Eye-Tracking Analysis of Near-Term Terminal Automation for Arrival Coordination

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Sponsored by the Federal Aviation Administration (FAA), The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) developed the Relative Position Indicator (RPI) concept. RPI is an automation concept to aid air traffic controllers in coordinating arrival traffic, reducing the need to vector for spacing during merging operations and, thus, retaining the benefits of Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures. Using an RPI research prototype, CAASD has conducted Human-In-The-Loop (HITL) simulations with ATC specialists at Denver Terminal Radar Approach Control (TRACON) facility. Utilizing an eye-tracking capability, CAASD evaluated the change in attentional allocation between scenarios with RNAV procedures utilizing the RPI automation and with RNAV procedures alone. The eye-tracking analysis provides preliminary indications that RPI does change air traffic controller visual scanning patterns, likely resulting from the increased density of desirable information in a smaller region of the surveillance display.

I. Introduction

Implementation of terminal Area Navigation (RNAV) and Required Navigation Performance (RNP) arrival procedures in the National Airspace System (NAS) have resulted in operational benefits, including reduced ground to flight-deck voice communication, improved situational awareness, reduced flying time and distance, improved predictability, and increased throughput. To maintain these benefits, aircraft must fly the assigned RNAV or RNP procedure to the extent possible. This objective is complicated in high density arrival terminal airspace, where the current Air Traffic Control (ATC) practice is to vector aircraft off RNAV and RNP procedures in order to achieve the proper sequencing and spacing (Fig. 1) [1]. Even with existing Time-Based Metering (TBM) capabilities, such as the Traffic Management Advisor (TMA), and workload management through the splitting of busy terminal controller positions, controllers often cannot achieve proper spacing of merging traffic using speed control alone and must vector flights off of the RNAV or RNP procedures.

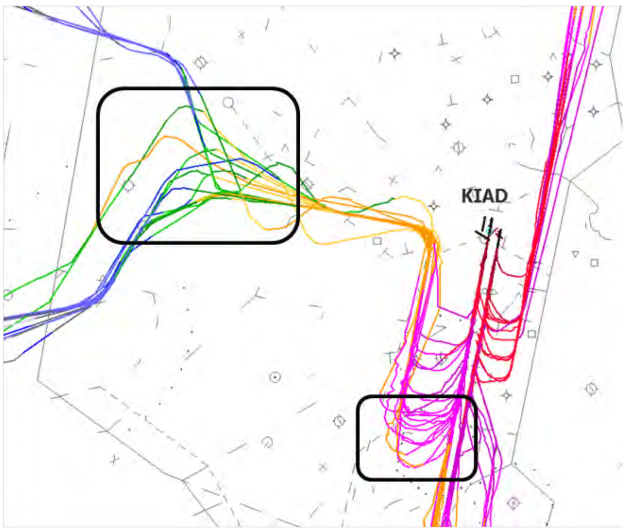

Figure 1. Vectors for Arrival Spacing. *This historic track data depicts RNAV arrival operations into Dulles International Airport. Note the dispersion of the tracks near within the highlight merge points.*

A. Near-Term Automation for Arrival Coordination

In order to formulate the clearances needed to achieve the desired spacing for merging aircraft, air

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traffic controller often estimate the flight path distance of each aircraft to the merge point (taking into account the geometry of the RNAV or RNP path for each aircraft). Ideally, the controller would use one relatively minor speed clearance early in the process to retain the predictability of the operations while achieving the desired spacing. While speed control alone does not always provide enough maneuverability to resolve a merging and spacing conflict, often the inability of controllers to fully utilize speed clearances results from a difficulty in visualizing the relative distances of aircraft from the merge point on converging paths. The Relative Position Indicator (RPI) is a concept for an automation capability which accurately projects an *indicator target* (or *target image*) of an *aircraft target* on a multi-segmented RNAV arrival path [2] (Fig. 2)[5]. A previous study determined that flight dynamics of target images produced by RPI are acceptably close to their aircraft targets over a wide range of operational conditions [3].

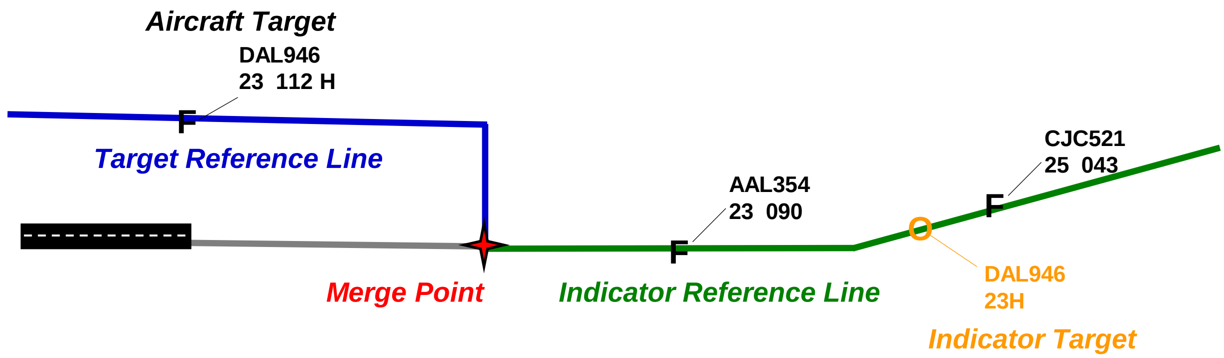

Figure 2. Depiction of a Generic Relative Position Indicator (RPI) Application. *The indicator target of the aircraft on the Target Reference Line is depicted the same distance away from merge point along the Indicator Reference Line, accounting for turn anticipation through the route segment transition.*

The authors consider RPI a near-term automation concept because it leverages current aircraft equipage, utilizes existing surveillance data, and it is believed its implementation would involve negligible changes to the current activities and responsibilities of the air traffic controller workforce. Other concepts, including flight deck based merging and spacing, required or controlled time of arrival (RTA or CTA) capabilities, and more "active" advisory based automation (often utilizing trajectory modeling), are feasible compliments or alternatives to RPI in the long term, but the authors consider the wide spread implementation of these concepts to be difficult in the near term timeframe. In contrast, RPI's ability to leverage existing automation in the Common Automated Radar Tracking System (CARTS) and Standard Terminal Automation Replacement System (STARS), in the form of the Converging Runway Display Aid (CRDA), may allow for relatively low cost and a short implementation schedule[6].

Implementation of any new automation with an interface component changes the way that the human interacts with the system. These changes may provide both opportunities for benefit and risk of unintended impacts. The means of achieving benefit and the potential magnitude of the benefits of RPI implementation have been explored in a previous study [5]. That study posited a preliminary estimate of $100 million annually in reduced aircraft operating cost through implementation at the top 35 busiest airport in the United States' National Airspace System (NAS). This study, which focuses on the results of an eye-tracking analysis of Human-In-The-Loop (HITL) simulations of operations at Denver Terminal Radar Approach Control (TRACON), intends to expand on that study's interpretation of how the benefits of RPI are achieved. It also expands the scope of the discussion to include potential impacts which may result from use of RPI in conjunction with other controller automation tools and concepts.

II. Background

One of the primary ways a controller gathers information is by visually scanning the surveillance display. Visual scanning refers to a systematic and continuous effort to acquire all necessary visual information in order to build and maintain awareness of activities and situations that may affect the controller's area of responsibility [6]. Controllers

[5] RPI is a concept developed by the Center for Advanced Aviation System Development. An RPI research prototype has been developed and integrated in to CAASD's "TARGETS" simulation capability. All subsequently described studies and evaluations have used this RPI research prototype.

[6] CRDA is more fully specified in Ref. 4.

not only scan the location of aircraft but also the data block fields (e.g., speed, altitude, aircraft identification, and equipment type) to update their understanding of the current state of the airspace. Controllers scan using saccades, which are discrete jerky eye movements that jump from one stationary point in the visual field to the next. In between saccades, the visual system uses fixations, which are characterized by a location (the center of the fixation), a useful field of view (diameter around the central location from which information is extracted), and a dwell time (how long the eye remains at that location) [7]. During the saccade, the visual system suppresses visual inputs and so display information can only be properly processed during fixation.

Controllers build a comprehensive mental representation of the current traffic scenario using information perceived through visual scanning (external) (e.g., on the radar situation display) and mental model[7] sources (internal) [8]. The representation is commonly referred to as 'the picture'. Mental models (i.e., knowledge) guide the controller's visual sampling process [7]. An accurate and up-to-date mental model, supported by a high level of situation awareness[8] is critical because "it provides a mechanism for guiding attention to relevant aspects of the situation, integrating information perceived to form an understanding of its meaning, and projecting future states of the system based on its current state and an understanding of its dynamics" [9].

B. Controller Visual Scan Changes

Because controllers depend on information acquired through visual scanning, it is critical to quantify the effect of new technology or procedures on visual scan behavior. A study performed by the Federal Aviation Administration (FAA) Technical Center measured TRACON controller visual scan in high and low traffic loads [11]. The terminal operations evaluated consisted of conventional procedures (i.e., with arrivals vectored on the downwind and turned to base to intercept the localizer). Results showed that controllers developed scanning patterns that focused on the areas of highest traffic density. Findings showed that controllers spent 78% of their time in fixations with controllers spending most of their time fixating on aircraft targets and data blocks [11]. That result also means that controllers spent 22% of their time in saccades, which means they are not acquiring viable information 22% of the time [11]. Fixations on aircraft representations lasted longer than fixations on any other item, suggesting that controllers were engaged in deeper levels of mental processing when they looked at aircraft representations [11]. Other findings showed that with increased traffic, the number of fixations on the situation display decreased [11].

To date, it is unknown how the introduction of RNAV and RNP procedures may affect the controller's scan. Understanding how the amount of saccades, fixations, and dwell time experienced by the controller changes, especially when managing airspace with multiple types of RNAV or RNP procedures, should be evaluated. As more cognitive processing is required to determine whether aircraft are conforming to the RNAV or RNP procedure, dwell time is likely to increase. Additionally, increasing the amount of traffic managed by a controller, as a result of adding RNAV and RNP procedures within the same airspace, may have the potential of decreasing fixations and dwell time while increasing saccades, as the controller makes an effort to keep pace with the increase of traffic. Because visual information is not gathered during saccades, such a scanning change could have an adverse impact on controller performance. Further study regarding controller visual scan is needed in order to assess the operational impact of future RNAV and RNP procedures.

C. Previous RPI Eye-Tracking Study

A preliminary usability assessment of the RPI research prototype, using an eye-tracker, showed an interesting trend in the visual scanning behavior of one controller [12]. The controller, who was familiar with the RPI tool, was asked to work two scenarios in which aircraft were merging from two paths onto one (Fig. 3). The scenarios were 20 minutes each, and were identical, except for the aircraft identifications. Fig. 3 depicts regions of the screen which were used in conjunction with the eye-tracking equipment to determine the percentage of time that the controller's gaze was fixed in different areas of the display when RNAV procedures and RPI were available, and when only RNAV procedures were available. In the scenario with RNAV and RPI, the indicator targets were projected onto the bottom path. The region 8 labeled "markers" refers to any area of the map display that controller used to help make distance calculations, such as range rings or map markings. Note that these are data from only <u>one</u> controller, and more research is needed to more fully understand the impact of this tool on controller behavior. These data simply

[7] Mental models embody stored long-term knowledge that can be recalled upon to direct problem-solving and interaction with the relevant system when needed [9].
[8] Situation awareness is "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" [10].

suggest a trend that helps demonstrate how RPI can impact the visual sampling behavior of a controller. The results of these two simulations are presented in Table 1.

The data illustrated in Table 1 suggest that controllers may spend considerably more time fixated on the path where the RPI tool allows the controller to view indicator targets, while spending less time looking at the path where those aircraft are actually flying. Furthermore, it appears that less time is spent fixating on other regions of the display (including more conventional distance estimation markers on the display map). This is an example of the impact that changing any feature of the operational environment has on the demands of the task, and ultimately the behavior of the human. It is important to highlight that new behaviors, driven by the existence of automation, have a number of positive implications. Mainly, humans are able to optimize their efforts by reallocating their cognitive/perceptual resources away from tasks where the automation is providing assistance onto other tasks that can benefit from additional attention. In most cases, this shift in attention increases the overall performance of the system. For example, in a study in which the impact of RPI was evaluated, controllers subjectively "indicated that it helped them provide better service" [13]. However, it is important to understand that this automation-driven shift of attention means a controller is less likely to notice a situation or event within the space or task that is receiving support from the automation.

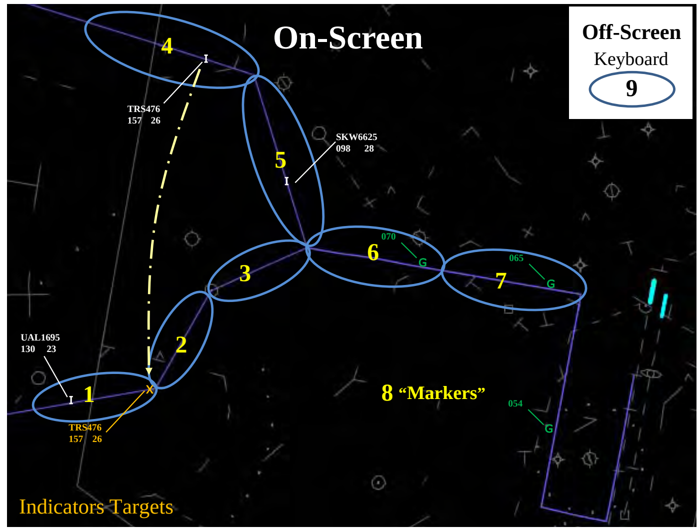

Figure 3. Eye-tracking Areas of Interest. *Nine zones were established for fixation analysis of the West feeder controller.*

Table 1. Fixations for RNAV and RNAV WITH RPI Scenarios. *The table shows the percentage of time that one controller spent fixated on different areas of an ATC display when using the RPI tool, and without it (Mapped to Regions in Figure 3).*

Region	RNAV (% of total)	RNAV & RPI (% of total)	RPI minus RNAV (% of total)	Change Greater than 5% (% of total)
1	9	18	9	9
2	13	39	26	26
3	8	7	-1	0
4	13	4	-9	-9
5	13	2	-11	-11
6	12	7	-5	-5
7	7	8	1	0
8	24	13	-11	-11
9	3	5	2	0

Because the expectations of controllers' responsibilities are likely to remain unchanged in near-term terminal environments, controllers will still be required to maintain high levels of situation awareness, as well as detect and resolve potential aircraft conflicts. Similar to the new skill requirements identified as a function of introducing RNAV procedures, the implementation of automated decision support aids such as RPI may require training programs that instill disciplined visual scanning patterns throughout the entire ATC display. As expressed by the controller who participated in the RPI usability evaluation, "you'll need to make sure controllers continue to look at aircraft up there [on the non-RPI path] to make sure there isn't other traffic around them."

III. Methodology

A. Overview of Denver Human-in-the-Loop Evaluation

New RNAV SID and STAR procedures are currently being designed to balance workload between the Denver Air Route Traffic Control Center (ARTCC) facility (ZDV) and the Denver TRACON facility (D01) to address workload and efficiency of operations at Denver International Airport (DEN). The RNAV and RPI eye-tracking analysis was conducted as part of the HITL simulation, depicted in Fig. 4, which evaluated a set of proposed RNAV arrival procedure designs into DEN.

Figure 4. Human-In-The-Loop (HITL) Evaluation at Denver TRACON. *The mobile HITL equipment includes monitors, QWERTY keyboards, trackball mice, and laptops for simulation pilots to input the controller-issued instructions into the simulation software.*

The intent of the Denver HITL simulation was to assess the operational acceptability of proposed RNAV STAR procedure designs, from the perspective of Denver TRACON controllers. The HITL simulation was also used as a means for identifying issues that might preclude publication of these procedures at Denver in the near-term. To evaluate the effects of RNAV on TRACON operations, baseline scenarios were conducted to capture the "as is" state of operations, from which comparisons to the RNAV scenarios could be made. In the baseline scenarios, controllers worked traffic as they do today, using existing conventional arrival procedures. In the RNAV scenarios, controllers worked the same traffic from the corresponding baseline case (with different aircraft identifications), using the proposed RNAV arrival procedures. Additional RNAV scenarios introduced RPI to help controllers identify potential merge issues at the intersections of the RNAV arrival flows.

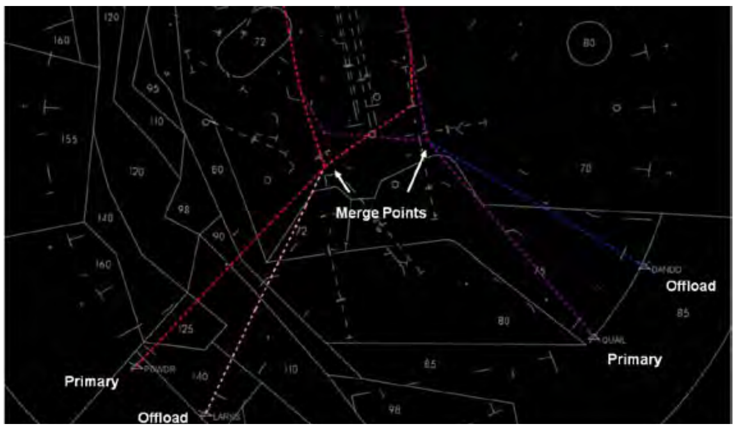

Figure 5. Denver HITL STAR procedures. *The RPI eye-tracking analysis focused primarily on the South East Feeder controller airspace (highlighted region).*

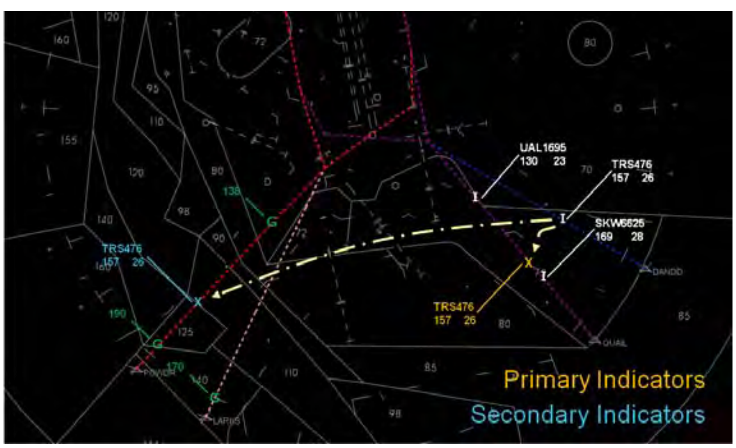

Figure 6. Denver HITL RPI Applications. *The RPI eye-tracking analysis focused primarily on the South East Feeder controller airspace (highlighted region).*

The evaluated RNAV design for aircraft landing to the south (depicted in Fig. 5) consists of dual arrival procedures from the southeast and southwest corner posts, with each pair of routes merging into a single flow at the start of their corresponding near-side downwind leg. One route at each corner post is designated as the primary route for turbojet aircraft, while the other route serves as an offload option for slower turboprops, or for turbojet aircraft that cannot be accommodated on the primary route due to heavy traffic volume. The design also includes an alternate runway transition for each route for sending aircraft over the top of the airport to the far side downwind for landing on an alternate runway.

It was envisioned that RPI might be able to assist controllers with managing the initial merge point of the dual RNAV arrivals, or for assisting with the decision of whether to send an aircraft over the top to the opposite downwind to provide a better fit in the arrival sequence. An illustration showing how RPI was applied in the scenario is provided in Fig. 6. The eye-tracking evaluation portion of the HITL focused on the South East Feeder controller position at Denver TRACON.

B. Eye-Tracking Equipment

The equipment used was the Applied Science Laboratories Mobile Eye eye-tracking system. The Mobile Eye is a head-mounted eye-tracker which records a scene video with an overlaid image of the subject's eye gaze. Data reduction and analysis are conducted manually, through a frame-by-frame playback of the video at a rate of .5 Hz.

C. Evaluation Participant

The evaluation participant was a Denver TRACON Certified Professional Controller (CPC) currently certified to work the affected South East controller position. The participant had no prior experience being evaluated with eye-tracking equipment.

IV. Results

A. Eye-Tracking Results

To analyze the eye-tracker playback, regions were defined on the simulated surveillance display and for off-screen areas within the vicinity of the controller's workstation (Fig. 7). The numerical results of the fixation analysis clearly depend entirely on the size and location of the defined regions[9]. Based on the previous RPI eye-tracking study, the regions were defined considering the hypothesis that RNAV procedures and the RPI indicators would be the primary fixation zones on the surveillance display. The extent of each region was defined with the intent of enabling a comparison across the two scenarios that was both meaningful (tending towards creating more regions) and accurate (tending toward fewer regions, based on the accuracy of the eye-tracking equipment). An example of one eye-tracking observation from the RNAV and RPI scenario is depicted in Fig. 8. Due to the manual process for calculating the fixations in each region, the regions were decided upon prior to binning the results. Until a more automated process for converting the eye-tracking playback into bins is established, each manipulation of the regions would result in a need to review the playback for the new binning schema.

Each eye-tracking scenario lasted approximately 45 minutes; however, only 17 minutes of data were analyzed as part of the fixation analysis due to the

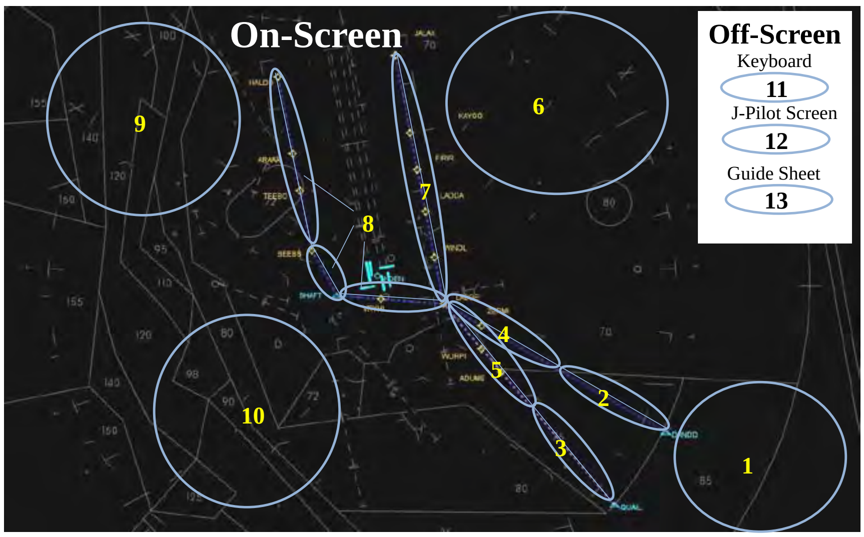

Figure 7. Eye-tracking Areas of Interest. *Thirteen zones were established for fixation analysis of the South East feeder controller.*

Figure 8. Example Eye-Tracking Observation from RNAV with RPI Scenario. *The red line facilitates locating a fixation point for each ½ second observation.*

[9] For purposes of the analysis, the fixation location is defined as the center of the participant's fixated gazed during a particular snapshot of the video playback, taken at ½ second intervals.

manual nature of the result tabulation. Table 2 presents the results of the eye-tracking analysis as a percentage of total time spent during the 17 minute scenario (using regions defined in Fig. 7). A total of 2,000 observations were taken for each scenario at ½ second intervals to derive the percentages. Due the small sample size, the table also reports out only those regions with a fixation percentage value above 5% (corresponding to approximately 50 seconds of fixation). It is also important to note that if two or more adjacent discrete fixations occurred within the same region, these discrete fixations cannot be distinguished from a single fixation in the data as processed; however, this was not observed to be a common occurrence.

Table 2. Fixations for RNAV and RNAV with RPI Scenarios. *The table shows the percentage of time that the participant spent fixated on different zones of controller workstation area with the RPI tool, and without it (Mapped to Regions in Figure 7).*

Region	RNAV (% of total)	RNAV & RPI (% of total)	RPI minus RNAV (% of total)	Change Greater than 5% (% of total)
1	16	13	-3	0
2	6	1	-5	-5
3	8	18	10	10
4	8	4	-4	0
5	11	10	-1	0
6	2	1	-1	0
7	28	25	-3	0
8	2	2	0	0
9	1	1	0	0
10	5	12	7	7
11	11	9	-2	0
12	1	3	2	0
13	1	0	-1	0

Table 3 reports out the number of distinct fixations which occurred during the scenario and the average length of each fixation with the scenario. From this data a distinction can be made between more frequent yet shorter glances compared to fewer, yet longer fixation periods, each of which may indicate different information gathering strategies. Fig. 9 provides a visual depiction of fixation data which provides a sense for the frequency and duration of fixation in the area of interest across the RNAV and RNAV & RPI scenarios (using regions defined in Fig. 7). The relatively wide yellow and light blue "blocks" in the RNAV with RPI scenario corresponds to the increased percentage to time spent fixated on the primary downwind and the south westerly airspace compared with the RNAV only scenario. In addition to more frequent views in zones 3 and 10, these fixations also lasted longer (wider blocks) than in the RNAV scenario. Note that this is despite the fact that there are 6% more discrete fixation in the RNAV only scenario compared to the RNAV with RPI scenario (392 vs. 370).

Table 3. Discrete Views and Average Dwell Time per View. *The discrete views of zones metric counts the number of times non-consecutive fixations fell outside of the zone of the previous fixation. Average time per view is the length of the average discrete view.*

Metric	RNAV	RNAV & RPI
Discrete Views of Zones	392	370
Average Time per View (sec)	1.8	2.3

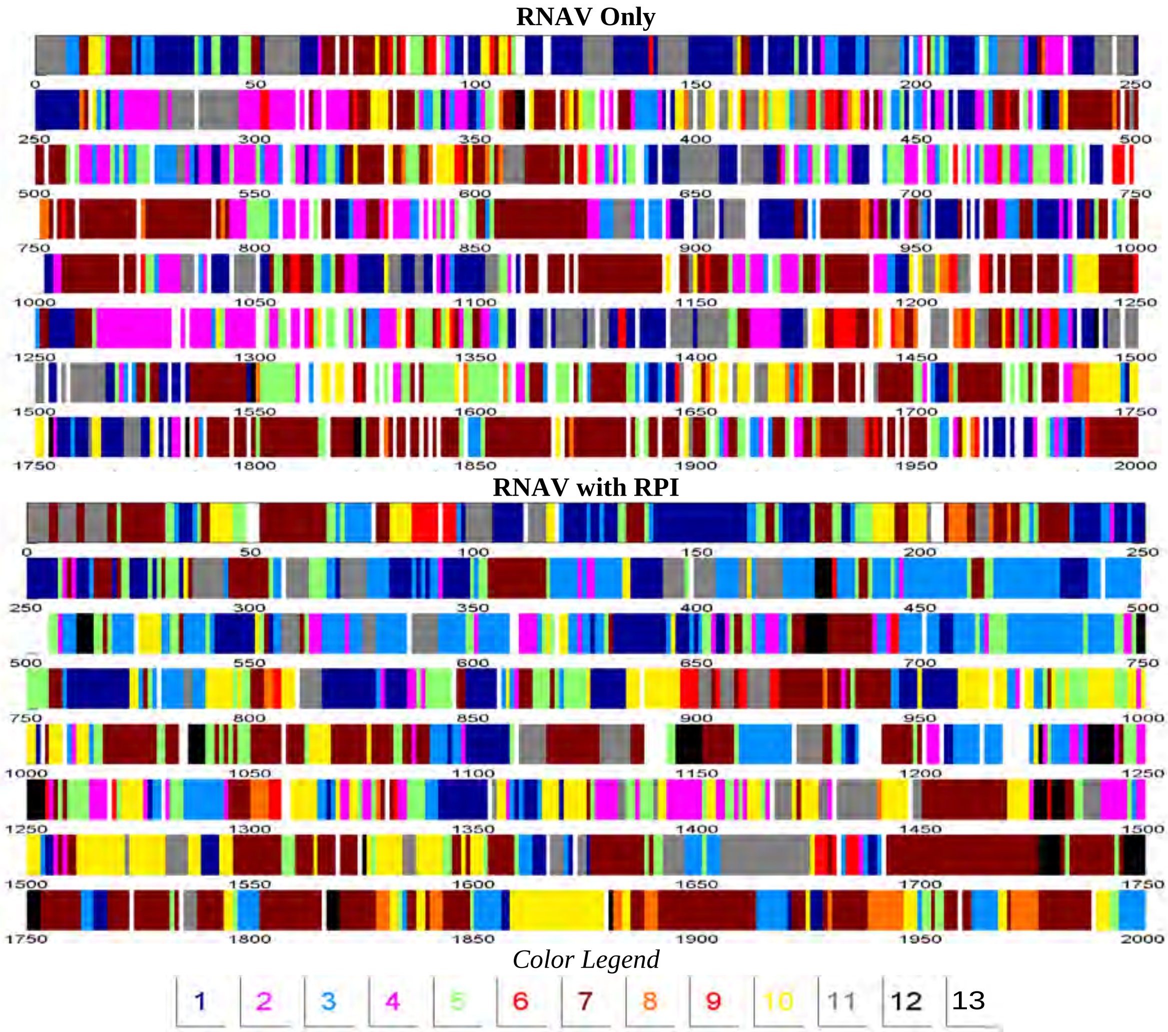

Figure 9. Fixations in Areas of Interest for RNAV only and RNAV with RPI. *The plots present color-coded lines whose thickness indicate the number of ½ second observation (out of 2000) which fell with the area indicated in the color legend (mapped to Fig. 7). The white spaces correspond to "error", which occurred when the eye-tracking equipment was unable to determine a fixation point.*

B. Subjective Results

In addition to the fixation metrics captured through eye-tracking playback, the controller's subjective feedback was captured after each run (Fig. 10). Across the captured workload metrics, the controller found the RPI scenario to result in lower workload scores, and a slightly higher overall performance when compared to the RNAV only scenario. The high frustration in the RNAV scenario was attributed by the participant to a simulation artifact involving the handoff of aircraft which only affected that particular scenario.

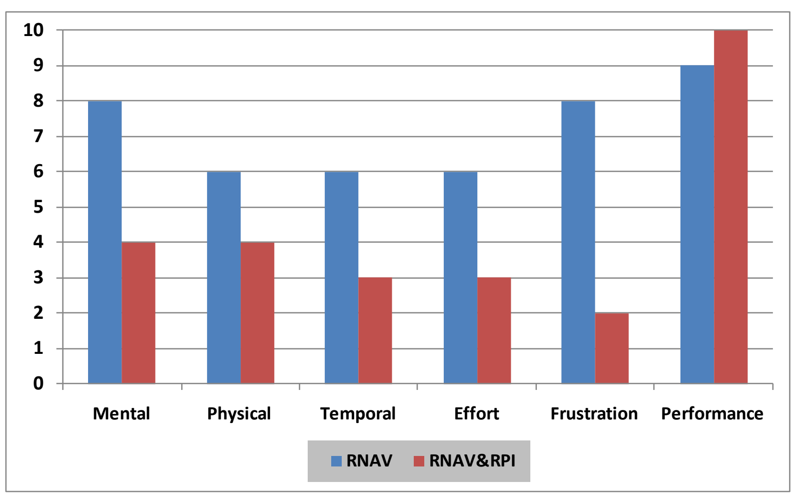

Figure 10. Controller Participant Workload in RNAV and RNAV with RPI Scenarios. *Ten is high.*

In a questionnaire administered after each run, the specific questions were posed t o the controller participant (Table 4). In general, the controller participant responded that the availability of RPI when using RNAV procedures resulted in decreased workload, increased situation awareness, reduced required communications, reduced complexity, increased predictability, increased feeling of control, and increased performance.

Table 4. Questionnaire Responses after RNAV only and RNAV with RPI Scenarios. *The participant was given a questionnaire following each scenario which included the following questions. The responses were limited to "greatly decreased", "slightly decreased", "no change", "slightly increased", and "greatly increased".*

Question	RNAV relative to Baseline	RNAV&RPI relative to RNAV alone
How did you overall workload change with RNAV/RNAV&RPI availability?	Greatly decreased	Greatly decreased
How did you overall situation awareness change with RNAV/RNAV&RPI availability?	Greatly increased	Greatly increased
How did the amount of voice communication required with pilots change with RNAV/RNAV&RPI availability?	Greatly decreased	Slightly decreased
How did the amount of contorller-controller coordination required change with RNAV/RNAV&RPI availability?	Slightly decreased	Slightly decreased
How did the complexity of traffic in your airspace change with RNAV/RNAV&RPI avaialability?	Greatly decreased	Greatly decreased
How did the predictability of traffic change with RNAV/RNAV&RPI availability?	Greatly increased	Greatly increased
How did the amount of contorl you felt over the traffic change with RNAV/RNAV&RPI availability?	Slightly increased	Greatly increased
Do you think you could have acchieved the same performance level in this scenario withou RNAV procedures/RNAV&RPI availaiblity?	No	No

V. Discussion

A. Change in Controller Workload

Manipulation of an additional automation tool adds workload associated with managing the tool. In the NAS today, the Philadelphia International Airport air traffic control tower automation utilizes the Converging Runway Display Aid (CRDA) on a continual basis, negating the need to adjust the automation, except for during airport runway configuration change, which requires a simple controller keyboard input. The RPI research prototype is designed to work in a similar passive fashion, which was how it was evaluated in the Denver HITL simulation. The difference in fixation times on off-screen areas, including the keyboard and guide sheet, between the RNAV only and RNAV with RPI scenarios was only approximately 10 seconds. Considering the relative inexperience of the controller participant with the RPI tool, this relatively low difference (in fact, lower in the RPI scenario) is encouraging.

Concerns with workload and effectiveness during dynamically changing operations were addressed in a previous study, which reported on more advanced RPI uses and capabilities [14]. These include the ability to suppress display of indicator targets and quickly adjust indicator target offsets. However, evaluation of the workload and visual scan impacts of using these advanced features should be considered.

B. Coordination and Runway Load Balancing

The RNAV design in the Denver HITL evaluation included an alternate runway transition for each route for sending aircraft over the top of the airport to the far side downwind for landing on an alternate runway. Conceptually, RPI supports the controller's ability to provide added efficiency by utilizing this alternate runway transition because it can project indicator targets for the controllers traffic projected onto the alternate flow (Fig. 6). This benefit seems to be supported by the additional visual fixations by the south east controller on the south westerly airspace in the RPI scenario (a 7% increase). This runway balancing task requires coordination between the two controllers involved. Creating a "shared" view of the traffic situation, by projecting indicator targets onto the south west controller's primary flow, may reduce coordination prior to the alternate runway reassignment decision. For example, RPI may obviate the need for verbal coordination between controllers to express the intent to issue a runway reassignment in the near future (for the controller delivering the aircraft) or the ability to accommodate a reassigned aircraft in the near future (for the controller receiving the aircraft).

C. Reduced Fixations on a Secondary Flow

The secondary flow (region 2 and 4 in Fig. 7) received fewer fixations during the RNAV with RPI scenario, which reinforces the observations from the IAD evaluation [12]. Since no "secondary task" was provided to aid in rating the controller's available attentional resources, it is difficult infer the implications of a reduction in fixations on the secondary flow. A potential concern is that the reduced observation of the traffic could result in reduced awareness of the traffic's proximity to surrounding traffic, increasing the risk of loss of separation events for this traffic. However, based on the pre-simulation instructions issued to the controller participant (that is, the participant was to assume responsibility for separation) and the subjective feedback that the controller experienced a higher level of situational awareness with RPI, this concern may be unfounded. Clearly, additional study in this area is warranted.

D. Fixation Frequency and Duration

The higher number of discrete fixations in the RNAV only scenario corresponding to a more even spread of visual scan may indicate an increase in the information gathering task during this scenario. This corresponds with expectations, since RPI presents a higher density of information in a smaller region of the surveillance display. The RPI scenario resulted in an approximately ½ second of increase in time per fixation, with these generally being allocated in regions in which RPI indicator targets were being projected. The may suggest additional cognitive processing of when viewing RPI indicator targets on an indicator reference line, which appears to be a trade-off with time spent viewing the actual aircraft targets on the target reference line.[10]

E. Relation to Traffic Management Advisor

While the eye-tracking evaluations focused on an arrival feeder control position and did not include the use of Traffic Management Advisor (TMA), conceptually, use of RPI by a Traffic Management Coordinator (TMC) may provide some complimentary benefits to TMA. In particular, the following excerpt from the NASA web page for TMA will be addressed:

> *An important feature of TMA is its ability to sequence and schedule aircraft to the outer fix, meter fix, final approach fix, and runway threshold in such a way as to maximize airport and TRACON capacity without compromising safety. In addition, TMA will assign the aircraft to runways to optimize the schedule.* ***All of this activity takes place while the aircraft is in the Center's airspace (approximately 40 to 200 miles from the arrival airport).***

(emphasis added) [15]

TMA is not used directly by terminal radar controllers. Instead, it is used primarily by Center TMCs and, to a lesser extent, Center radar controllers (through the use of delay indicators in aircraft data blocks). While the goal of the TMA is to promote airport and TRACON capacity, it does so prior to TRACON airspace. As such, it has little impact on the activities and responsibilities of terminal radar controllers. In this sense, there is no direct overlap in the functionality of TMA and RPI. Instead, the ability of TMA to help generate more efficient sequencing and scheduling of aircraft to the meter fix improves the probability that a terminal radar controller, with the help of RPI, will be able to resolve sequencing and spacing issues within the terminal area with the use of minor vectoring and speed clearances.

The Scheduled Time of Arrival (STA) within TMA is fixed prior to the meter fix (at a time called the "freeze horizon"). As such, sequencing needs which arise after the freeze horizon must be addressed by the TMC and downstream controllers using other methods. RPI is one such method for enabling improved sequencing of arrival traffic in a TRACON serviced by a Center utilizing TMA.

To estimate the amount of delay which an aircraft must incur to meet its STA, the aircraft's Estimated Time of Arrival to the various points in the airspace (meter, final approach, runway threshold) must be estimated. These estimates utilize nominal flight times for a particular configuration. The use of RPI to provide a more predictable delivery time for aircraft within the terminal area will improve these delay estimation calculations and reduce the error between TMA scheduling and actual aircraft delivery.

[10] Recall Fig. 2 for definitions.

F. Relation to Final Approach Spacing Tool (FAST)

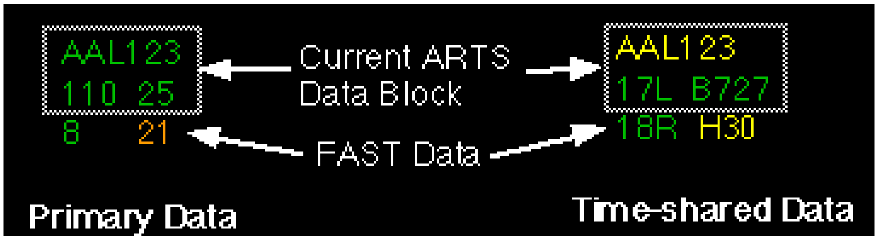

Figure 11. Passive Final Approach Spacing Tool (FAST) Data Block [16]. *The third line of the displayed data block contains the FAST advisory information. The green field is time shared between the pFAST relative sequence number to the runway and the pFAST runway assignment advisory. The second, colored data field is only used FAST.*

The Final Approach Spacing Tool (FAST) is an automation capability which produces heading and speed advisories, as well as runway and sequence advisories on the controller's surveillance display within the terminal area[11]. A limited functionality version called Passive FAST or pFAST, includes only the runway and sequence advisory components of the FAST capability (Fig. 11) [16]. RPI is more passive than both FAST and pFAST since it does not offer suggested speed or heading clearances, nor does it provide runway or sequence advisories. In addition, while FAST and pFAST were developed prior to the widespread implementation of RNAV and RNP, RPI was developed distinctively for this environment. Specifically, active advisories may not be as critical in an environment where the lateral (and perhaps vertical) profiles of aircraft are known with great certainty. In such an environment, the simplicity of RPI may improve operational acceptability among air traffic controllers by reducing learning curves, using little additional screen space, and providing controllers with a sense of still being responsible for providing one of the primary value-added services of air traffic control (efficient spacing). In a pFAST environment, RPI could be used to mitigate the controller concern, observed during pFAST testing, that "occasionally, controllers had a tendency to doubt runway allocation advisories because FAST could "see" aircraft that are out of the controller's view and thus make an accurate assessment at an earlier stage" [16].

G. Relation to Controlled Time of Arrival Concepts

RPI can be used at any point subsequent to the last Required Time of Arrival (RTA) or Controlled Time of Arrival (CTA) point in a given aircraft's trajectory. In an airspace where CTAs are the sole mechanism for achieving arrival spacing, it does not make sense to use RPI for spacing; however, if the radar controller is still responsible for separation, use of RPI by the radar controller in this airspace may still provide safety benefits by improving the controller's situational awareness of converging traffic.

VI. Conclusion

This study takes a step toward illuminating trends and expectations of RPI eye-tracking results that could aid in developing the experiment design of more detailed evaluations, including the types of data which can be drawn from such an evaluation. It is not intended to advocate that a single participant, single run evaluation should be the basis for implementation decisions nor that they provide adequate data to support implementation processes, such as the Safety-Risk Management (SRM) process. Acquisition and policy decision makers should view this evaluation as an executive summary of a tool in a tool box of analyses that could be performed in the future if needed to support an RPI implementation decision.

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