# Transition Airspace Controller Tools (TACT) Visualization Aids for Radar Controllers


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## Abstract

This paper discusses the research of visualization aids to assist air traffic controllers. The MITRE Corporation's Center for Advanced Aviation System Development performed this work as Mission Oriented Investigation and Experimentation (MOIE) under the sponsorship of the Federal Aviation Administration.

The initial stages of TACT research identified that time-based metering represents both a visual and cognitive challenge for air traffic controllers. To address this issue, the research explored the value of visualization tools to assist the radar controller in performing time-based metering. The TACT tools display metering information in a manner that is intuitive, visually apparent, and integrated into the controller's traffic. The TACT evaluation method utilized human-in-the-loop experimentation with participating air traffic controllers. The results indicated that visualization tools provide an advantage to controllers during time-based metering activities.


## Introduction

The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) initiated the Transition Airspace Controller Tools (TACT) research effort to explore problems associated with operations in transition airspace. In general terms, transition airspace includes the high and low altitude en route airspace sectors adjacent to the Terminal Radar Approach Control. The initial approach included visits to six air traffic control (ATC) facilities to survey and identify areas of complexity. Input from controllers regarding tasks performed, and means of approaching them, was instrumental in this early stage of problem identification.

Time-based metering in air traffic control was among the issues identified in the early stages of the TACT research. This paper discusses TACT research of visualization tools for the radar controller, and contains the results of human-in-the-loop experimentation that explored their value during time-based metering.

Time-based metering is a method of managing periods of high arrival demand at major airports. Using an aircraft's estimated time of arrival, metering software calculates a time-delay for arrival aircraft and a scheduled time to cross a pre-determined point in space referred to as a Meter Fix. The scheduled times for arrival aircraft are posted in a Metering List on the air traffic controller's radar display. The controller uses ATC techniques, such as vectoring and speed control, to meet the prescribed schedule; in this way the flow of traffic is restricted, or *metered*.

Federal Aviation Administration (FAA) plans include the increased use of time-based metering by the radar controller. Early metering software, known as the Arrival Sequencing Program (ASP), had inherent limitations which are being addressed by the present implementation of Traffic Management Advisor (TMA) as a replacement for the ASP metering software. TMA provides, among other things, much more sophisticated trajectory modeling, which is instrumental for time-based metering.

## Issues

Currently, time-based metering information is not integrated into the controller's traffic. Instead, it is displayed in lists that require the controller to switch focus away from traffic to scan for metering information, then correlate that information back into the traffic.

Air traffic control, using a radar display, is fundamentally a spatial activity. This is evident, and ingrained, in the radar controller's environment, including the distance-based separation standards controller's apply and the scaled two-dimensional video map display used to apply them. The time-oriented display of metering information is non-intuitive in the context of this spatial environment.

Operations in transition airspace can be dynamic, requiring the controller's planning horizon to span the range from strategic to tactical. For some, the above-noted issues represent a potentially significant element of added complexity and workload during time-based metering. With consideration for these issues, as well as for the characteristics of the operational environment, the focus of TACT research for metering assistance centered around three basic tenets:

1. Making the metering information intuitive, visually apparent, and spatial to the degree possible.
2. Integrating the metering information into the controller's traffic, thereby mitigating the need to glance away from traffic to scan additional lists or supplemental displays of information.
3. Ensuring the proposed tools are acceptable at the radar position. When priorities dictate, tool flexibility must permit the controller to minimize any potential distraction the display may cause. The tools must be "information facilitators," not suppliers of suggested actions, allowing the controller to make decisions fluidly without directing their thinking.

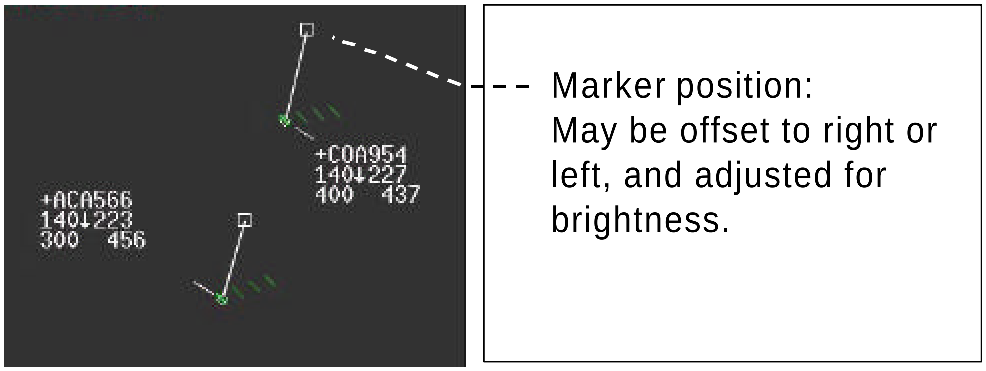
CAASD applied these tenets with research primarily focused on two TACT tools: the Mileage Distance Marker (MDM) and Mileage in the Data Block (MDB).

## Visualization Tools

Both the MDM and MDB tools are intended to enhance the effectiveness of time-based metering by rendering the metering task more achievable and acceptable to the controller. The TACT tools work in partnership with the resident metering software whether it be ASP, TMA, or some other scheduling software. The TACT role is to assist the controller by providing metering information in a manner that is intuitive, visually apparent, and integrated into the controller's traffic.

The MDM allows the controller to display a marker that visually provides a spatial indication of the delay magnitude (see Figure 1). Since the time-based restriction is relayed via the spatial gap between the aircraft position symbol and the marker, controllers can relate to the MDM display in much the same way they would relate to the spacing between two aircraft with a Miles-In-Trail restriction. As actions are taken (such as vectoring and/or speed control) to meet the required restriction, the marker and the corresponding aircraft symbol will move closer together. This provides the controller with continuous visual feedback on performance.

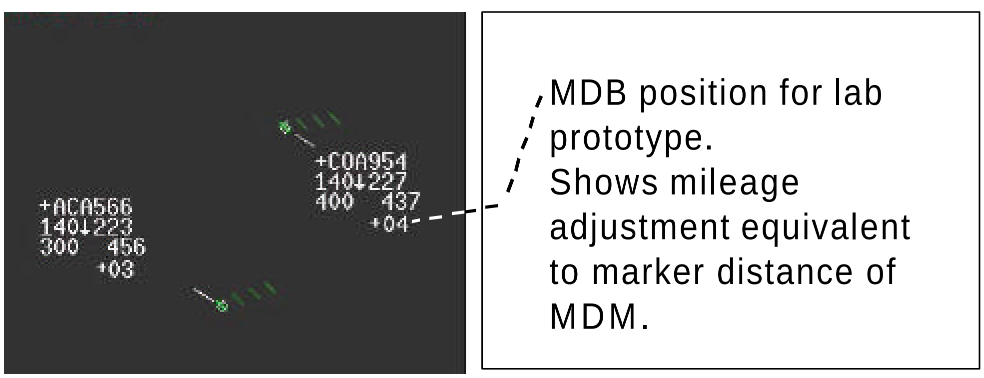
**Figure 1. MDM display**




The MDM makes it visually apparent when an aircraft requires adjustment in order to meet the given restriction. More importantly, it provides intuitive feedback about the size of the adjustment that needs to be made. This allows the controller to make early decisions as to the course of action most applicable given the operational circumstances.

The MDB also provides cognitive assistance to the radar controller with a spatial increment that represents the magnitude of the time-based restriction. The MDB, as shown in Figure 2, displays a positive or negative number in the aircraft's data block that reflects the mileage adjustment needed to meet the required restriction. The number will count down or up, displaying zero when desired spacing is achieved. The underlying functionality of the MDB is identical to that of the MDM. The key difference between the MDM and MDB is the method of displaying information to the controller.

**Figure 2. MDB display**




During the tactical operations common to transition airspace, TACT tool information is available, but does not advise or otherwise direct the controller's decision making. Therefore, the radar controller is free to establish other priorities and handle problems that arise. This may include actions that are sub-optimal for meeting the flow restriction, but are critical to other operational priorities (such as separation). In such cases, the TACT tools do not restrict the controller's shift in priorities or actions. When circumstances permit, TACT tool information facilitates recovering the flow schedule, and helps minimize effort and error in meeting the prescribed restrictions.

In FY01 several enhancements were added to the tools for the TACT experiment. These enhancements were based on feedback from earlier work with former controllers and active controllers.

Some feedback indicated that it would be helpful if the controller had an aid for estimating appropriate speed changes to use in conjunction with the MDM and MDB. In response to this, a proposed “speed cue” feature was made available for both the MDM and MDB tools. The speed cue is an estimate of the speed that should deliver the aircraft from its present position to the meter fix at the scheduled time. It is intended to provide “information only,” not a suggested action. The controller must decide how to use the information based on momentary operational conditions. The speed cue appeared near the marker for the MDM tool. For the MDB tool it appeared in the full datablock, time-shared with the MDB’s mileage information. The speed cue could be displayed for all or for selected aircraft, upon controller request.

Once controllers found that delay information could be obtained from the tools without referring to the Metering List, they expressed a desire to access sequence information without referring to the Metering List as well. A sequence number feature was made available for both the MDM and the MDB tools. The feature used a two-digit number representing the relative position of the aircraft in the Metering List, beginning with the first metered aircraft. The sequence number appeared in the fourth line of the full datablock and could be displayed for all metered aircraft or for no aircraft, upon controller request.

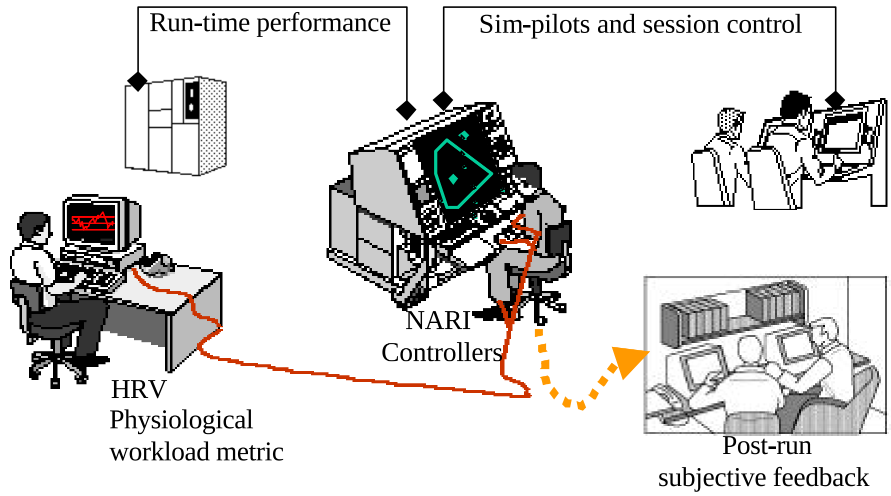
Controller feedback was also instrumental in addressing issues such as the potential for increased clutter caused by the marker display. For example, the capability to offset the marker position (left and right), adjust the brightness of the marker, and selectively display specific markers, are now part of the design.

## Process

The early stages of TACT research investigated the tool concepts via front of the panel demonstrations to people with operational ATC experience, combined with interviews to verify that the tool concepts seemed visually supportive toward the designed purpose.

The FY00/FY01 TACT research approach was focused on answering lower level questions pertinent to the utility and operational acceptability of the tool concepts. To address these lower level questions, an experimentation environment was established in which controllers could use the TACT tools and a Baseline Metering List in an interactive air traffic control setting. This environment served to allow the formulation of more informed opinions concerning operational utility and acceptability than was previously possible. The environment also provided a medium for capturing objective performance data to help substantiate subjective feedback. Figure 3 illustrates the general experiment setup. CAASD contracted access to appropriate participants through the National Aviation Research Institute (NARI). Active air traffic controllers from two Air Route Traffic Control Centers (ARTCC) provided the operational expertise as experiment participants.

**Figure 3. TACT Experiment Setup**




The laboratory used for experimentation was built upon an emulation of the Host Computer System (HCS) dynamic simulation (DYSIM) capability. The laboratory provided a staffed radar position and an additional DYSIM sector representing all other sectors below, beside, and above the sector being evaluated. Only one sector was evaluated for this experiment.

The radar position included a keyboard, trackball, and Sony 20" x 20" display. The controller display was an emulation of the Display System Replacement (DSR). The HCS interface allowed access to all the normal HCS functions plus new functions representing the capabilities to be evaluated. The interface was "DSR-like," having quick action keys, functions displayed in the R-CRD (controller readout device), and the route readout display.

Controller participants were given overall procedures to follow during each evaluated scenario run as well as procedures specific to each tool evaluated. In general, these procedures were as follows:

1. The number one priority is separation and safety.
2. Attempt to meet meter fix times whenever possible without compromising separation and safety.
3. Use the (evaluated) tool when appropriate.
4. Use the tool display modes (or options) available to you, as appropriate.

As shown in Table 1, three general categories of metrics were utilized for the experiment, Objective-Quantitative, Subjective-Quantitative, and Subjective-Qualitative. Traffic demand measures characterize the traffic situations under which the tools were tested and the impact on that traffic. Controller performance measures indicate whether the controller is helped by the availability of the new tool(s). Controller workload measures indicate the cost to the controller of using the tools. An automated data collection application captured run-time performance, and traffic information and stored the data for off-line post-processing and analysis. Objective-Quantitative workload was assessed using Heart Rate Variability (HRV). HRV refers to the variability in the inter-beat interval of the participant's heart. For TACT, two measures of this data were collected: low frequency (LF) and high frequency (HF).

LF HRV[1] has been linked to mental engagement.

[1] LF HRV is the power spectrum range between 0.04 Hz and 0.15 Hz.

**Table 1. Metrics Categories**

| | Quantitative | Qualitative |
|---|---|---|
| **Objective** | Controller performance<br>Controller workload via HRV<br>Traffic demand | |
| **Subjective** | Modified NASA Workload Scales<br>Controller Acceptance Rating Scales (CARS) | Structured Interviews |

Mental engagement is viewed as a positive form of mental workload that indicates the consistent application of cognitive effort during task accomplishment. Lower LF HRV generally indicates a state of higher mental engagement; higher LF HRV indicates a state of lower mental engagement. [6, 8, 9] HF HRV[2] primarily reflects parasympathetic activity. HF HRV corresponds to the heart rate variations related to the respiratory cycle, or what is known as respiratory sinus arrhythmia. [7, 5, 6]

In this experiment, it was hypothesized that there would be a difference among the TACT tools in both the LF and HF HRV. The TACT workload assessment approach used HRV as an objective, physiological measure to supplement the subjective forms of workload assessment.

The TACT experiment employed a 2 x 3 (Scenario x TACT Tool) factorial repeated-measures design. This design is shown in Table 2. Controllers were assigned randomly to one of three treatment groups. Independent variables in the experiment were Scenarios A and B, the Baseline Metering List, and the TACT tools: MDB and MDM. Dependent variables included performance measures, subjective assessments using NASA's Task Load Index (TLX) workload scales and a post-test questionnaire, the Controller Acceptance Rating Scale (CARS), and Low Frequency and High Frequency HRV measures.

There were two main reasons the factorial repeated-measures design was chosen for the TACT experiment. First, this design controlled for most of the common threats to the *internal validity* of the experiment; namely, history, maturation, testing, instrumentation, statistical regression, differential selection of respondents, and experimental mortality.

**Table 2. FY01 Order of Treatments and Scenarios by Participant**

| Group # | Participant # | Tool/Scenario | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Run 1** | **Run 2** | **Run 3** | **Run 4** | **Run 5** | **Run 6** |
| 1 | 1, 4, 7, 10 | BSN/A | MDM/B | MDB/A | BSN/B | MDM/A | MDB/B |
| 2 | 2, 5, 8, 11 | MDM/A | MDB/B | BSN/A | MDM/B | MDB/A | BSN/B |
| 3 | 3, 6, 9, 12 | MDB/A | BSN/B | MDM/A | MDB/B | BSN/A | MDM/B |
| BSN refers to the Baseline Metering List | | | | | | | |

[2] HF HRV is the power spectrum range between 0.15 Hz and 0.50 Hz.

(A discussion of these threats is found in [1].) Controlling for these classes of extraneous variables reduced the chance that they could produce effects that might be confounded with the effect of the TACT tools. Secondly, the use of repeated measures, i.e., having each controller receive treatments with each level of the independent variables, increased the power of the effects tests for the TACT tools by removing the variation of each controller from the residual variance. [2]

It should be noted that while the experiment was designed for 12 controllers, only 9 controllers actually participated. Still, the design of the experiment fully accommodated the reduced number of participants, as there were three controllers in each treatment group.

## Results

CAASD's laboratory research revealed that TACT visualization tools provide a clear advantage where controllers perform time-based metering, and in several of these cases the results were statistically significant. In general, it was demonstrated that the TACT tools assisted controllers, while metering, with regards to two critical measures simultaneously:

- Workload
- Performance

Other advantages to using TACT tools during time-based metering were observed as well. In addition to workload and performance, CAASD research sought to better understand questions relating to the following areas:

- Operational impacts of the tools
- Operational acceptance of the tools
- Controller interaction with the tools

### *Workload*

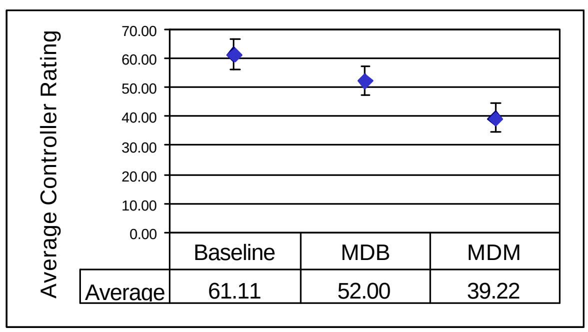
The research sought to understand whether using the TACT tools created an appreciable change in workload for the controller. During the TACT experiments, indicators of workload were observed and collected using, results from the modified NASA TLX, Feedback from post-scenario interview questions, and HRV metrics.

Results across these indicators varied by degree, but generally agreed in overall outcome: workload was lower with the TACT tools than with the Baseline Metering List. Average controller responses in FY01 consistently rated the TACT tools as providing lower workload than the Baseline in every aspect of the modified TLX:

- Mental Demand
- Physical Demand
- Time Pressure
- Effort (i.e., physical and mental effort put forth)
- Frustration
- Performance

On the modified TLX, the FY01 data showed the TACT tool effects on Mental Demand ($F(2,16) = 4.94$, $p = 0.02$), Effort ($F(2,16) = 4.18$, $p = 0.03$), and Overall Workload ($F(2,16) = 4.56$, $p = 0.03$) were statistically significant, and the MDM tool was favored specifically. Figure 4 shows the average TLX response for Mental Demand.

**Figure 4. Average Mental Demand**



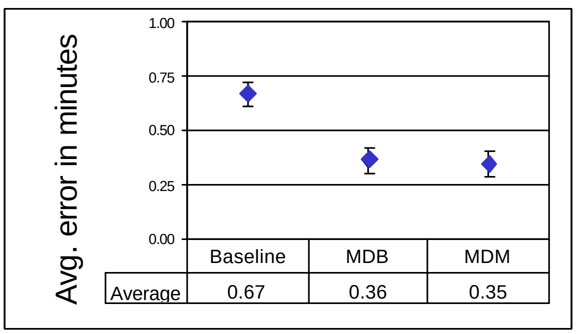

Other subjective results showed that the majority of controllers felt that less time and attention was spent performing metering, and that overall job (metering and otherwise) was less difficult using the MDM and MDB TACT tools.

The TACT workload assessment approach used HRV as an objective, physiological measure to supplement the other forms of workload assessment mentioned. In FY01, two measures of this data were collected: the low and high frequency components of HRV. Although there is room for interpretation with HRV, both of these measures indicated a generally lower mental workload with the TACT tools than with the Metering List.

### *Performance*

While workload was decreased, controller performance was increased with the TACT tools during metering. As a measure of performance, delivery accuracy with respect to the assigned metering fix time was tracked. The results showed that controllers delivered aircraft on average more accurately with TACT tools than without. This is illustrated in Figure 5 below, where zero on the Y-axis represents accurate delivery. Accuracy was greatest in FY01 with the MDM tool, followed by the MDB and Baseline tools, respectively.

**Figure 5. Average Accuracy by Tool**




A repeated measures analysis of variance test showed the effect of the TACT and Baseline tools on delivery accuracy to be statistically significant, F(2, 16) = 9.65, p=0.002. Significant differences among the tools were obtained through a Tukey Honestly Significant Difference (HSD) test. The Tukey HSD test showed that there were significant differences between the MDM tool and the Baseline tool, as well as between the MDB tool and the Baseline tool, q=2.58, =0.05. The power statistic for this test was 0.7906. Furthermore, a contrast between the MDM tool and the Baseline tool yielded a statistically significant difference, F=(1,16) = 15.26, p=0.001. Also, a contrast between the MDB tool and the Baseline tool yielded a statistically significant difference, F=(1,16) = 13.63, p=0.002. No significant differences were noted between the MDM and MDB tools.

It was noteworthy in FY01, that on their subjective assessments, controllers indicated that the MDM and MDB tools had a positive effect on their ability to meet meter fix times; again, in the same rank order.

### *Operational Impacts of TACT Tools*

Beyond workload and performance, there were effects on overall sector operations, as well as on the metering task itself.

Controller approaches to metering were affected by the use of TACT visualization tools. The effects manifested themselves in various ways, to varying degrees, from one individual to the next. Among those effects was a decreased use of the Metering List as comfort with the tools increased. Controllers generally liked the fact that they could scan the metering data and traffic simultaneously. In some cases, controllers actually turned off the display of the Metering List while using the tools, citing it as unnecessary and distracting.

Data collected at runtime indicated that controllers took action to maneuver metered aircraft approximately four radar updates sooner, on average, with TACT tools than with the Metering List[3]. This effect is partially attributed to needed actions being more visually apparent to the controller. However, it is also consistent with an increase in situational awareness [3] indicative of greater perception of elements in the environment, as well as greater ability to project future status. [4] This is supported by the controller responses which directly indicated that TACT tools permitted increased scanning of traffic and situational awareness.

One question pertinent to operational impact is that of TACT tool effect on efficiency and complexity during transition airspace operations. No

[3] Refers to data collected during FY00 regarding timeliness of actions. Timeliness data was not available in FY01.

quantitative way of assessing complexity was employed during the experimentation. However, given the above observations of reduced workload, increased situational awareness, and increased performance, one could argue that the task of time-based metering is less complex for the controller while using TACT tools than without.

There are three basic ways to delay an airborne aircraft: holding, vectors, and speed control. The mixture of these techniques, including the degree each is applied, is based on the controller's perception of the operational conditions on a momentary basis. The data indicated that speed control was used more with TACT tools than without. The data also showed that controllers vectored aircraft farther using TACT tools than without. The number of vectors increased only minutely (on average less than one vector per run), meaning controllers did not defer to vectors in lieu of other techniques, just that the length of time aircraft were left on their vector was slightly longer. The differences in technique imply that controllers perceived the actions needed differently with TACT tools than without. The fact that accuracy increased implies that their perception was more accurate.

Taken together, these factors imply that better decision support was afforded: under the tool-use conditions, controllers took action earlier, altered the degree and mixture of technique, and delivered greater accuracy, while experiencing less workload.

### *Operational Acceptance*

Operational acceptance is an extremely important aspect when considering a radar display-based support tool for an air traffic controller. TACT research sought to ascertain the best sense of controller operational acceptance possible while using a laboratory environment. One way to gauge acceptance is to refer to the CARS results for each tool individually, as a specified level of acceptance corresponds to the answers provided. The average response was in the acceptable range for the MDM, MDB and Baseline. Another, perhaps more compelling, way to gauge acceptance is to make a comparison with the Baseline. The Baseline Metering List was designed to emulate the look, feel, and general functionality of the Metering List employed with TMA. The TACT tools ranked above the Baseline in terms of operational acceptance.

Another perspective on acceptance relates to tool effect on the general acceptance of the metering task itself. TACT results indicated an increased acceptance of time-based metering, as a mode of operation, with TACT tools.

### *Controller Interaction*

Controllers have visualization tools on the radar display today. Items such as vector lines, J-circles, and route display lines all serve to help the controller visualize pertinent ATC-related aspects as deemed appropriate. Here, too, the TACT visualization tools are intended to be used as the controller deems appropriate. As with other display tools, the means to turn them on, off, and configure them must be fluid and physically economical.

The tools, including enhancements, were well received by controller participants during experimentation. Some enhancements are extremely important to a successful implementation, while others could be added at a later time. For example, the offset and brightness adjustments are critical for using the MDM tool.

The speed cue received positive feedback from controllers. However, its implementation in the laboratory was based on very preliminary design, both conceptually and technically. Further development and testing would be necessary prior to attempting to implement this enhancement in a higher-fidelity environment.

Most controllers found the sequence number feature useful despite the scenario configurations which made the aircraft sequence somewhat obvious. Under live operational conditions, this is not always the case: in fact, controllers occasionally deem it necessary to alter the prescribed Metering List sequence. Under such conditions, the usefulness of the sequence number would be expected to increase beyond that of the laboratory environment.

Although the research indicates that TACT tools are more useful to metering operations than the Metering List, the results also show that the Metering List itself is useful to some degree. There are certain to be traffic configurations that limit the momentary effectiveness of a visualization tool. For these reasons, it is recommended that the controller be given the option of using both the list and/or a visualization tool.

***Next Steps and Recommendations***

Given that TACT visualization tool experiments were largely successful in CAASD's medium-fidelity laboratory environment, there are two logical paths this work should take, development in a high-fidelity environment, and integration with emerging technologies and procedures

The CAASD laboratory environment in FY00 and FY01 did not use TMA as the metering software, nor an actual DSR as the display platform. For TACT visualization tools to advance in operational and technical readiness, they should be tested in a higher-fidelity environment that utilizes those elements. Adjustments and potential enhancements to the tools may be desirable to facilitate maximum performance under field-like conditions. A high-fidelity environment, such as an ARTCC DYSIM lab or a Federal Aviation Administration Technical Center lab, would help target appropriate areas for such adjustments, and provide an environment to evaluate them with operational experts.

The evolution of the National Airspace System (NAS) in the coming months and years will include the implementation of new capabilities and procedures. The expanded use of TACT, and TACT-like, visualization tools holds potential for leveraging additional benefits by integration with those capabilities and procedures. Multi-center TMA, Controller-Pilot Datalink Communications (CPDLC), and CAASD's Problem Analysis and Resolution Ranking (PARR) are examples of some capabilities where TACT tools may unlock additional benefits in metering/flow restriction environments.

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## Biographical information

Chris DeSenti is a former United States Air Force Air Traffic Controller. He joined MITRE/CAASD in 1997 after completing a B.S. in Computer Science and Business. He is a Project Team Manager and the Principal Investigator for the Transition Airspace Controller Tools research, and has played a role in several projects relating to En Route and Oceanic air traffic management.

Celesta G. Ball received the A.B. and M.S. degrees in mathematics from West Virginia University, Morgantown, WV, and the Ph.D. degree in information technology and engineering from George Mason University, Fairfax, VA. She joined MITRE in 1983, where her work has included the development of requirements for Automated En Route ATC (AERA) 2; analysis of the need for paper flight strips in the current NAS environment; and concept development and evaluation for future NAS operations under the Free Flight paradigm, for conflict probe capabilities for the radar controller in the near-term NAS environment, for transition airspace controller tools, and for collaborative weather rerouting decision support tools. She is currently a lead staff member working on issues in collaborative weather rerouting and congestion management.

Dennis Rowe joined the MITRE corporation as a member of the Technical staff in 1983. While at MITRE/CAASD, Dr. Rowe has worked closely with the FAA's Systems Engineering and Air Traffic Organizations in advancing the concepts of Free Flight, and has played a role in several projects related to National Airspace Redesign. He holds a B.S. in Engineering from the United States Military Academy, an Ed.M. in Education from Boston University, and an M.S. and DSci. In Engineering from The George Washington University.

Gretchen Jacobs joined the MITRE corporation in 1983. Her expertise is in Human Factors analysis, information requirements, and concept evaluation. Her work has included many human-in-the-loop studies, and such areas as: TCAS resolution advisory, causes and prevention of runway incursions, evolution of radar-side capabilities, concept development for distributing Traffic Management Unit (TMU) reroutes to the sector, concept development for reducing reliance on flight strip printers and flight strip usage in en route air traffic control in the midterm, Transition Airspace Controller Tools (TACT), and operational evaluations of Collaborative Routing Coordination Tools (CRCT).