Impact of ATD-2 Tools on Human Factor Metrics at Charlotte Douglas International Airport

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***Abstract*—New decision support tools were introduced at Charlotte Douglas International Airport (CLT) as part of NASA's Air Traffic Demonstration 2 (ATD-2) project. ATD-2 is based on concepts which enable integrated arrival, departures, and surface (IADS) operations in a metroplex environment. Metrics on environmental benefits from ATD-2's surface metering at CLT have shown impressive reductions in fuel consumption and CO_2 emissions. Questions have remained on 1) the human factors impact of these new ATD-2 tools and surface metering and 2) the users' perceptions of how these tools affect operations. To address these questions, post-bank surveys were designed for the four types of users of the new tools at CLT: Ramp Controllers, Ramp Managers, Tower Traffic Management Coordinators (TMCs) and Terminal Radar Approach Control (TRACON) TMCs. These surveys were administered during five-day blocks at three different times. Three types of banks were compared: No ATD-2 tool use, ATD-2 tool use, and ATD-2 use plus surface metering. Results indicate that higher workload or decreased situation awareness was not significantly associated with ATD-2 tool use more than no ATD-2 tool use--in fact for many users the opposite was true. Also, acceptability and operational efficiency measures indicate that the users did not perceive that banks with ATD-2 tools were significantly less acceptable or less efficient than banks without ATD-2 tools.**

Keywords—Airspace Technology Demonstration 2; Integrated Arrival, Departure, and Surface Operations; Human Factors Field Evaluation; Surface Metering

I. Introduction

A. Background

Airspace Technology Demonstration 2 (ATD-2) is an ambitious NASA project which, in collaboration with the Federal Aviation Administration (FAA), air carriers, airports, and the general aviation community, aims to integrate multiple concepts and technologies to enable integrated arrival, departures, and surface (IADS) operations in a metroplex environment. The project has used the Charlotte Douglas International Airport (CLT) and surrounding FAA facilities as a test bed. Among the concepts and technologies being integrated into new software tools for Ramp and Air Traffic Controllers at CLT is Data Exchange and Integration (DE&I), which refers to the foundational need for surface data exchange and system-wide integration across domains, agencies, and viewpoints. DE&I communicates such information as flights receiving different runways, if, for example the pilots need a longer runway for operational necessity. It includes updates on the availability of gates and earliest off-block times from the carriers and enables automated coordination of release time of controlled flights for overhead stream insertion. DE&I supports surface modeling, which supports surface scheduling, which in turn enables surface metering. Surface metering, as outlined by the Surface Collaborative Decision Making (S-CDM) Concept of Operations [1], aims to reduce aircraft wait times in the departure runway queue, with its attendant fuel burn and emissions, by redistributing some of that time back to the ramp area, typically to the gate. Reference [2] presents an historical analysis of the precursors to this concept and the tools involved, as well as previous approaches to surface metering.

B. Operational Benefits from Surface Metering at CLT

Between 29 November 2017 and 30 April 2020 (about 29 months), 25,748 departures (3.8% of all departures) were held at the gate for an average of 5.9 minutes. It was estimated that 2,883,410 pounds of fuel were saved and CO_2 emissions were reduced by 8,880,901 pounds, the equivalent of planting 66,038 urban trees [3]. Further, surface metering was found to have no negative impact on on-time arrival performance of either outbound and inbound flights [4].

II. Research Questions and Approach

It is important to determine the human factors impact of the new software tools and the additional information they convey to the users. Does the increase in availability of information increase users' workload? Do the tools improve their situation awareness? Are airport operations seen as acceptable when using the tools? To answer these questions in a systematic way, three rounds of surveys were administered to users. Each round of surveys consisted of surveys administered after each of four banks (clusters of arriving and departing aircraft) per day for 5 days. The first round was in September 2017, while the tools were being introduced. During this round, the surveys were made available to all the new tool users in the CLT Airport facilities: Terminal Radar Approach Control (TRACON), Air Traffic Control Tower (ATCT), and Ramp Tower Controllers and Managers. A second round of surveys was administered only to Ramp Controllers and Managers in November 2017 when they were more familiar with the tools and had used them more frequently. A third and final round of surveys was administered to all users in March 2018 when some of the banks had a Surface Metering Program (SMP) in operation.

This paper describes 1) the software that conveyed DE&I elements, 2) examples of these elements, 3) the surveys designed to elicit human factors input, and 4) the results of these surveys.

III. ATD-2 Data Exchange and Integration Tools in the CLT Airport Facilities

In September 2017, the ATD-2 Ramp Traffic Console (RTC) and the Ramp Manager Traffic Console (RMTC) were installed in the CLT ramp tower. These tools were designed to enhance information exchange with the ATC Tower and to provide surface metering information to the Ramp Controllers. The Surface Trajectory Based Operations (STBO) Client tool was installed in the Air Traffic Control Tower (ATCT) as the primary Traffic Management Coordinator (TMC) display, and the RMTC in Observer Mode was also made available there. The STBO Client and RMTC in Observer Mode were also placed in the CLT TRACON. Finally, the STBO Client in Observer Mode was placed at the Air Route Traffic Control Center (ARTCC or Center). Before this, much of the data exchange information was conveyed via phone calls between facilities.

A. Ramp Controller and Ramp Manager Software Tools

Fig. 1 shows the new RTC software displaying the CLT ramp area. Digital flight strips at the gate and elsewhere show flight-specific information and are color-coded: blue flight strips indicate that the aircraft will depart to the east, and brown to the west. Arrival aircraft are depicted with flight strips that are green (or magenta, if the arrival has a gate conflict). The CLT Terminal has five Concourses (A-E) and the ramp area is made up of four ramp sectors. Fig. 1 also shows example "spots," yellow circles that show the transition points between the ramp area and the ATC-controlled Airport Movement Area (AMA).

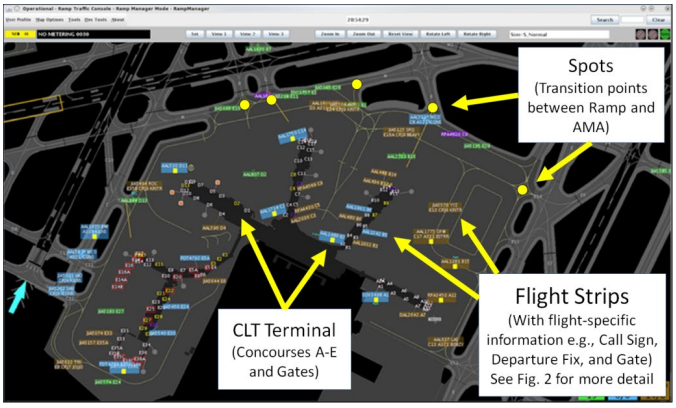

Fig. 1. Display of the Ramp Traffic Console (RTC) tool.

Fig. 2 shows details of the flight strips at the gate (left) and while taxiing in the ramp area (right) when there is no surface metering. Some of the specific flight data shown on the strips can be configured by the user.

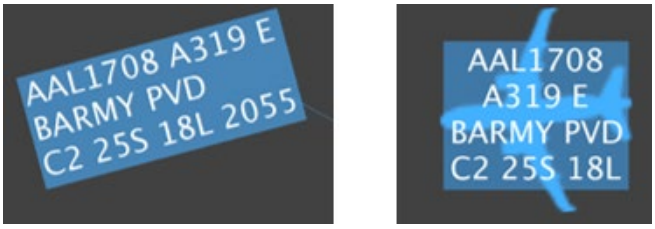

Fig. 2. Digital flight strips on the RTC display in the no metering condition: at the gate prior to pushback (left) and following pushback, while taxiing in the ramp area (right).

Figs. 3 and 4 show the flight strips during surface metering. Fig. 3 shows an advisory of 6 minutes indicating the optimal time to push back from the gate, the Target Off-Block Time (TOBT) is 6 minutes from now and a "PUSH" advisory when that time has arrived. The Ramp Controllers are asked to aim for pushback within a ±2-minute window of the "PUSH" time.

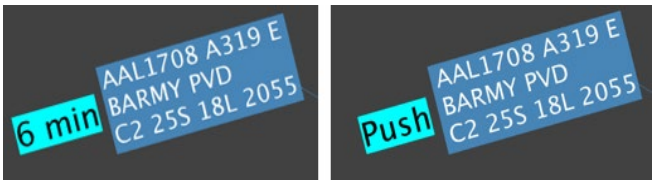

Fig. 3. Flight strips at the gate for aircraft in a Surface Metering Program (SMP) showing on the left the gate hold advisory countdown ("6 min") to the TOBT (Target Off-Block Time) and, on the right, when "PUSH" is indicated.

Fig. 4 shows the flight strip after the countdown to the TOBT has been reached, and the timer has begun counting up. (In this example, the flight is 4 minutes past its TOBT.)

Fig. 4. The countdown timer begins to count up after the TOBT has been reached and the color of the time notification changes to red. Also, a red border appears around the flight strip to alert the Ramp Controller.

Flights with Traffic Management Initiatives (TMIs) such as an Approval Request/Call for Release (APREQ/CFR) or an Expect Departure Clearance Time (EDCT), both of which require take-off within a given time window, have the relevant TMI information highlighted in yellow, as shown in Fig. 5. A recommended gate hold time is provided to reduce unnecessary wait time in the runway queue where they might burn excess fuel and block other aircraft. TMI information is shown on the ATD-2 tools whether there is surface metering or not, as it is relevant at all times.

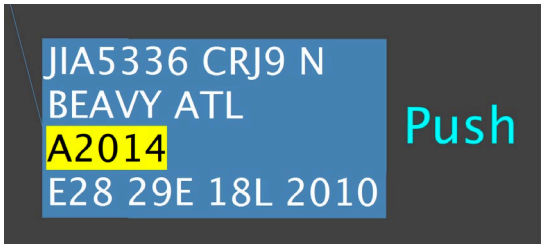

Fig. 5. Close up of flight strip at gate with APREQ release time highlighted in yellow.

Information available to users on the RTC includes the following:

- Runway utilization
- Runway assignments
- Miles-in-Trail (MIT) restrictions
- Approval Requests/Call for Release (APREQs/CFR)
- Expect Departure Clearance Times (EDCTs)
- Ground Stops at other airports
- Runway closures at CLT
- Departure fix closures
- Flight cancellations
- Gate conflict notifications for both arriving aircraft and aircraft at the gate
- Ramp closure
- Manual updates/corrections of flights
- Long on Board (LOB) common awareness

Also, many aircraft management options are available on the RTC including the ability to update a flight's hardstand, gate, spot, and runway assignments, including requesting a runway change for operational necessity. All of these updates will appear on both the RTC and STBO displays. The Ramp Managers' version of the RTC—the RMTC, differs from the RTC mainly by providing surface metering options, the operational status of the ramp, and a list of priority flights. Further information on the RTC and RMTC is available elsewhere [5].

B. ATD-2 Traffic Management Coordinator (TMC) Software Tools for the Tower and TRACON

The main display of the STBO Client is shown in Fig. 6. The Map shows surface traffic, and to the left and right of the Map, the runway Timelines show departing and arriving aircraft. The closer the aircraft are to the bottom on these timelines, the sooner they will depart or arrive. The leader lines of the aircraft datablocks (modified flight strips) on the Timelines are colored to indicate the current location of the aircraft (not visible in Fig. 6), e.g., whether aircraft are at the gate, in the ramp area untracked by the surface surveillance system, in the ramp area tracked by the surface surveillance system, or are on the airport surface.

The Flights Table provides more detailed information on each flight, and enables sorting on more than 50 variables, such as destination, departure fix, actual take off time (ATOT), estimated time of arrival (ETA), estimated time of departure (ETD), departure gate, airport origin, tail number, Target Movement Area entry Time (TMAT), etc. The specific information shown in the Flights Table can be configured by the user.

Fig. 6. The Surface Trajectory Based Operations (STBO) Client tool placed in the Tower, TRACON, and, in observer mode, in the Center.

The highlighted times on the right of some of the Timeline datablocks indicate that the flight has a "wheels up" or release time, i.e., it is subject to a TMI such as an APREQ/CFR when the aircraft must depart within a certain time window. Automation is in place such that the Tower TMC can now negotiate this time electronically via the datablocks on the Timelines with the Center TMC instead of

making a phone call, as was previously the case. Other types of TMIs are also shown on the timelines, for example EDCTs and Miles-in-Trail or MIT (restricted distances between departures going to a specific departure fix).

The Map, the Timelines and the Flights Table are all integrated with each other. Selecting an aircraft's callsign on the Timeline also highlights its location on the Map and in the Flights Table. This enables the user to find out all information on an aircraft quickly by highlighting its callsign on any one element.

The STBO Client also offers many aircraft management options, such as the ability to input into the system TMI restrictions such as current APREQs, MITs, and Ground Stops and information about airport operations such as runway closures, airport configuration, runway utilization, etc., that are disseminated to other ATD-2 tool users. Similarly, the Ramp can also input their decisions or requests (e.g., runway assignment, flight cancellation and ramp closure) through their RTC and RMTC user interfaces which are in turn displayed on the STBO Client. With the inputs of both the Tower and the Ramp, the ATD-2 tools provide a full operational view of the airport at any given time. Further information on the STBO is available elsewhere [6].

IV. Method of Assessing Human Factors Impact

A. Overview

Since CLT has periodic well-defined "banks" or clusters of arrivals and departures, brief electronic *post-bank* surveys were designed to tap respondents' workload, situation awareness, and perceptions of operations after each bank. This approach is typically used in air traffic management simulations after each "run," with different conditions in each run. The questions used in the post-bank surveys were pre-tested in earlier simulations [7, 8] to make sure they were sensitive to changes in conditions.

The online surveys were made available on the primary workstations of the users. Respondents were told that the surveys were voluntary, anonymous, and that they could stop at any time in conformance to the requirements of the Institutional Review Board at NASA Ames Research Center. Users were asked to take the surveys during the lulls between four banks (banks 2, 3, 6, and 7), two occurring in the morning and two in the afternoon per day, and to continue this for 5 days for each of the three rounds taking place in Sept. 2017, Nov. 2017, and March 2018. The surveys consisted of 1-5 item Likert-type rating scales and questions designed to elicit any comments the respondents might have.

B. Survey design

The introduction of the ATD-2 software tools occurred at different times depending on the timing of the respondents' training. The first step, therefore, was to ascertain the degree to which respondents were using the ATD-2 tools. This was accomplished by asking the following question: "Did you use ATD-2 tools to manage your traffic in this bank? Three options were given:

- Yes, I did actively use the ATD-2 tools a great deal to make decisions in managing traffic in this bank.
- Yes, I did occasionally refer to or use the information provided by ATD-2 tools during this bank.
- No, I did not use or refer to ATD-2 tools for any information in this bank.

In the third round of surveys, the respondents were also asked if there was a Surface Metering Program (SMP) in place during the bank.

1) Questions asked to All Respondents

In all facilities, respondents were asked to rate their workload on an adapted version of the NASA TLX rating scales on two of the most sensitive NASA TLX rating scales, Mental Demand and Time Pressure [9]. Situation awareness was measured with the 3D version of the Situational Awareness Rating Technique (SART), which consists of a score obtained by adding an item rating "your understanding of the traffic situation" to an item rating "the availability of your attentional resources" and subtracting an item rating "demand on your attention" [10].

2) Questions with Different Items for Each Type of Respondent.

Respondents in all facilities were asked to rate the acceptability and efficiency of airport operations that were important in their work domains. This required different items for each type of respondent since their tasks were different. In addition, Ramp Controllers and Managers were asked to rate how satisfactory the suggested hold times at the gates were for all aircraft, including those with APREQs and EDCTs.

V. Results

Survey results were compared between the following conditions based on the responses to the questions on ATD-2 tool use that were described earlier.

(1) No ATD-2 tool use,

(2) Active or occasional ATD-2 tool use, and

(3) Active ATD-2 tool use during surface metering.

Table I shows the number of those who returned surveys in each condition by each type of respondent. As can be seen, the number of those who returned surveys was smaller than desired in some categories, most notably the TMCs in Conditions 1 and 3. This reduces the extent to which there are statistically significant differences in ratings between conditions with the TMCs. (Comparisons with the

TRACON TMCs, with only 1 survey returned in Condition 1, are between Conditions 2 and 3.) To access the number of respondents in each condition in the following results section, the reader should refer to this table.

TABLE I. NUMBER OF SURVEY RETURNS IN EACH TYPE OF BANK BY TYPE OF USER

Respondents	Condition #1 No ATD-2 Tool Use	Condition #2 Active/ Occasional ATD-2 Tool Use	Condition #3 ATD-2 Tool Use + Metering	*Totals*
Ramp Controllers	55	107	37	*199*
Ramp Managers	11	30	10	*51*
Tower TMCs	5	13	4	*22*
TRACON TMCs	1	27	4	*32*
Totals	*72*	*177*	*55*	*304*

Results are presented graphically when possible. The error bars in the graphs are 95% Confidence Intervals (CIs) as recommended by the American Psychological Association [11]. These error bars can be used to gauge whether the means are significantly different from each other. If the confidence intervals around two means do not overlap or overlap only slightly, then generally the means are significantly different from each other. If there is a statistical difference between conditions on an item, the item will have standard asterisks indicating their significance level—p less than 0.05, one asterisk (*), p less than 0.01, two asterisks (**).

Results for three questions asked to all respondents will be presented first—two dealing with workload and one on situation awareness. In the section following this, the results for each type of respondent will be covered separately.

A. Workload

Respondents were asked to rate their Level of Mental Demand (thinking, deciding, calculating, remembering, and searching) when they were busiest during the previous bank. As can be seen in Fig. 7, respondents reported moderate or lower workload in all conditions except the TRACON TMCs in the ATD-2 tools only condition. The higher ratings of "4" in that condition were described as being caused by unbalanced arrival flows, dual feeds, and volume; the TRACON TMCs fared significantly better in the metering condition, perhaps due to less congestion in the AMA from metering ($t(df\ 29) = 2.6$, $p = .02$). The Ramp Managers rated their level of mental demand as lower in the condition without ATD-2 tools, but this was not statistically significant.

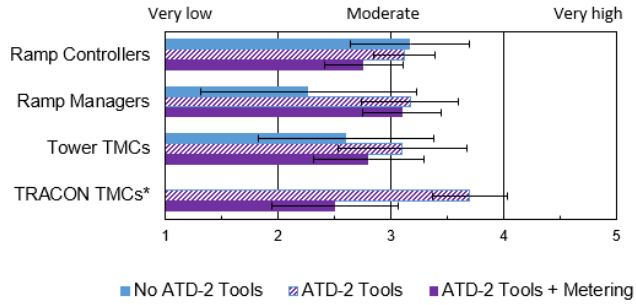

Fig. 7. Respondents' ratings of mental demand when they were busiest during the previous bank.

Respondents were also asked to rate the level of time pressure (pace or time to complete task goals) when they were busiest during the previous bank. As can be seen in Fig. 8, all respondents rated the level of time pressure as moderate or lower. The Ramp Managers rated the time pressure as statistically significantly lower in the condition without ATD-2 tools than in the ATD-2 tools only condition (ANOVA $MS = 4.3$ $F(2,162) = 4.5$, $p = .02$).

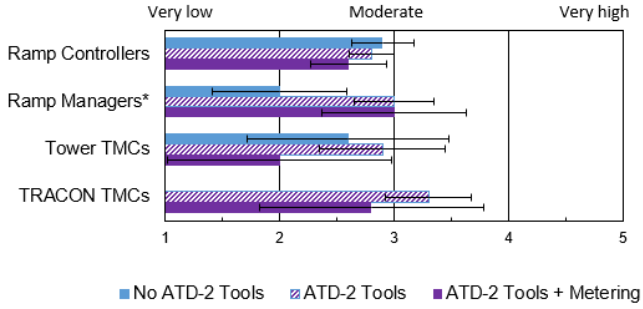

Fig. 8. Respondents' ratings of level of time pressure when they were busiest during the previous bank.

B. Situation Awareness

Fig. 9 shows that SART scores were moderate or higher for all respondents. Ramp Controllers had a statistically significant increase in their average SA score in the metering condition compared to the condition without ATD-2 tools (ANOVA $MS = 7.3$ $F(2,162) = 4$, $p = .02$). All conditions were significantly different from each other for the Tower TMCs, with both ATD-2 tool conditions increasing situation awareness scores (ANOVA $MS = 14.0$, $F(2,17) = 8.6$, $p = .003$).

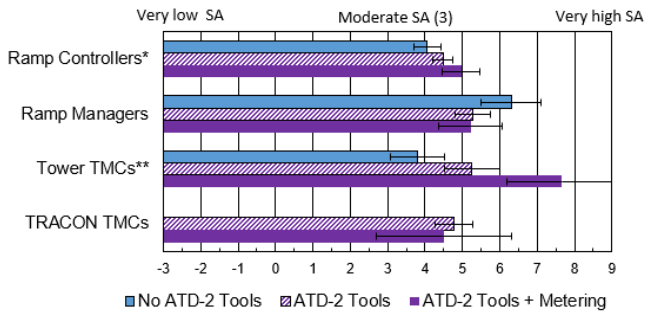

Fig. 9. Respondents' SART situation awareness scores. Error bars = 95% CIs.

C. *Overview of Each Type of Respondent by Condition*

1) Ramp Controllers

As shown in Figs. 7 and 8, Ramp Controllers' workload as measured by the TLX items "Mental demand" and 'Time pressure" was moderate or lower in all conditions. These results address one of the major questions of this research, since Ramp Controllers could logically be expected to have higher workload in the metering condition since they are responsible for considering aircraft hold times at the gates in addition to their other tasks. Their average situation awareness score was significantly higher in the metering condition compared to the condition without ATD-2 tools.

Ramp Controllers were also asked to rate the acceptability of operations in various performance areas when they were busiest during the previous bank. As can be seen in Fig. 10, the ATD-2 tools only condition trended highest in all performance areas, and "hold times at the hardstands" had statistically significant higher acceptability ratings in the ATD-2 tools only condition than both other conditions (MS = 9.2, $F(2,109)$ = 6.4, p = .002). The result regarding "hold times at the hardstands" indicates that the early notification of gate conflicts displayed in the RTC tool may have led the Ramp Controller to arrange for an earlier departure for the aircraft at the gate. This would lead to a reduced time for arrivals to wait in the hardstands, where they typically are held to wait for their gate to open in case of a gate conflict. The metering condition was seen as significantly less acceptable than the ATD-2 tools only condition for both "Hold times at the gates" (ANOVA MS 3.6, $F(2,171)$ = 3.9, p = .04) and "Hold times at the hardstands" (MS = 9.2, $F(2,109)$ = 6.4, p = .002). This suggests that there may be more congestion in the metering condition with more aircraft in the ramp area. However, for both these items the metering condition was not significantly less acceptable than the condition without ATD-2 tools.

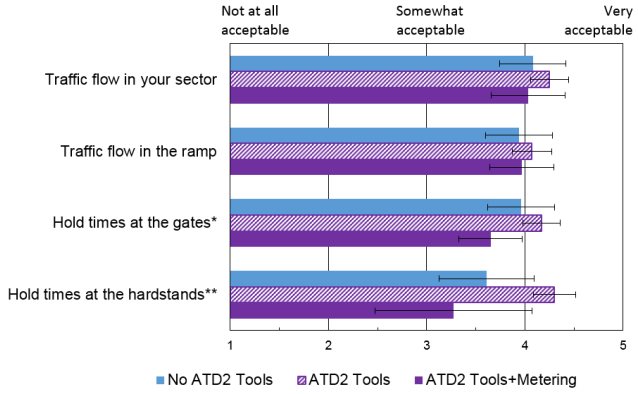

Fig. 10. Ramp Controller responses to "During the busiest time in this bank, how acceptable were the following?" Number of ratings = 53, 106, 37 in Conditions 1, 2, and 3 respectively for top 2 items; less for hold times at gates (50, 87, 37) and hardstands (36, 61, 15) since not all Ramp Controllers had a hardstand in or near their sector. Error bars are 95% CIs.

Ramp Controllers were asked "During the busiest time in this bank, how did the following impact operational efficiency?" Fig. 11 shows that the conditions had little impact on efficiency, either negative or positive. The one exception was "Hold times at the hardstands" in the metering banks which was judged to decrease efficiency compared to the banks with ATD-2 tools only (ANOVA MS = 4.0, $F(2, 115)$ = 4.1, p = .02), but again, not compared to the banks without ATD-2 tools.

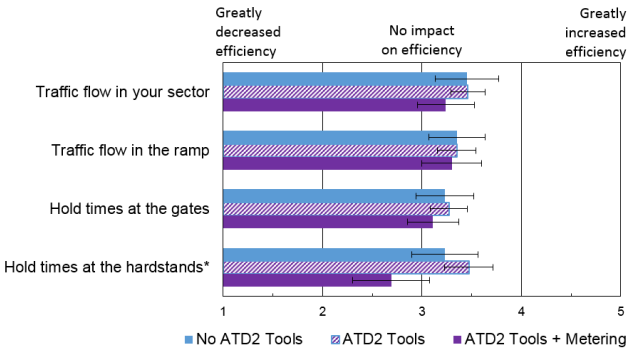

Fig. 11. Ramp Controllers' responses to "During the busiest time in this bank, how did the following impact operational efficiency?" Error bars are 95% CIs.

An important contributor to efficiency is whether the length of the hold times in the ATD-2 tool conditions are appropriate for flights with TMIs. As shown in Fig. 12, Ramp Controllers rated gate hold times as "just right" for aircraft with scheduled departure times at the runways in both ATD-2 tool conditions. The Ramp Managers' ratings were similar.

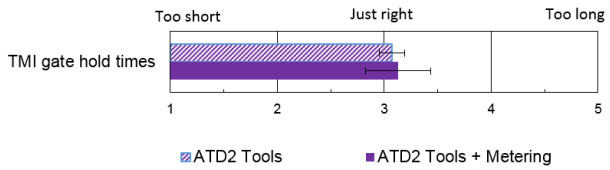

Fig. 12. Ramp Controllers' responses to "Please rate the length of TMI gate hold times recommended on the RTC to support airport efficiency." Error bars are 95% CIs.

In sum, the human factor results for Ramp Controllers indicate that 1) there were no statistically significant differences between the conditions on the workload measures, and 2) situation awareness scores were higher in the metering condition with the tools than the condition without the tools. Regarding perceived acceptability and efficiency of operations, in no case were banks with ATD-2 tools rated as having operations statistically significantly less acceptable and efficient than the no ATD-2 tool banks.

2) Ramp Managers

As shown in Figs. 7 and 8, the Ramp Managers' ratings trended higher with the ATD-2 tools than without on mental demand, and time pressure was rated as statistically significantly higher when with the ATD-2 tools than without. The Ramp Managers' situation awareness scores also trended lower in the ATD-2 tools conditions (Fig. 9).

It may be that Ramp Managers engage in more tasks while using the ATD-2 tools. The ATD-2 tools offer Ramp Managers earlier information on EDCTs, APREQ/CFRs, and gate conflicts, which increase their options for improving airport efficiency, but which may demand more of their attention. For the metering condition, Ramp Managers described surveillance of the "entire airport operation" as a factor contributing to their workload. At the time, the Ramp Managers were in charge of deciding when surface metering would occur, and this would indeed increase the need to attend to the entire airport operation, instead of just the ramp. Since it is the Tower TMC who now decides when to institute surface metering, with the help of automation, this workload factor would have markedly decreased for the Ramp Manager.

However, it should be noted that the average ratings on the human factors measures in the ATD-2 conditions did not indicate any severe problems. For example, the Ramp Managers rated "Time pressure" in the ATD-2 tools conditions as "Moderate," i.e., an average of "3" on a scale of 1-5 compared to an average of "2" in the no tools condition. The average ratings were similar regarding "Mental demand." Hence the minor increase in workload and time pressure in the ATD-2 tool conditions did not appear to be problematic for the Ramp Manager.

Turning to acceptability of operations, Ramp Managers rated all of the performance areas most relevant to them as about a "4" on a scale of 1-5, with 5 being "Very acceptable," as shown in Fig. 13. The condition without ATD-2 tools trended to be most acceptable, although the only item that reached statistical significance was "Hold times at the gate" (ANOVA MS = 1.3, $F(2,38)$ = 4.7, p = .02) which, in the two ATD-2 conditions, was still rated as acceptable at an average of 4 on a 1-5 scale.

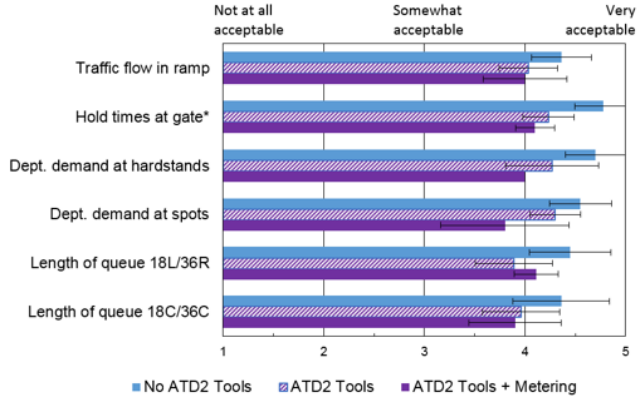

Fig. 13. Ramp Managers' responses to "During the busiest time in this bank, how acceptable were the following?" Error bars are 95% CIs.

Further evidence that "Hold times at the gate" was not seen as a problem in the ATD-2 tool conditions by the Ramp Managers were their average ratings for the same item regarding operational efficiency. It can be seen in Fig. 14, that "Hold times at the gate" had, if anything, a slight positive impact on operational efficiency, although this was not statistically significant.

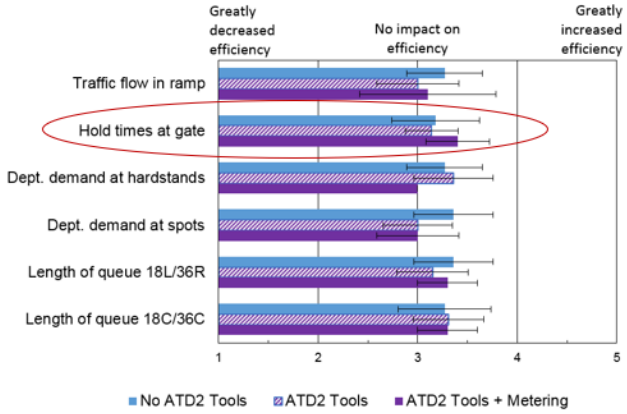

Fig. 14. Ramp Managers' responses to "During the busiest time in this bank, how did the following impact operational efficiency?" Error bars are 95% CIs.

In sum, the Ramp Managers may have more tasks when using the ATD-2 tools which may increase their workload and time pressure somewhat, and which might cause slightly less acceptable increased hold time at the gates, but the increases are not major and do not appear to be problematic for the Ramp Manager nor for operations.

3) Tower TMCs

Tower TMCs rated their workload and time pressure as moderate or below in all three conditions, as shown in Figs. 7 and 8. Their SART scores for situation awareness shown

in Fig. 9 were statistically significantly different by condition, being rated as "Moderate" in the condition without ATD-2 tools, higher in the ATD-2 tools only condition, and as "very high" in the ATD-2 tools plus metering condition. Tower TMCs were especially enthusiastic about the increased situation awareness the ATD-2 tools provided them. Example comments were:

> "The STBO timelines and tables provide a very comprehensive view of what is occurring now, and what is about to occur in the immediate and near future."

> "Having all Departures, Arrivals, and TMIs on one timeline provides an invaluable view of the traffic picture on the surface and immediate vicinity of the airport."

Regarding ratings on the acceptability of areas within the Tower's domain, as shown in Fig. 15, there were no significant differences between the conditions, although there was a trend for the banks with ATD-2 tools (both ATD-2 tools only and ATD-2 tools plus metering) to be more acceptable.

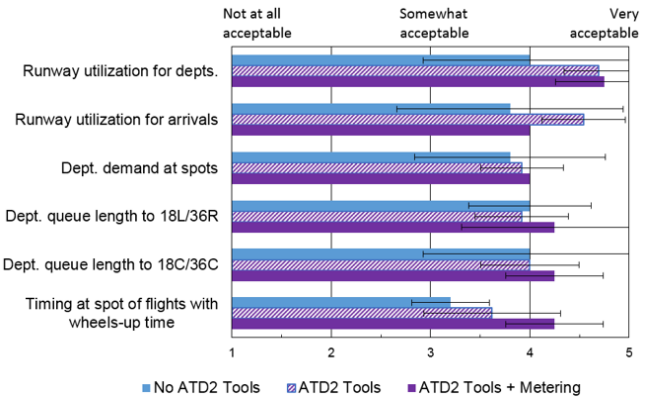

Fig. 15. Tower TMCs' responses to "During the busiest time in this bank, how acceptable were the following?" Error bars are 95% CIs.

However, regarding efficiency of operations, there were statistically significant differences in the Tower TMCs' ratings. They were asked, "During the busiest time in this bank, how did the following impact operational efficiency?" Fig. 16 shows that in the banks with ATD-2 tools (both tools-only and tools plus metering), the TMCs rated the following two items as more efficient than the banks with no ATD-2 tools: "Runway utilization for arrivals" (ANOVA MS = 7.3, $F(2,14)$ = 5.8, p = .01) and "Timing at spot of flights with wheels-up time" (ANOVA MS = 4.2, $F(2,19)$ = 5.6, p = .01). Correct timing at the spot for TMI aircraft contributes to airport efficiency since it reduces the extent to which the Tower TMCs have to renegotiate a take-off time for TMI aircraft with the Center and reduces possible interference with traffic flow in the AMA by TMI aircraft with times they cannot meet.

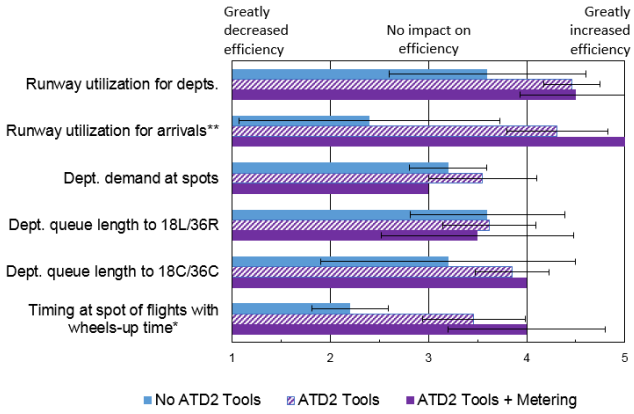

Fig. 16. Tower TMCs' responses to "During the busiest time in this bank, how did the following impact operational efficiency?" Error bars are 95% CIs.

In sum, Tower TMC situation awareness increased significantly with the ATD-2 tools and again increased significantly with the ATD-2 tools plus metering with a "Very high" SART score. Their comments expressed enthusiasm and appreciation for their increased situation awareness. Efficiency of operations was rated statistically significantly higher in the two tools conditions compared to the no ATD-2 tools in regard to increased efficiency for "runway utilization for arrivals" and "timing at the spot for TMI flights."

4) TRACON TMCs

There was only one TRACON TMC rating in the no ATD-2 tools banks due to their early training on the STBO Client. Therefore, the comparison of the ratings was limited to banks in conditions 2 and 3, the ATD-2 tools with and without metering.

Regarding the human factor items shown in Figs. 7, 8, and 9, TRACON TMCs rated their average "Mental demand" as above "Moderate" (3.8) in the ATD-2 tools without metering, and below "Moderate" (2.5) in the metering banks, a difference which is statistically significant. Their higher average ratings for "Mental demand" in banks without metering were described as being caused by unbalanced arrival flows, dual feeds, and volume. "Time pressure" trended lower in the metering condition for the Tower TMCs as well. It is possible that metering during the busiest time improved operations in the AMA which affected the TMCs' mental demand and time pressure. TRACON TMCs described their situation awareness as moderate and similar in both conditions. As one former TMC said, "When departures are able to get off the airport more efficiently, arrivals are able to land more consistently with fewer requests by the tower to stay off a badly delayed or backed-up departure runway."

In terms of acceptability of operations in areas important to the TRACON TMC, as shown in Fig. 17 ratings were not significantly different between the two ATD-2 tool conditions, although the acceptability of the banks with metering trended higher.

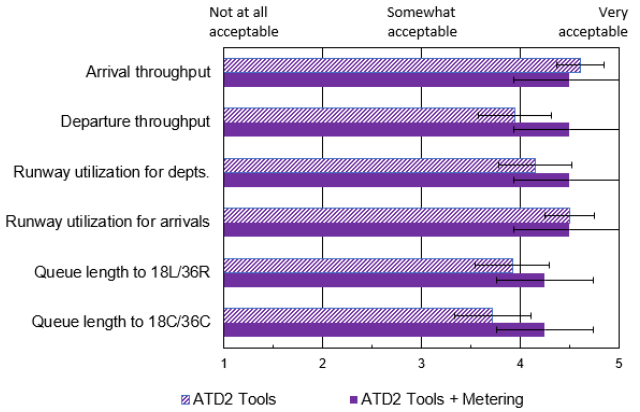

Fig. 17. TRACON TMCs responses to "During the busiest time in this bank, how acceptable were the following?" Error bars are 95% CIs.

In terms of efficiency of operations, as shown in Fig. 18, all of the TRACON TMCs' average ratings were on the efficient side of the scale (i.e., greater than 3) and were similar in the two tool conditions, with the metering conditions trending higher.

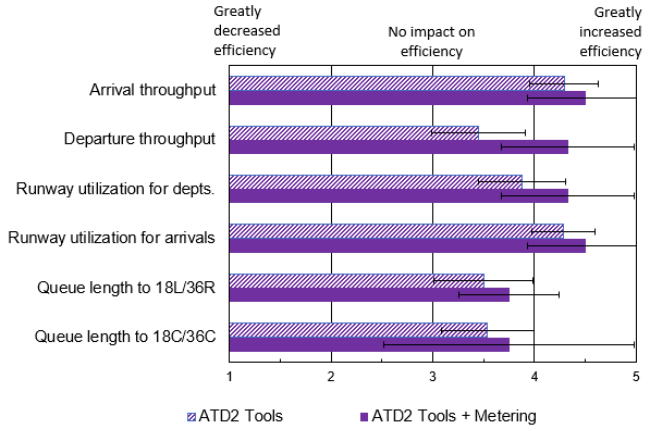

Fig. 18. TRACON TMCs' responses to "During the busiest time in this bank, how did the following impact operational efficiency?

In sum, the TRACON TMCs' workload was significantly reduced in the metering condition compared to the ATD-2 tool condition without metering, and acceptability and operational efficiency ratings in areas important to the TRACON TMCs, also trended higher in the metering condition. It is possible that metering improved conditions on the AMA and contributed to this improvement.

5) All Respondents Rated ATD-2 Tools as Helpful

In November 2017 and March 2018, the Ramp Controllers and Ramp Managers were asked, "Were the ATD-2 tools helpful in this bank?" The Tower and TRACON TMCs were asked this question in March 2018 only.

As can be seen in Fig. 19, all respondents rated the ATD-2 tools as helpful, with means ranging from 3.8 for the TRACON ATC in the ATD-2 tools only condition to 5.0 for the Tower TMC in the ATD-2 tool plus metering condition. One TMC respondent who worked in both the Tower and the TRACON noted that,

> "ATD-2 is very beneficial to the efficiency of the operation in the tower, [but] not as much in the TRACON."

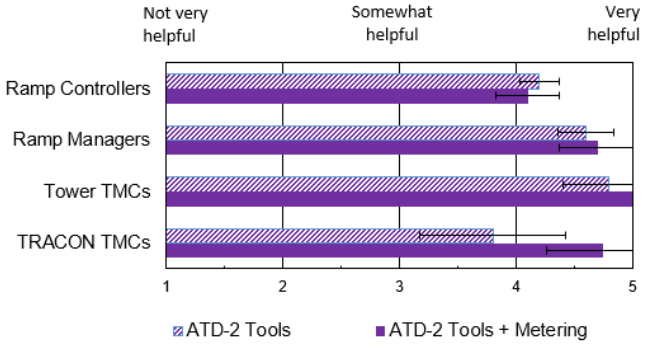

Fig. 19. Respondents' ratings of helpfulness of ATD-2 tools. Number of ratings were 93 & 36 for Ramp Controllers, 27 & 9 for Ramp Managers, 5 & 4 for Tower TMCs, and 9 & 4 for TRACON TMCs. Error bars are 95% CIs.

VI. Discussion

1) Pros and Cons of the Post-Bank Survey Approach

Eliciting human factors' input through surveys available to respondents during lulls between different types of banks in the field is an ambitious undertaking. It has the advantage of eliciting non-biased responses from respondents that are based on actual operations in each type of bank, which increases confidence in the results. This approach is similar to simulated research environments where a survey is often administered following each *run*. However, it does not take advantage of the respondents' own comparative assessments of the conditions after experiencing them all, as is typically done at the *end* of a simulation. This "post-simulation" type of survey can be a useful substitute for, or addition to, the "post-bank" approach [12].

Costs to the post-bank approach involve the need to carefully design and test the survey items in previous simulations to make sure the items tap differences between conditions. It appears that the items chosen for this study were successful in that regard. Perhaps the most significant cost, however, has to do with the workload of the respondents themselves, who understandably would much prefer to take their breaks than to fill out surveys. This can result in further costs incurred by researchers and project personnel in efforts to encourage them to take the surveys. In these efforts, care must be taken not to jeopardize the operators' good will, which is essential for a successful field demonstration.

VII. Conclusion

Considerable information was gained from the surveys on how using the ATD-2 tools affected the various users. In no case was there prohibitively high workload or decreased situation awareness associated with the tool use--in fact for many users the opposite was true. Also, the acceptability and operational efficiency measures indicated that the users did not perceive that the banks with ATD-2 tools were less acceptable or efficient than the banks without ATD-2 tools. The Ramp Controllers and Ramp Managers described the TMI hold times at the gate as "about right." All respondents rated the ATD-2 tools as helpful.

The summarized results for each of the four different types of respondents at CLT are briefly described below.

Ramp Controllers' human factor ratings showed no significant differences between mental demand and time pressure in the three conditions. Situation awareness was rated as significantly higher in the ATD-2 tools with metering condition than with no ATD-2 tools. Regarding perceived acceptability and efficiency of operations, in no case were banks with ATD-2 tools rated as having operations that were statistically significantly less acceptable and efficient than the no ATD-2 tool banks.

Ramp Managers' average ratings of mental demand and time pressure increased to "Moderate" when using the ATD-2 tools. ATD-2 tools offer Ramp Managers many options to improve airport efficiency and interacting with these features may require cognitive resources. Ramp Managers perceived less acceptable increased hold times at the gates in the banks with metering, but this item was still rated as a "4" on a 1-5 scale of acceptability.

The Tower TMCs' situation awareness increased significantly with the ATD-2 tools and again increased significantly with the ATD-2 tools plus metering to produce a "Very high" SART score in that condition. In their comments, Tower TMCs expressed enthusiasm and appreciation for their increased situation awareness. Efficiency of operations was rated statistically significantly higher in the two tools conditions compared to the no ATD-2 tools condition specifically in regard to increased efficiency for "runway utilization for arrivals" and for "timing at the spot for TMI flights."

The TRACON TMCs' workload was significantly reduced in the metering condition compared to the ATD-2 tool condition without metering. The acceptability and operational efficiency in areas important to the TRACON TMCs also trended higher in the metering condition. It is possible that surface metering improved conditions on the AMA which allowed for this improvement.

It was important to assess the human factors impacts of the ATD-2 tools and surface metering, even though the post-bank survey technique was costly in terms of requiring controller input after multiple banks.

Acknowledgments

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