Trajectory-Oriented Time-Based Arrival Operations: Results and Recommendations

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Contents

- Introduction
- Recent Results
  - Scenario and Conditions of Interest
  - Results
    - Inter-Arrival Spacing at the Meter Fix
    - Mean Altitude of Arriving Aircraft
    - Controller Workload
    - Problem Areas
- Recommendations for Ground-Based Automation Facilitating 4D Trajectory Operations
  - Recommended Toolset
  - Discussion: Guidelines on Level of Automation and Automation Behavior
- Complimenting 4D trajectory based operations with aircraft-to-aircraft based operations
- Concluding Remarks

Introduction

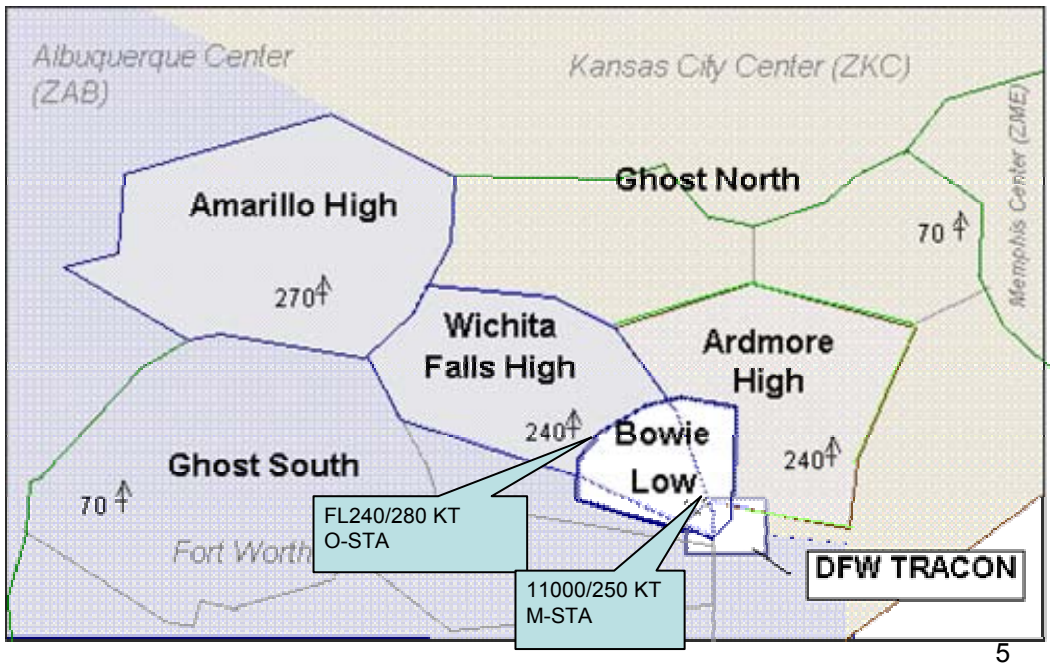
- Two research trends
  - Aircraft-to-aircraft based relative operations supported by Airborne Separation Assistance Systems (ASAS)
  - 4D trajectory-based operations supported by strategic tools like CTAS, advanced CDTI and trajectory negotiation

- NASA's DAG-TM includes both concepts (among others)
  - CE6 "En route trajectory negotiation" in en route and transition airspace
  - CE11 " in trail merging and spacing" in approach airspace

- Discussion:
  - Trajectory-based operations are sometimes said to be most beneficial for traffic flow management and not too useful for air traffic control
  - DAG-TM results show benefits of trajectory-based operations for air traffic controllers
  - ASAS and trajectory-based operations can complemented each other

Simulation: Scenario and participants

- Current day peak arrival traffic in northwestern ZFW area
- ~90 aircraft (half arrivals, half overflights and departures
- Metering to 7 nautical miles in trail -> delay 2 to 5 minutes
- 5 controller participants (1 high altitude en route, 2 high altitude arrivals, 1 low altitude arival, 1 TRACON)
- 2 pilot participants in full mission simulator
- 6 pilot participants controlling desktop simulators
- 3 confederate controllers
- 8 confederate pilots handling Multi Aircraft Control Stations (MACS)
- Observers on each participant position
- Comprehensive data collection



Simulation: Conditions

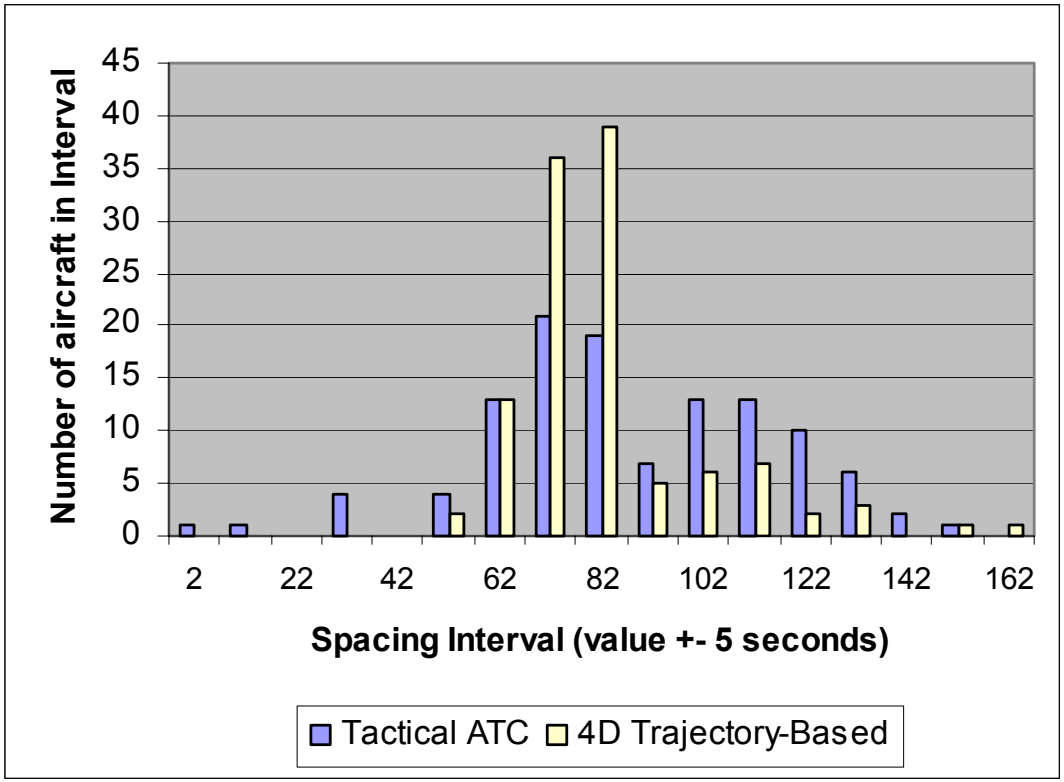
Control Condition
"Current Day Metering"

- Data link
  - ADS-B for state and trajectories
- Controllers:
  CTAS-based Decision Support Tools:
  - Meter list
  - Delay information in data tag
- Flight Crews:
  - CDTI
- Procedures
  - Current day operations

Experimental Condition
"Trajectory Negotiation"

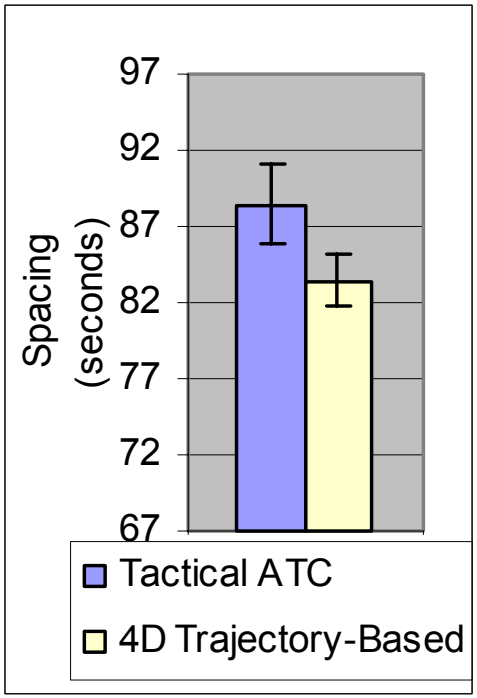
- Data link
  - ADS-B for state and trajectories
  - CPDLC integrated with DSTs for trajectory data exchange
- Controllers:
  CTAS-based Decision Support Tools:
  - Timeline display
  - Cruise/descent speed advisory function
  - Route modification trial planning
  - Conflict probe
- Flight Crews:
  - CDTI
  - Route Assessment Tool (RAT)
  - Conflict probe
  - Experimental Required Time of Arrival (RTA) function
- Procedures
  - Precision Descent procedure

Results: Inter-Arrival Spacing at the Meter Fix



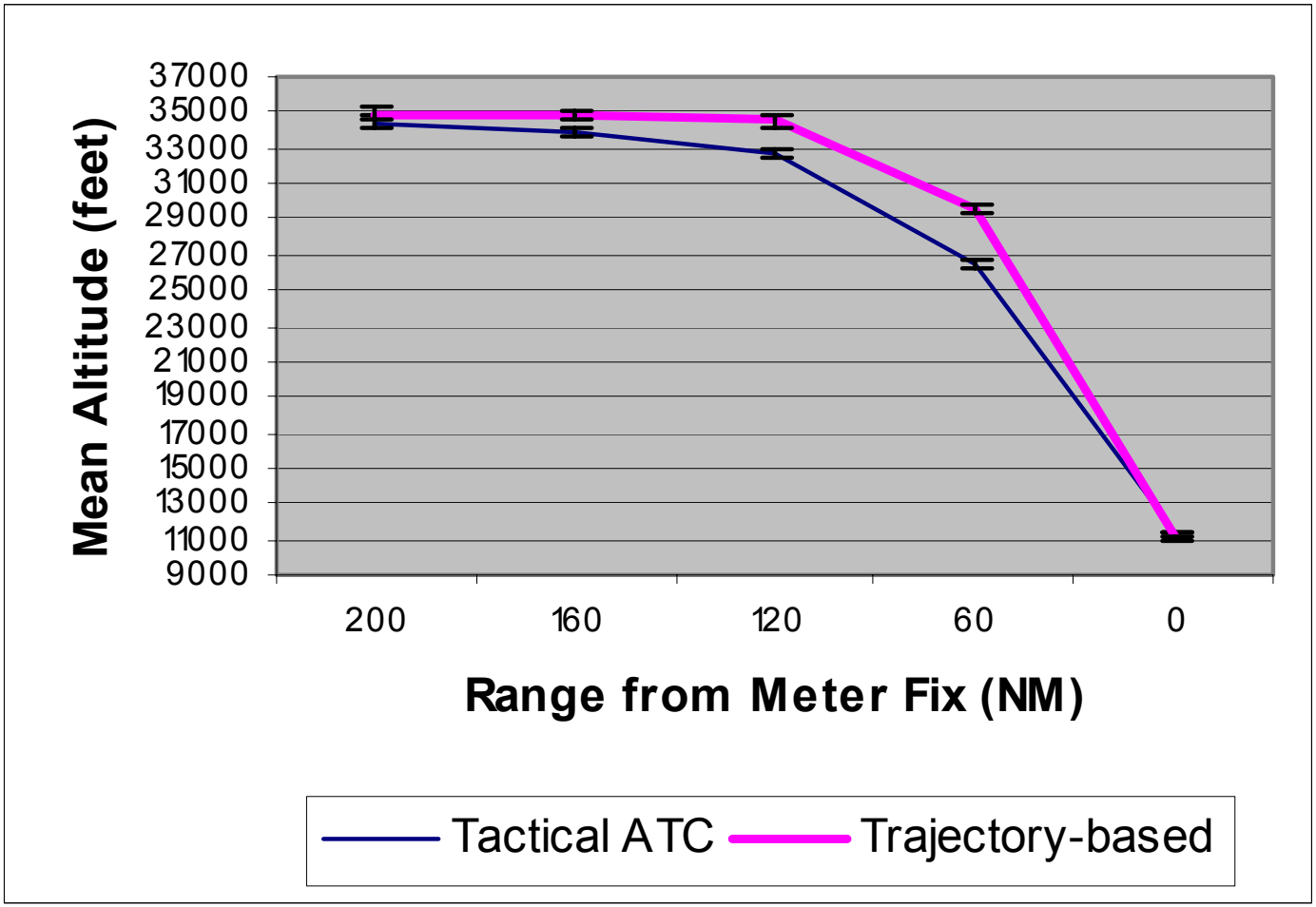
Inter-Arrival Spacing Histogram

Inter-Arrival Spacing Mean and Standard Error



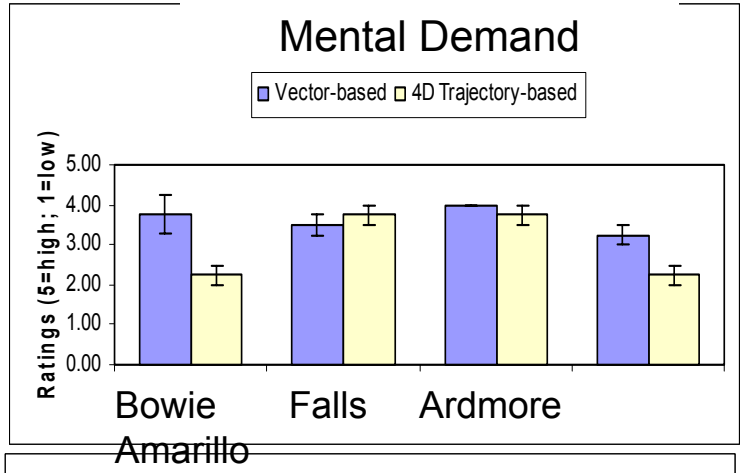
In the trajectory-based condition more aircraft were delivered within their target spacing of 84 seconds and the variance was significantly reduced

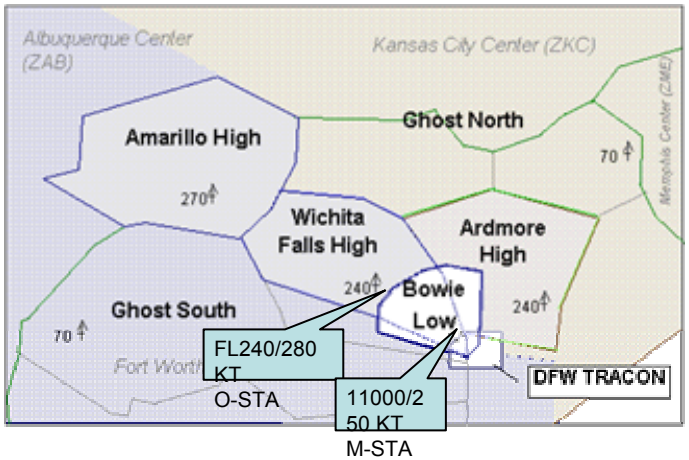
Results: Mean Altitude of Arriving Aircraft

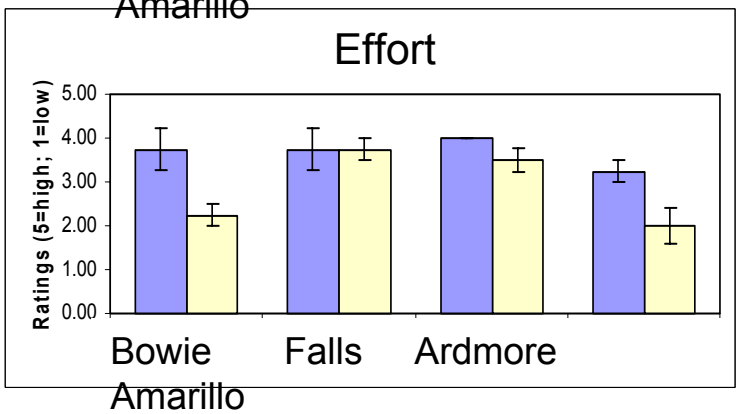


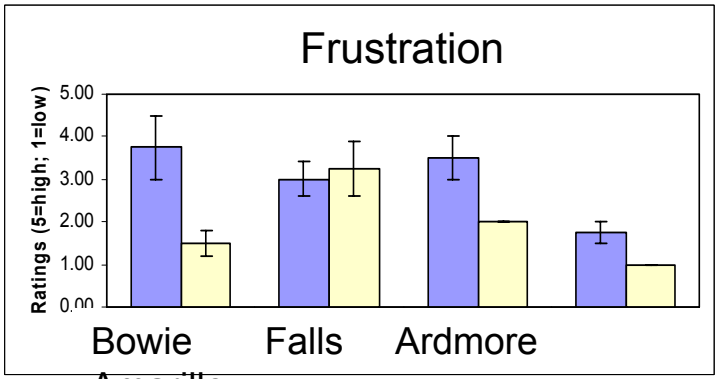
More aircraft could stay longer at a higher altitude in the trajectory-based condition

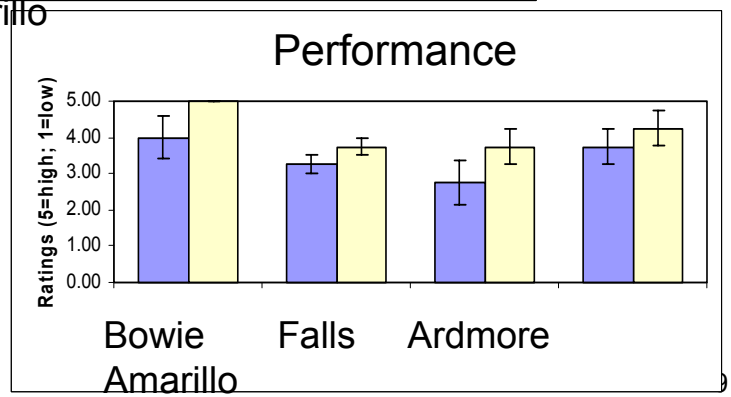
Results: Controller Workload











The trajectory-based condition caused the biggest impact on the low altitude controller (BOWIE)

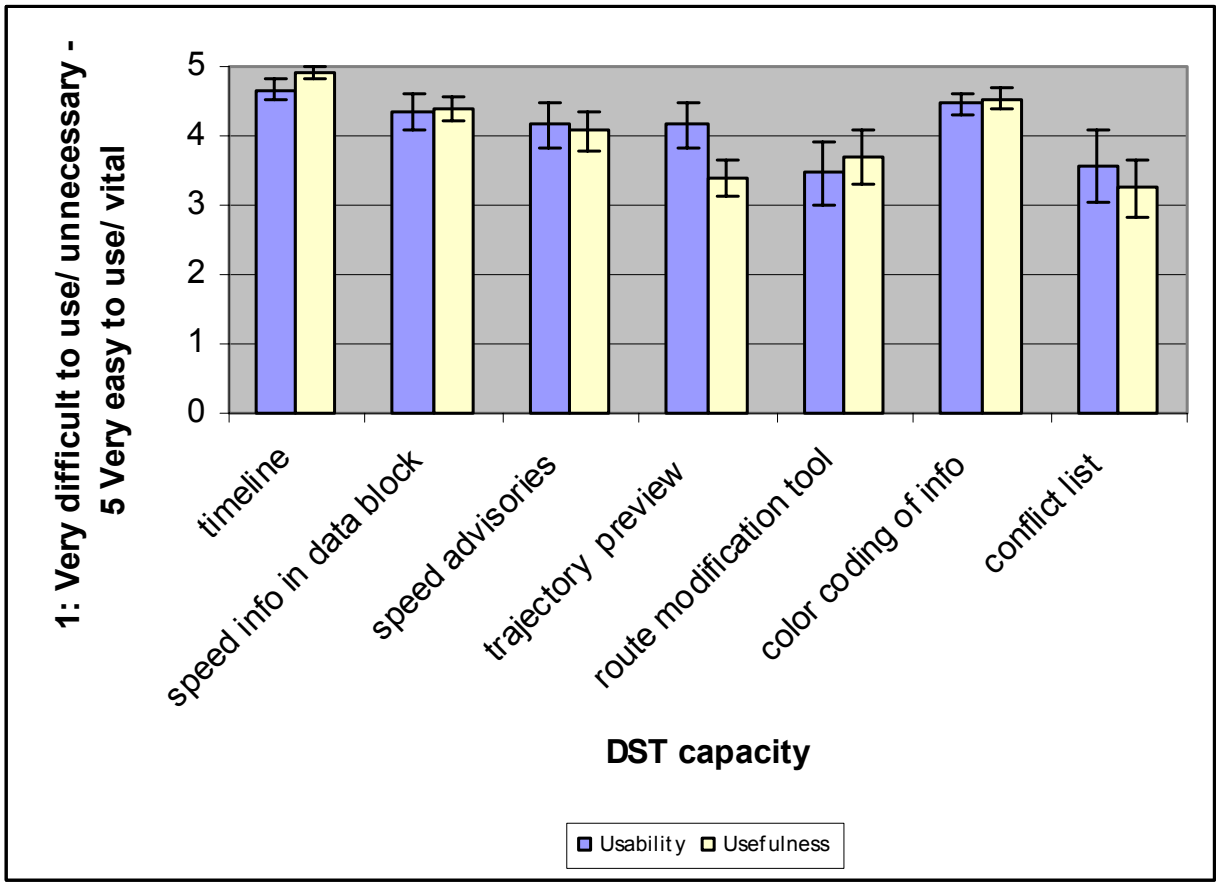
Results: Problem Areas

- Spatial vs. time constraints (trajectory de-confliction)
  - Scheduling separates aircraft at the meter fix, but does not assure trajectories are de-conflicted along the way
  - The speed advisories provided trajectory modifications that could absorb the delay, but were not always conflict free
  - The conflict feedback appeared to be inappropriate to make the controllers aware of this

- Tool usability
  - The tools sometimes required too much attention to complete a given task, which distracted controllers
  - The responsiveness (up to one second delay for trajectory computations) was sometimes insufficient
  - Creating trajectories to absorb large delays (>six minutes) was cumbersome

Usability and Usefulness of Different Tools

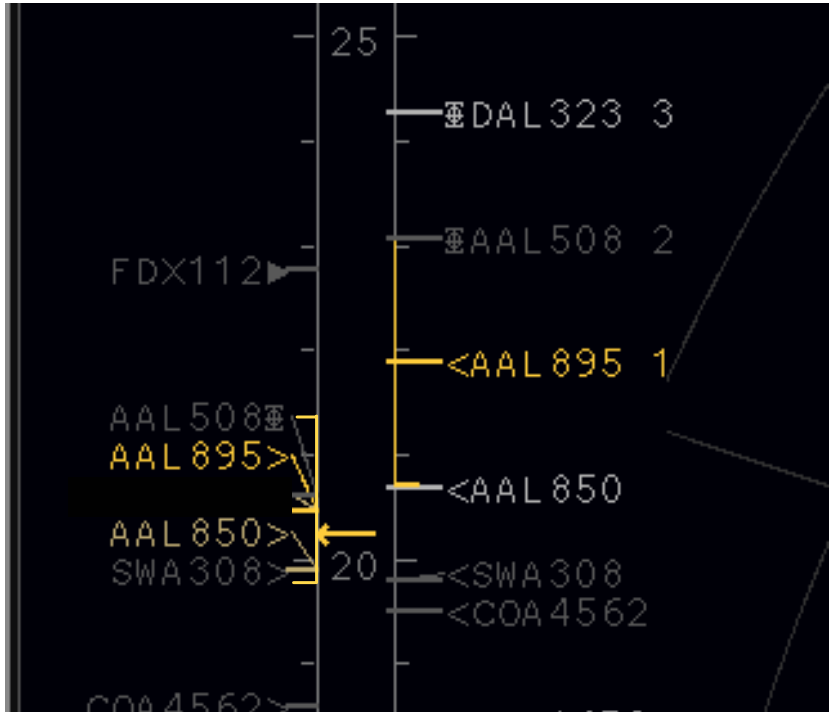
Mean and standard error of usability and usefulness



Observations and post-run questionnaires from 13 controllers who had each used variations of the same toolset for several days (usually 4 days training 4 days experimental runs) to control arrival traffic in a trajectory-oriented manner. The data was gathered in 3 simulation studies in 2002

Recoomendations: Toolset

- Timeline
  - Graphical representation of the time dimension
  - Consistently ranked the most useful and usable tool
- Color coding and expandable data tags
  - Color to distinguish flight categories
  - Data tags that expand when dwelled upon and present additional information
- Speed display and speed advisories
  - Speed advisories on request were considered very useful
- Route modification tool
  - Needs to be highly responsive
  - Semi-automatic function might be desirable
- Holding function
  - insert holdings into trajectories to absorb large delays



Guidelines: Level of Automation and Automation Behavior

- **Controllers accept automation support if they are in command**
- **The automation should provide instantaneous feedback**
- **The trajectory computations must be highly reliable and clearly indicate failure**
- **The active trajectories should always be available, “What if” planning should be done on provisional trajectories**

Concept*

- *Use trajectory-based operations to create efficient, nominally conflict-free trajectories that conform to traffic management constraints and,*

- *maintain local spacing between aircraft with airborne separation assistance*

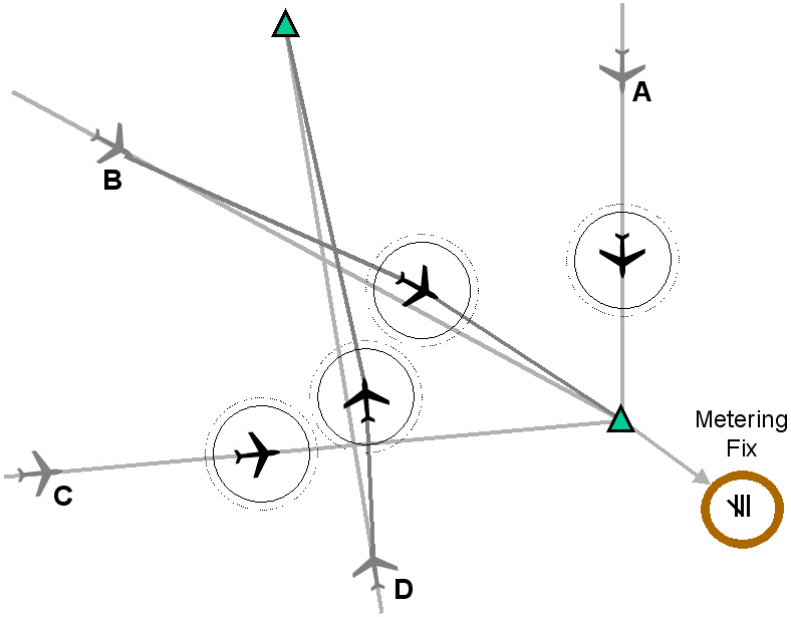
* Prevot, T., V. Battiste, E. Palmer, and S. Shelden (2003)
"AIR TRAFFIC CONCEPT UTILIZING 4D TRAJECTORIES AND AIRBORNE SEPARATION ASSISTANCE"
AIAA Guidance, Navigation and Control Conference, Austin, TX, August 2003

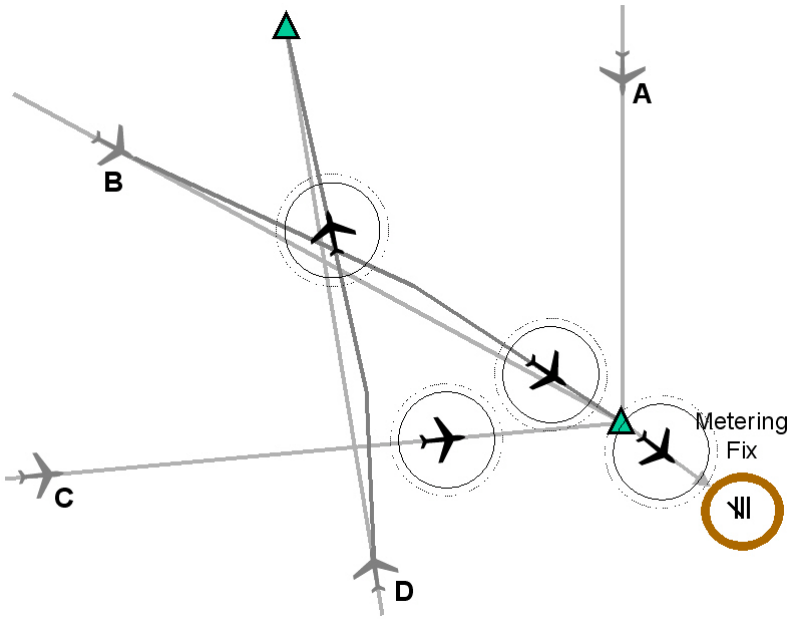
Complimenting 4D trajectory based operations with ASAS

- Problems with absolute (trajectory-based) operations
  - Trajectories need to be planned with additional buffers for trajectory prediction uncertainty and navigational inaccuracy
  - Aircraft have to be scheduled further apart to avoid violating minimum separation requirements without controller intervention

- Problems with relative (aircraft to aircraft-based) operations
  - No global traffic flow strategy
  - Limited range on the flight deck

Example*





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Concluding Remarks

- Trajectory-oriented, time-based arrival operations have shown potential benefits for throughput, efficiency, and controller workload.

- A well-designed set of ground automation tools and procedures is required.

- The necessary flexibility for applying trajectory-oriented concepts in high-density air traffic control sectors can be achieved.

- The trajectory-oriented approach can be complimented with aircraft-to-aircraft based operations to increase the potential benefits even further while at the same time solving some of the problems with 4D trajectory-based operations.