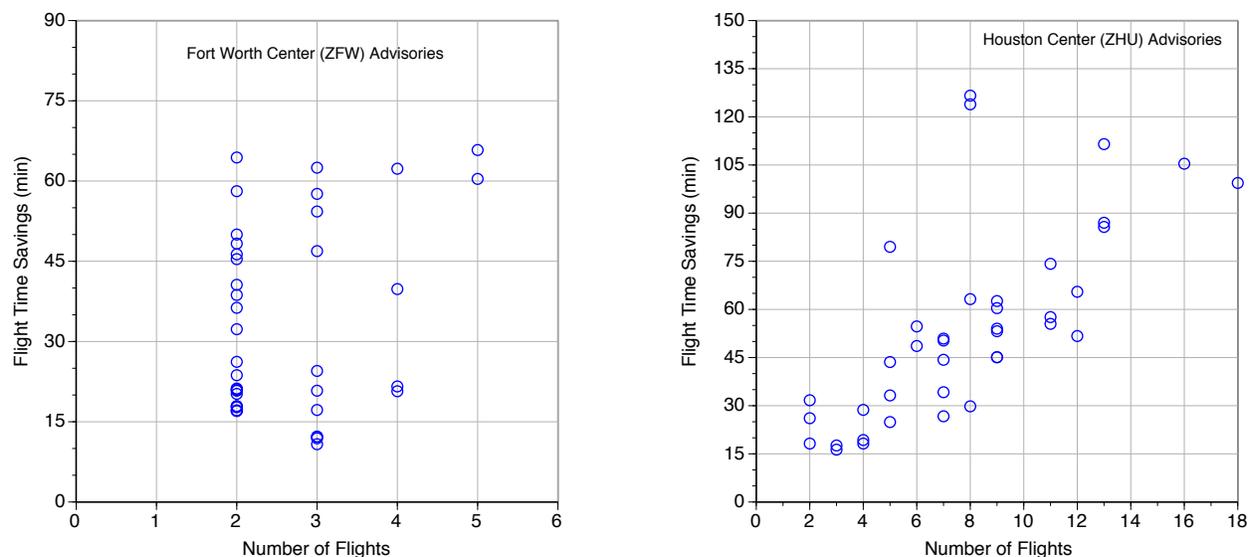


Fig. 2. Characteristic parameters of advisories for ZFW (left) and ZHU (right)

Evaluation Procedures

The two ZFW SMEs evaluated all 40 ZFW scenarios, and the two ZHU SMEs evaluated all 40 ZHU scenarios. The ATCSCC SME evaluated 20 ZFW scenarios and 20 ZHU scenarios, presented in counterbalanced blocks to reduce any learning biases. The ZFW and ZHU SMEs evaluated MFCR advisories from the perspective of TMCs managing traffic flows in their Center’s airspace. The ATCSCC SME evaluated MFCR advisories from the perspective of a Traffic Management Specialist managing traffic flows across the NAS, including an assessment of any coordination required across two or more Centers and the ATCSCC.

Figure 3 depicts the timeline (~15 min) of a nominal data collection run for a typical scenario. The process began with the loading of all data files associated with the scenario. After the data were loaded, the simulation built up the various panels of the MFCR tool’s display. When the scenario buildup was complete, the simulation was automatically paused, and the SMEs began their evaluation of a static re-route advisory. An observer shadowed each SME to take research notes and answer any questions about the tool’s functionalities. After the SMEs completed their evaluation of the advisory (no time limit was imposed), they filled out a post-run questionnaire. In total, 200 data sets were provided by five SMEs evaluating 40 scenarios each.

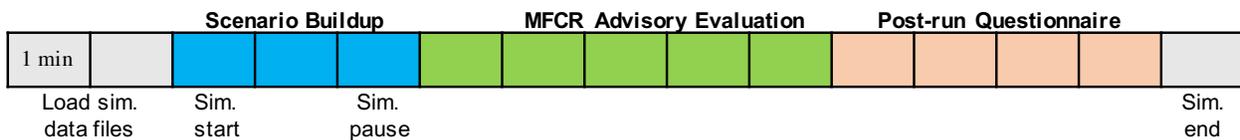


Fig. 3. Nominal timeline of a data collection run

In this work, the re-route advisory presented to the SME by the MFCR tool is called the Initial Advisory. The tool’s GUI enables modification of any advisory via mouse and keyboard inputs; all relevant data (e.g., flight time savings, weather proximity cues, sector loading) are updated accordingly. The GUI also provides the option of reverting to the Initial Advisory with a click of the “Revert” button. The end result of any sequence of SME-generated modification(s) of the Initial Advisory is called the Post-Modification Advisory. For the purposes of analysis, the Final Advisory is defined as the Initial Advisory if no net modification was made, or the Post-Modification Advisory if any net modification was made.

Results

The post-run and post-study questionnaires collected various types of data, including SME commentary and ratings on several aspects of the MFCR advisory. This section presents results and insights derived from an analysis of these data.

Acceptability

The post-run questionnaire collected ratings of the acceptability of the Initial Advisory and Final Advisory. To assess the Initial Advisory, the SMEs rated their level of agreement with the statement: “The MFCR re-route advisory as originally presented to you was acceptable.” Responses were collected on a 7-point Likert scale, with 1 = Disagree, 4 = Neutral, and 7 = Agree. Similarly, the SMEs also rated the acceptability of the Final Advisory. Results are shown in Fig. 4 for ZFW data (left panel) and ZHU data (right panel). In this analysis, MFCR advisories with ratings of 5, 6, or 7 are considered to be “acceptable.” For ZFW, 55% of Initial advisories and 86% of Final Advisories were acceptable. For ZHU, 22% of Initial advisories and 75% of Final Advisories were acceptable. The substantial difference between ZFW and ZHU acceptability results may be attributed to the very different nature of the advisories in those two Centers. As covered above in the discussion of Fig. 2, the ZHU advisories typically had a higher level of complexity, albeit with larger time savings.

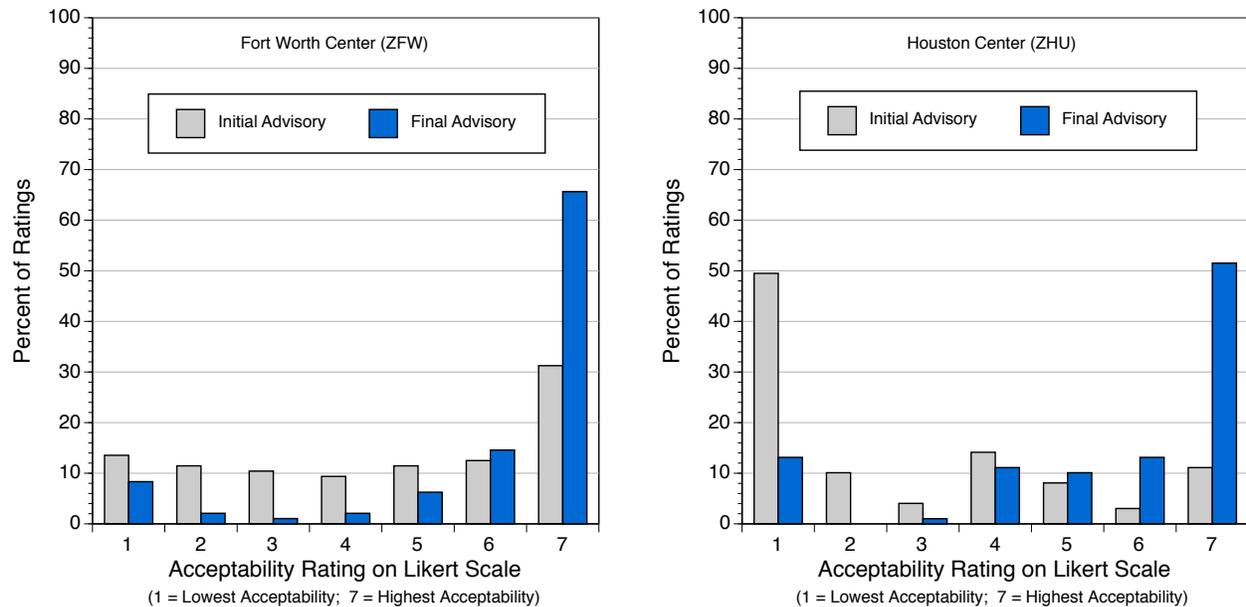


Fig. 4. Acceptability ratings for ZFW (left) and ZHU (right)

To gain some insight into the acceptability ratings of Initial Advisories, a regression analysis was performed on this data set. First, SME comments in the post-run questionnaire and the observers' narrative notes were analyzed using a qualitative/subjective data coding method. In this method, each advisory was coded for one or more attributes (keywords or concepts) frequently found in SME comments or observer notes. Examples of attributes include: "crossing a busy sector" or "too close to weather." A total of 18 such attributes were identified across all of the Initial Advisories. Next, these attributes were used to construct a linear regression model. Since the ZFW and ZHU advisories were distributed differently among the 18 attributes, separate regression models were constructed for ZFW and ZHU data. Some attributes that were coded only for one or two advisories were dropped from the model. In addition to the qualitative attributes, five quantitative attributes of each Initial Advisory were included in the regression model: number of red sectors, number of yellow sectors, total time savings in minutes, total number of flights in the advisory, and number of flights with weather penetration. Additionally, numerical responses on the post-run questionnaire (i.e., Likert-scale ratings and checkbox responses) were included in the regression model. Finally, if any pair of the terms in the regression model were strongly correlated with each other (correlation factor ≥ 0.6), one of those terms was dropped from the model.

Regression analysis results for ZFW data showed, with greater than 95% confidence, that acceptability ratings of Initial Advisories were decremented by 1.6 rating points (on the 7-point Likert scale) when the routes were close to weather, by 1.8 rating points when the routes crossed departure or arrival flows, by 1.6 rating points when the flights were close to a Center boundary, and by 1.4 rating points when the proposed Merge Point was judged to be inappropriate.

Regression analysis results for ZHU data showed, with greater than 95% confidence, that acceptability ratings of Initial Advisories were decremented by 1.5 rating points when the routes crossed a busy sector, by 0.9 rating points when the routes crossed arrival or departure flows, and by 1.9 rating points when the routes did not follow ZHU's standard flow patterns. Also, the acceptability ratings were incremented by 2.2 rating points when the routes would be acceptable under the mitigating circumstances of the specific scenario being evaluated (e.g., time of day, low traffic, weather characteristics), but would in general not be considered acceptable.

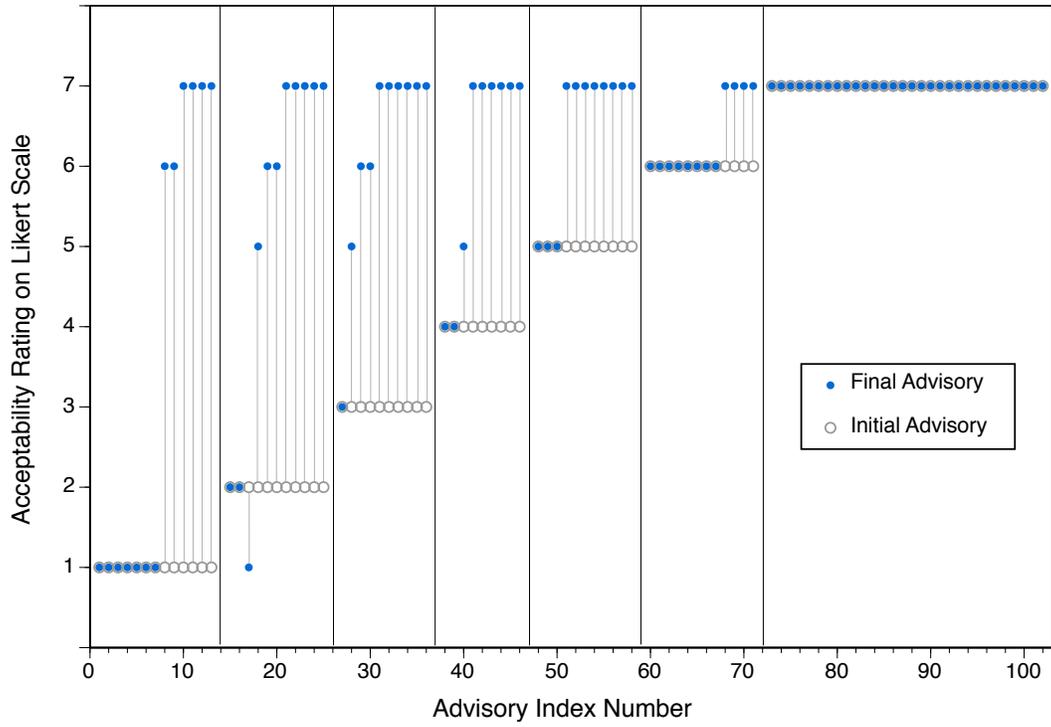


Fig. 5a. Details of acceptability ratings for ZFW

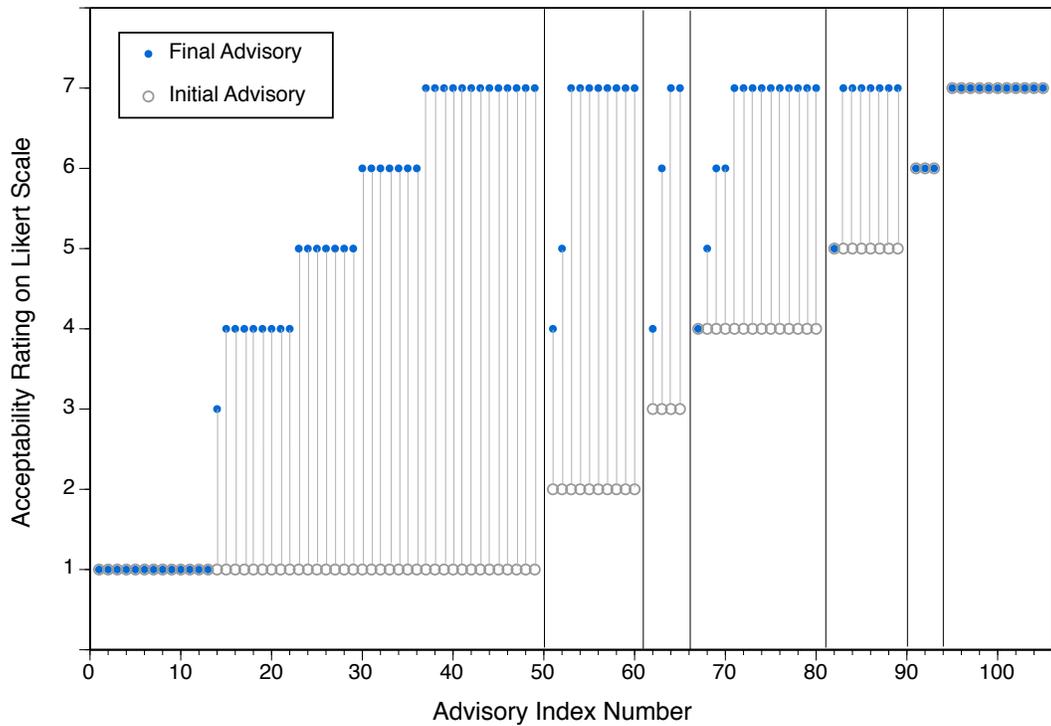


Fig. 5b. Details of acceptability ratings for ZHU

The raw ratings for Initial and Final Advisories are presented in Figs. 5a (ZFW) and 5b (ZHU), with data points sorted by acceptability ratings to provide additional insight. Consider the ZFW data presented in Fig. 5a (third panel from left), where 10 of the Initial Advisories received a rating of 3, indicating a low level of acceptability. In one of those cases, the Initial Advisory received no net modification; hence the Final Advisory was assigned the same rating of 3. In other cases, SME modifications substantially improved the ratings of the Final Advisories to 5 (one case), 6 (two cases), and 7 (six cases). The rest of the data show a similar trend, with Final Advisories often receiving substantially better ratings than the corresponding Initial Advisories. This indicates that the MFCR tool provides the operator (TMC) with the functionality to modify the Initial Advisories to incorporate complex operational features not considered by the algorithm. According to the regression analysis presented above, undesirable features include: crossing busy sectors, crossing arrival/departure flows, proximity to weather, proximity to Center boundaries, inappropriate merge points, and non-conformance with standard flow patterns. Relying on the human operator to incorporate these factors into their modification of the re-route advisory may be an acceptable arrangement if the workload associated with using the MFCR tool is relatively low.

Workload and Situational Awareness

The post-run questionnaire also collected SME ratings of workload and situational awareness. To assess workload, SMES rated their level of agreement with the statement: “My workload caused by having to assess the MFCR advisory was negligible.” Responses were collected on the 7-point Likert scale described earlier, and the workload ratings are presented in Fig. 6 (after reversing the polarity of the Likert scale for ease of presentation). In this analysis, ratings of 1 and 2 are considered to be “low” workload. 80% of ZFW advisories and 56% of ZHU advisories were associated with low workload. The simulation environment used for the SME evaluation did not model the baseline tasks performed by TMCs. Hence the workload ratings obtained were part-task in nature, reflecting only the tasks associated with using the various functionalities of the MFCR tool for a static advisory.

To assess situational awareness, SMEs rated their level of agreement with the statement: “I had all the necessary information to make the right decision.” Responses were collected on the 7-point Likert scale described earlier, and the data are presented in Fig. 7. In this analysis, ratings of 6 and 7 are considered to be “high” situational awareness. 94% of ZFW advisories and 64% of ZHU advisories were associated with high situational awareness. It may be inferred that high situational awareness was one of the factors contributing to low workload.

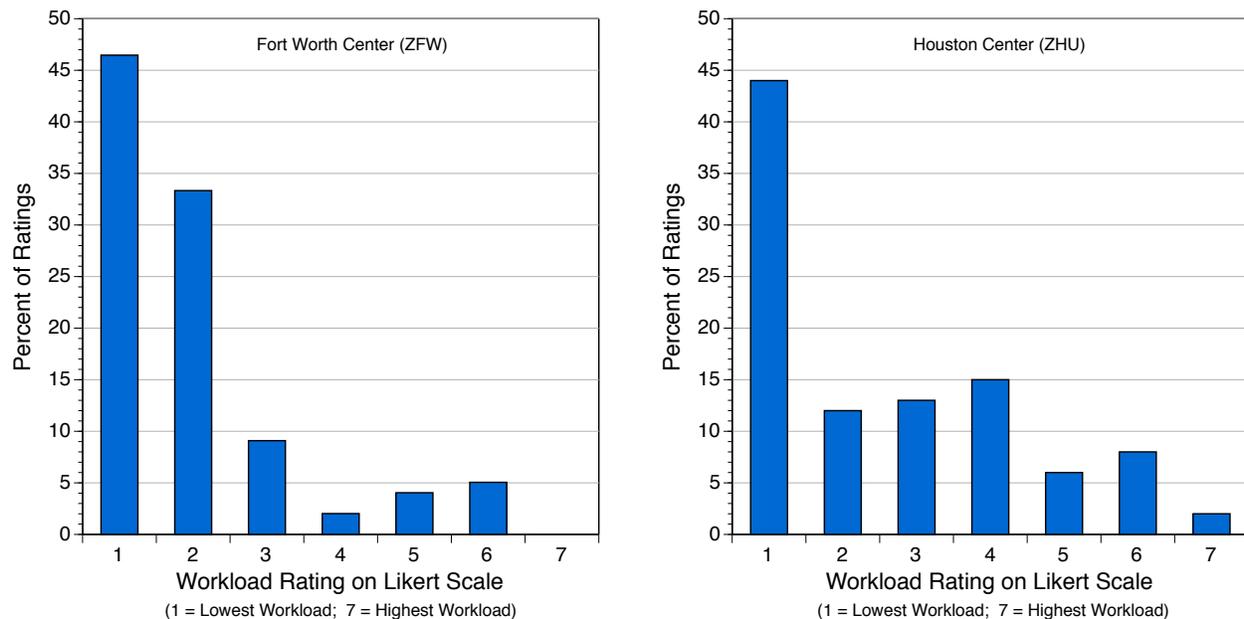


Fig. 6. Workload ratings for ZFW (left) and ZHU (right)

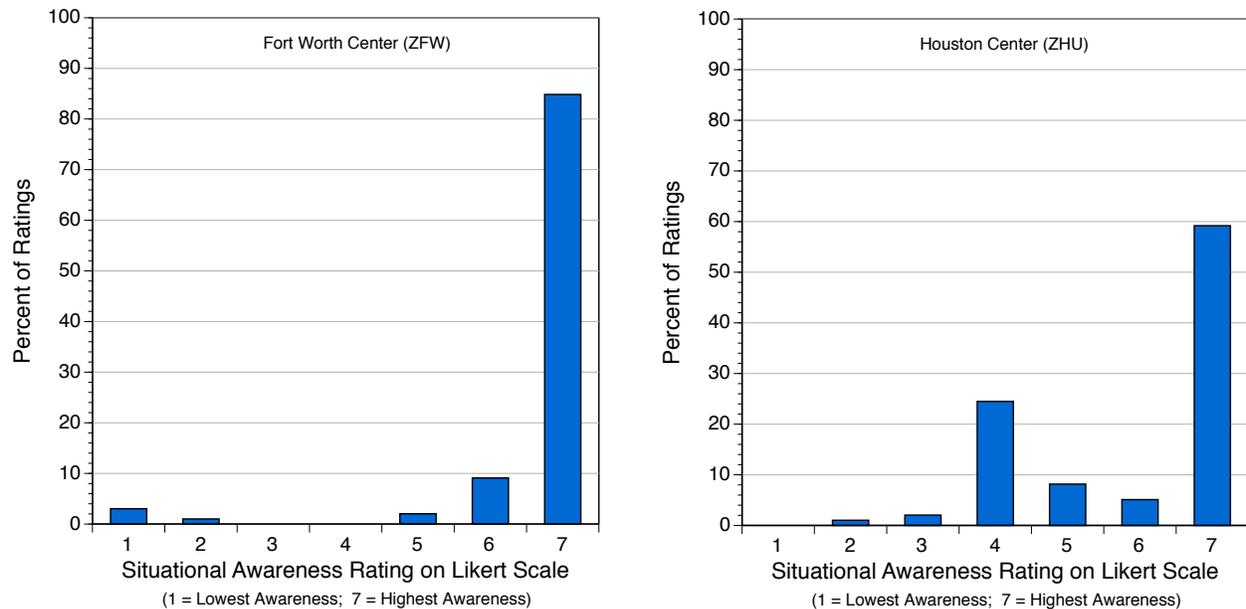


Fig. 7. Situational awareness ratings for ZFW (left) and ZHU (right)

System Usability

A post-study questionnaire was administered after all advisories had been evaluated. This questionnaire included usability ratings elicited by the System Usability Scale (SUS) survey. The SUS, originally designed to quickly measure perceived usability of computer systems [6], has been widely used by researchers over the past 25 years. The SUS score is computed by combining responses to 10 aspects of usability rated on a Likert scale. According to the literature [7], SUS scores from 50 to 70 are considered “Marginal” and scores from 70 to 100 are considered “Acceptable.” The SUS scores of the five SMEs ranged from 60 to 90, with values of 60 for the ATCSCC SME, 85 and 87.5 for the ZHU SMEs, and, 80 and 90 for the ZFW SMEs. The median score was 85, indicating good usability of the MFCR tool.

Debrief Discussion

Additional key insights were obtained from the debrief session and SME comments in the post-run and post-study questionnaires. The SMEs indicated that MFCR identified many time-saving re-routing opportunities that would be difficult to identify manually during air traffic operations in bad weather conditions. Some advisories were found to be operationally acceptable as originally presented by MFCR, while others needed modification for operational reasons. Researcher observations and SME comments revealed that a major reason for modifying Initial Advisories was undesirable sector-traversal features. For example, a route sometimes ran for many miles in close proximity to a sector boundary. In some other cases, the path had a very small dwell time in a corner of one or more sectors. In yet other cases, the path crossed busy arrival/departure sectors. These types of path attributes would create undesirable complexity and workload for the corresponding sector controllers. However, in most of these cases, SMEs were able to easily rectify the issue with minor route modifications using the MFCR tool’s GUI.

Another topic of discussion was the need to coordinate with other air traffic managers. SME feedback emphasized the need to coordinate with Area Supervisors of the sectors that currently control the flights in the advisory. This coordination would, in some cases, result in the TMC modifying the advisory to address an Area Supervisor’s concerns. The SMEs also reinforced the need to coordinate with TMCs in other Centers that would be affected by the re-routing. They indicated that this coordination may often be quick and simple, especially with adjacent (first-tier) Centers due to familiarity with their traffic flows and standard operating procedures. Coordination with more distant (second-tier) Centers may be less routine, and would also require coordination with the ATCSCC.

Finally, the SMEs indicated that route modifications suggested by MFCR advisories may provide a more efficient transition out of Playbook re-routing. A follow-on study featuring dynamic advisories (rather than the

static advisories in the present study) will attempt to identify opportunities for this transition. That study will also evaluate new MFCR tool functionalities designed to help TMCs determine the best time to implement dynamic re-route advisories.

Conclusions

MFCR advisories provide time-saving re-routes for groups of flights whose current weather-avoidance routes have become outdated because the weather has dissipated and/or moved away. An SME evaluation of MFCR advisories was conducted by five recently retired traffic flow managers, in the simulated airspace of ZFW and ZHU.

The quantitative results of the SME evaluation were different across ZFW and ZHU advisories. On average, although ZHU advisories provided larger time savings, they were rated less favorably because their higher complexity made them more challenging to evaluate. The average acceptability rate of Initial Advisories was 55% for ZFW and 22% for ZHU, while the average acceptability rate of Final Advisories was 86% for ZFW and 75% for ZHU. In general, the improvement in acceptability arose from SME modifications that accounted for complex operational factors not considered by the MFCR tool's algorithm, such as sector traversal properties. However, these SME modifications via the MFCR GUI did not take a lot of effort; the total workload for all MFCR-related tasks was rated low for 80% of ZFW advisories and 56% of ZHU advisories. The GUI also provided a high level of situational awareness for 94% of ZFW advisories and 64% of ZHU advisories. The SUS ratings, administered post-study, indicated good usability of the MFCR tool. The need for coordination with Area Supervisors and TMCs of proximate Centers was emphasized in SME comments, with the reassurance that this coordination would often be quick and simple.

Overall, the SMEs were very positive about the MFCR tool's capabilities and its overarching concept of operations. Although difficult for human operators, the automation was able to quickly identify multi-flight route changes for delay recovery, taking into account flight plans, wind fields, and the spatial-temporal evolution of predicted convective weather. Conversely, the human operator was able to quickly modify this re-route advisory to account for complex operational factors that would be difficult to accurately and comprehensively program into the automation. These results make a good case for human-automation teaming to design re-routes for delay recovery.

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