Air Traffic Management Technology Demonstration – 1
(ATD-1)

NASA’s ATM Technology Demonstration #1
(ATD-1)
Scheduling Algorithm Overview

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This document is part of the ATD-1 Technology Development Activity documentation, controlled by the ATD-1 Change Control Manager at NASA Ames Research Center, Moffett Field, California, Aeronautics Directorate, Aviation Systems Division.
## Revision History

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NASA’s ATM Technology Demonstration #1 (ATD-1)

Scheduling Algorithm Overview

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**Preface**

Discussions and methods presented in this paper assume a basic understanding of the Traffic Management Advisor (TMA) and frequently refer to components of TMA’s Dynamic Planner (DP). The reader is advised to have a copy of NASA/TM-2000-209586 in hand for reference while reading this paper. The Appendix includes descriptions of the associated software change requests (i.e., PRs).

**1 Introduction**

NASA’s ATM Technology Demonstration #1 (ATD-1) system is being developed to assist ARTCC and TRACON air traffic controllers and traffic managers in managing flights navigating RNAV Standard Terminal Arrival Routes (STARs) on Optimized Profile Descents (OPDs). These horizontally precise and vertically efficient arrival procedures are called RNAV OPDs. ATD-1 builds upon the foundation of the Traffic Management Advisor (TMA) in use for Time-Based Flow Management (TBFM) at Air Route Traffic Control Centers (ARTCCs) today. ATD-1 uses the TMA’s DP with an enhanced set of features to support efficient use of RNAV OPDs during periods of high traffic demand. This enhanced DP is referred to as the ATD-1 DP. The purposes of this document are (1) to provide an overview of the primary differences between the TMA’s DP and the ATD-1 DP, and (2) to document the technical justification for algorithmic changes as they relate to Next Generation Air Transportation System (NextGen) arrival operations. Baxley et al., provides a complete description of the ATD-1 concept of operations.

**2 Background**

The need for improvements to the TMA is rooted in the transition from traditional operations (based on step-down descents and vectoring) to the precise trajectory-based operations envisioned for the NextGen. The following sections provide an overview of Time-Based Flow Management and the TMA, and detail the implications of this operational shift on the TMA and its DP scheduling algorithm.

**2.1 TBFM and the Traffic Management Advisor**

Time-Based Flow Management is a process for mitigating the effects of transient excess demand for airspace and airport resources through application of temporal constraints. TBFM has been shown in simulation and in practice to be preferred to spatial restrictions (e.g. Miles-in-Trail restrictions) in most operational scenarios. Traditional methods for TBFM include assigning utilization rates to airspace and airport resources (e.g. Airport Acceptance Rate (AAR), Airport Departure Rate (ADR)), and assigning Scheduled Times of Arrival (STAs) to individual flights consistent with the prescribed utilization rates.

The TMA is an element of the Center/TRACON Automation System (CTAS). It utilizes trajectory predictions that consider the performance of the aircraft, the route of flight, assigned arrival procedure, weather forecasts (including winds aloft) and any procedural constraints (i.e. speed and altitude restrictions). These trajectory predictions form the basis of the scheduling decisions made by the TMA’s DP.
For each schedulable flight, the DP assigns a landing runway and calculates STAs at the following locations: Outer Outer Arc, Outer Metering Arc, Metering Fix, Final Approach Fix (FAF) and Runway Threshold. To account for various traffic, weather, and airport conditions, the Traffic Management Coordinator (TMC) can input scheduling constraints such as separation distances and flow acceptance rates. The DP updates the schedule on a continuous basis to adapt to changes in the traffic situation, changes in the environment, and in response to inputs from the TMC. While the DP continuously updates the schedule, all scheduling is completed for an individual flight while the aircraft is in ARTCC airspace. The DP can be generalized as a constraint-based scheduling algorithm that schedules flights at the Metering Fix according to First-Come-First-Served (FCFS) priority while meeting user-supplied constraints. For further details of the Dynamic Planner algorithm and as a reference for further discussions in this document, please refer to Wong, 2000.2

The TMA uses the DP STAs to construct a series of metering lists (one for each Metering Fix) to advise controllers of required delay for each flight in the list to achieve the DP STA. The TMA-advised delay is derived from the DP STA for a given flight and its undelayed arrival time, or Estimated Time of Arrival (ETA). Controllers use the metering lists to assist their application of spacing and separation between arriving flights, and to ultimately adhere more precisely to the prescribed schedule and arrival rates.

Use of TMA for arrival TBFM has proven effective in the context of today’s operations. However, the original design of the TMA did not consider RNAV OPDs that afford less opportunity for TRACON delay than traditional terminal operations. For more detail on the design and operational evaluation of the TMA, the reader is referred to Swenson, et al.3

2.2 NextGen Arrival Operations

Expected long-term growth in air traffic demand has led to the development of a new concept for air traffic operations called the Next Generation Air Transportation System, or NextGen. Among NextGen’s objectives are increased airspace and airport capacity and reduced environmental impact (i.e., lower fuel consumption, noise impact, and emissions). The Joint Program and Development Office (JPDO) has documented a series of Operational Improvements (OIs) necessary to achieve NextGen’s objectives, and the FAA has initiated activities to realize those improvements. Among the technological and procedural improvements necessary for NextGen are the widespread use of precision arrival procedures and the conduct of efficient descent profiles into busy TRACONs and high-density airports.

2.2.1 RNAV/RNP

Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures enable the precision required for NextGen operations to provide accurate predictions of future aircraft states. While RNAV procedures have been around for some years, RNP procedures are relatively new. However, neither has been used extensively, and nor have they been used routinely for high-density arrival operations.

Typically, controller separation practice in mitigating the inherent uncertainty in today’s system precludes the use of RNAV or RNP procedures during high traffic demand periods. This is due to the fact that controllers often employ heading vectors in addition to speed and altitude clearances to separate aircraft in the arrival flows. As a result, most
STARs include language to “expect vectors to final approach course” to account for controller spacing and separation application. Lacking a precisely defined path of flight from cruise to touchdown in the STAR, trajectory predictions must rely on adaptation derived from archived operations and expert input to model the future flight path of aircraft. These “nominal interior routes” introduce a significant amount of prediction uncertainty.

Adherence to RNAV and RNP arrival procedures dramatically reduces trajectory prediction uncertainty compared to STARs including the “expect vectors” language. However, in the context of today’s operations, adherence to RNAV and RNP procedures has proven difficult during periods of high traffic demand.

### 2.2.2 Optimized Profile Descents (OPDs)

Optimized Profile Descents (OPDs) are a subset of RNAV STARs that include vertical and speed constraints. These additional constraints allow for more efficient descent profiles than traditional step-down descents. However, these additional constraints also reduce the amount of arrival time flexibility (i.e., maximum TRACON delay) after top-of-descent. The arrival time flexibility is referred to as the flight’s control margin, and it includes both delay and time advance. While RNAV and RNP routing increases the horizontal predictability of trajectories, OPD procedures allow flight crews to tailor their descent profiles to improve their flight’s efficiency (within the prescribed altitude and speed constraints). Using the Flight Management System (FMS), flight crews are able to determine the best descent profile that meets the OPD speed and altitude constraints.

To compute an efficient descent path meeting the OPD constraints, the FMS requires an a priori defined route of flight (i.e., "expect vectors" does not support OPDs). Because arriving flights must slow from cruise to landing speed, and an aircraft’s rate of deceleration is reduced in descending flight, OPDs serve to exacerbate the reduction in the control margin available to controllers managing RNAV or RNP arrivals; adherence to an RNAV STAR eliminates ad hoc heading vectors and conduct of the OPD reduces the effectiveness of speed control. To the extent that a controller’s ability to strategically space and separate aircraft with small adjustments to aircraft speed is rather limited, NextGen operations based on RNAV OPDs must explicitly account for this reduction in control margin available to arrival controllers. The following section illustrates the limitations of scheduling only to the arrival metering fixes and/or runways toward supporting operations utilizing RNAV OPDs.

### 2.3 Point-scheduling

Traditionally, arrival scheduling has been concerned with utilization of a constrained resource (usually a metering fix or runway), and imposed separation requirements at the constrained resource. This approach has been largely successful to date, as controllers have substantial flexibility (heading vectors, altitude and speed clearances) in managing traffic movements. Controllers have sufficient Degrees of Freedom (DoFs) to overcome minor trajectory prediction errors and simplifications in the scheduling algorithm. One such simplification in traditional scheduling algorithms is the enforcement of separation constraints only at the constrained resources.
2.3.1 Separation enforcement only at constrained resources

A common simplification of scheduling for TBFM is the enforcement of separation constraints, whether derived from separation requirements or flow constraints, only at scheduled/constrained resources. This ensures the scheduler does not violate flow rate restrictions or in-trail spacing requirements for arriving aircraft at the runway threshold. However, because separation is enforced only at the constrained resource(s), separation along the entire path of the trajectory is not ensured. The controller utilizes the available DoFs to enforce separation at points away from the scheduled resource(s).

2.3.2 Inherent feasibility assumption

Adherence to a prescribed schedule requires that controllers have sufficient DoFs to affect required separation at points between the constrained (scheduled) resources. It is thus assumed, for a given schedule, that the controller can enforce separation at all points between the constrained/scheduled resources. It is inherently assumed that the schedule is feasible. Unfortunately, this is not always the case.

2.3.3 Controller override/intervention and vertical profile inefficiencies

When the inherent assumption that the controller can enforce separation while adhering to the STAs proves false, the controller must intervene to override the schedule. Controller intervention can take a number of forms including STA modification and local resequencing (i.e., swapping). In both cases, a controller may issue heading vectors to the affected aircraft to provide required separation and implement a new schedule (STA, sequence or both). As long as the rate of controller intervention remains low, their impact to the overall arrival process is minimal in the context of today's operations.

In the context of NextGen operations, however, controller intervention runs directly counter to the fuel consumption, noise impact mitigation, and emissions reduction objectives. Aircraft navigating RNAV OPDs will necessarily increase fuel consumption and emissions and possibly increase noise impact whenever they are vectored to affect inter-aircraft separation. Moreover, because controllers are expected to separate arriving aircraft primarily with speed adjustments, the rate of controller intervention of point-scheduled operations would likely increase, possibly dramatically. This fact points to the need for a scheduling capability that explicitly considers the feasibility of prescribed STAs even in the context of controller separation provision. Failure to explicitly consider STA feasibility will inevitably sacrifice the stated NextGen efficiency objectives during periods of moderate-to-high traffic demand.

3 Objectives and Approach

The objective of the ATD-1 Scheduling Function is to provide STAs that support high-density arrival operations on RNAV OPDs with minimal controller schedule intervention. Toward this objective, the ATD-1 Scheduling Function explicitly considers the feasibility of prescribed STAs within the schedule in a manner consistent with speed-only control of aircraft navigating the RNAV OPDs. The approach being pursued by NASA extends the TMA DP scheduling algorithm to include separation enforcement at terminal merge points and consideration of speed control margin to verify STA feasibility. The next section
documents the algorithmic implementation of the ATD-1 Scheduling Function, and highlights differences between the TMA DP and the ATD-1 DP.

4 Terminal Area Precision Scheduling and Spacing

This section provides an overview of the ATD-1 Scheduling Function and its novel solution to ensuring STA feasibility on speed-controlled arrival procedures. Emphasis is given to the primary functional differences between the TMA DP and ATD-1 DP. For details of the ATD-1 concept of operations, including how the schedule is operationally implemented, the reader is referred to Swenson, et al.¹

4.1 General Description

The ATD-1 Scheduling Function generates conflict-free schedules for all TMA reference points (i.e., outer outer arc, outer meter arc, meter fix, final approach fix, and runway threshold), as well as meter points along the terminal portion of the arrival route. A terminal meter point is defined as a TRACON waypoint along the route where two or more routes merge or diverge, or a metering waypoint along the route where the flights’ schedules should be monitored and controlled. When computing the STAs for each arrival flight, in addition to satisfying the TMA’s scheduling constraints and utilizing the DP’s sequencing logic and runway allocation process, ATD-1 adheres to the required separation distance at each merge point. The required separation at the merge points is defined in FAA Order JO 7110.65T Air Traffic Control, Chapter 5, Section 5-5-4 Radar Minima, including application of wake vortex minima and 2.5NM separation within 10NM of the landing runway (when allowed).⁴

4.2 Assumptions

In addition to the assumptions already made by the TMA DP, the ATD-1 DP makes the following additional assumptions:

1. Terminal area arrival routes are known a priori from the meter fix to the runway.
2. The speed restrictions on the arrival routes are adapted at prescribed waypoints (using a combination of published speed profiles and facility SOPs).
3. Fast, nominal and slow flight profiles are defined for each route.
4. Terminal meter points are prescribed waypoints where the arrival routes merge, diverge, or need to be controlled.
5. Separate arrival routes are used for aircraft of significantly different speed performance until equivalent speeds can be achieved (at which point these streams can be merged).
6. Speed restrictions are monotonically decreasing from the meter fix to the runway threshold.

NOTE: Assumptions (5) and (6) are needed to ensure that the point of minimum separation between aircraft on each segment can be achieved at the downstream end of each segment. This does not necessarily hold true for the final approach segment due to different landing
speeds, but this is mitigated within ATD-1 by a separation buffer and will also be mitigated by the use of the Automated Terminal Proximity Alert (ATPA) function.

4.3 Primary ATD-1 DP Enhancements to the TMA DP

Two critical functional differences between the TMA DP and the ATD-1 DP allow ATD-1 to generate feasible schedules for precision operations in terminal airspace, including during periods of high demand: terminal meter point scheduling and terminal segment delay distribution. The following two sections provide an overview of these enhancements sufficient for a general understanding of how ATD-1 addresses the aforementioned shortcomings of the TMA scheduling of precision arrival operations.

4.3.1 Terminal Meter Point Scheduling

As previously discussed, the ATD-1 Scheduling Function provides STAs for terminal meter points in addition to the TMA provision of STAs at the Outer Outer Arc, Outer Arc, Meter Fix, Final Approach Fix, and Runway Threshold. The key implication of terminal meter point scheduling is that it allows for separation requirements to be enforced at key points along the path of flight between the meter fix and the runway. If aircraft have separation at the merge points, separation between them can be reasonably assumed if the speed of the trailing aircraft matches or exceeds that of the leading aircraft and both aircraft are descending or level (i.e., the point of minimum separation between two aircraft is achievable at the downstream end of the segment).

4.3.2 Terminal Segment Speed Control Margin

Dissecting the terminal arrival path into segments between terminal meter points, and producing STAs for each terminal meter point, has the effect of greatly reducing the speed control margin available between those points along the route. Speed control margin in this context is defined as the amount of delay that can be achieved through the application of speed reduction within procedurally defined limits (and subject to any limitations of aircraft performance). The ATD-1 Delay Distribution function calculates the individual flight's speed control margin for each terminal segment of flight.

Precision arrival procedures to all allowable runways are defined a priori for each flight. For each arrival procedure, the TMA RA function generates two 4-D trajectories: one applying the nominal speed profile along the route, the other applying the slow speed profile along the route (note: the fast speed profile is currently not used, but is intended to be used in future enhancements related to “partial slot recovery”). The speed profile of a particular arrival procedure is defined by speed restrictions at prescribed waypoints along the route. Aircraft are expected to maintain the speed dictated by a waypoint speed restriction until it needs to begin decelerating to capture the next speed restriction. Figure 1 is a notional representation of an arrival procedure’s speed profile. Currently, a constant flight path angle of 2.4 degrees is assumed instead of adapted vertical profiles for each procedure; a constant rate of deceleration of 1 knot per second is also assumed. The use of adaptable parameters should be a subject of future research.

The ATD-1 Scheduling Function is able to ensure STA feasibility and minimize controller interventions by enforcing separation constraints at terminal meter points while limiting delay distribution on each segment between the meter points to its computed
speed control margin. The speed control margin is preferred because it models the available STA range in terms of the acceptable speed range, wind conditions, and aircraft type to ensure that delay can be allocated in a manner consistent with predominantly using speed control for delay absorption and spacing adjustments.

![Figure 1: Notional Example of an Arrival Procedure's Speed Profiles](image)

4.4 Overview of ATD-1 DP Functional Commonality with TMA DP

The ATD-1 DP is principally based on the TMA DP with key enhancements intended to ensure STA feasibility at terminal meter points. The Top Level DP process remains unchanged with the exception of modifications to the DP Scheduling function (Wong 2000, Section I., pp. 20-38)². This section documents which steps of the DP Scheduling function have been modified, and characterizes these changes. Where no changes have occurred, the reader is referred to Wong 2000².

The following numbered descriptions refer to the steps of the DP Scheduling function documented in NASA/TM-2000-209586 section I (Wong 2000, beginning pg. 20)²:

1. **Scheduling Events**

   The events that trigger the TMA to reschedule all or some of the flights have not been changed. Refer to NASA/TM-2000-209586 section I.1

2. **Order of Consideration at the runway**

   The order in which flights have their runway threshold STAs computed has not been changed. Refer to NASA/TM-2000-209586 section I.2
3. Delay feedback (Modified for ATD-1)

Scheduling constraints at the airport and its runways often require that a flight be delayed at the runway threshold. With ATD-1, during the process of distributing the threshold delay to the segment(s) along an aircraft’s route from threshold to meter fix, additional delay caused by enforcement of terminal meter point separation constraints may delay the flight’s original threshold STA. Any delay that cannot be absorbed by the Delay Distribution Function will be pushed back to the meter fix.

4-7. Scheduling Process (4) and supporting methods (5-7) (Modified for ATD-1)

The overall DP scheduling process (Figure 36, Wong 2000) is unchanged, with the exception of Step 12 of that process. In Step 12, a flight will be scheduled according to one of three methods depending on the scheduling mode and the flight’s scheduling priority. In two of these methods: Reschedule at ETA and Insert (6) and Reschedule after Aircraft Ahead and Insert (7), a single change to the runway scheduling function is shared by these methods. No changes are made to the third scheduling method, Insert without Rescheduling (5).

Figure 2 shows the flowchart for the Reschedule after Aircraft Ahead and Insert scheduling method within the ATD-1 DP. As shown, Step 2G of this method contains the only modification to this DP scheduling method. While not depicted here, the same functional step is also the only step modified for the Reschedule at ETA and Insert scheduling method (Step 3D in Figure 37 of Wong 2000).

The modifications to this step of the scheduling process for both methods (Reschedule at ETA and Insert and Reschedule after Aircraft Ahead and Insert) include new functionality to perform terminal meter point scheduling and delay distribution along the terminal route segments and to the meter fix, as necessary. Section 4.4 of this document details the algorithmic modifications made to this step of the scheduling process.

8. Schedule to runway
No difference from TMA. Refer to NASA/TM-2000-209586 section II.I.8
4.5 Details of the ATD-1 Terminal Meter Point Scheduling and Delay Distribution

This section details the ATD-1 terminal meter point scheduling and delay distribution functions through their application for a single flight during the scheduling process. The steps detailed here are contained within Step 2G of the flowchart depicted in Figure 2 (and 3D of Figure 37 of Wong 2000)².

In constructing an arrival schedule, enforcing runway separation constraints causes the majority of a flight’s terminal area delay. The ATD-1 scheduling process distributes this delay to the control segment nearest to the runway first. At each terminal meter point...
location, additional delay may be incurred to satisfy separation constraints at the meter point. Any unabsorbed delay will be distributed to the next (upstream) segment, this delay distribution process continues from threshold to meter fix until either the required delay is absorbed, or all the terminal delay is exhausted. Any unabsorbed delay in the TRACON will be pushed to the ARTCC (as it is in the current TMA’s delay feedback process) and reflected in the meter fix STA.

4.5.1 Terminology and Notation
A segment between two consecutive terminal meter points is called a control segment. All control segments along a flight’s route are identified, and the flight’s flying times along each control segment for the nominal and slow speed profiles are calculated. Flying time on a given control segment is called the segment duration. For each control segment, the difference in flying time between the nominal and slow speed profiles is called the control segment delay. Control segment delay is the maximum amount of delay that a flight can absorb between the waypoints bounding a control segment. A terminal meter point is notated as MP(i) where i (between 0 and n) is an index corresponding to the sequential order of terminal meter points along the route from the runway (i=0) to the Meter Fix (i=n).

4.5.2 Algorithmic Example
The STA for each terminal meter point is calculated by progressing upstream. The process successively and iteratively schedules the flight at its terminal meter points, starting at the runway and concluding with the meter fix. As the flight is scheduled to a terminal meter point, the process verifies that the maximum segment duration is not exceeded. The STAs of the downstream terminal meter points are adjusted, if necessary. If the maximum segment duration is exceeded (and the downstream STAs are adjusted), the process restarts the scheduling from the runway again, using the adjusted terminal meter point STAs as new inputs into the scheduling process. Figure 3 shows the flowchart for the terminal meter point scheduling process detailed in this section.
**Step 1: Determine runway PTA.**

The Proposed Time of Arrival (PTA) to the runway is the earliest time that a flight can arrive at the runway. Initially, the runway PTA is set to the meter fix STA + TRACON transit time to runway (undelayed flight along TRACON route, starting at MF STA).
Step 2: Schedule to the runway using the flight’s PTA to runway.
The PTA may be delayed due to scheduling constraints at the runway. The resulting PTA is the new runway STA. During the terminal meter point scheduling process, a flight’s runway STA may be further delayed because enforcement of separation constraints at upstream terminal meter points along the route renders the previous runway STA infeasible. That is, delay incurred by enforcement of a terminal meter point separation requirement delays the STA at the meter point enough that the undelayed time of flight from the merge point to the runway has the aircraft arriving after the previous STA.

Step 3: Find the PTA of next upstream terminal meter point, MP(i)
The next terminal meter point along route is identified. The earliest time that the flight can be at the MP(i) is its PTA. The terminal meter point PTA \( T_{mp(i)} \) is the latest time of the following three times:

1) \( STA_{mf} + T_{mf->mp(i)} \):
   Meter fix STA (\( STA_{mf} \)) plus transit time from meter fix to terminal meter point i, \( T_{mf->mp(i)} \). This is the flight’s earliest time-of-arrival at MP(i), using its nominal speed profile, assuming it will meet its meter fix STA.

2) \( STA_{mp(i-1)} - T_{mp(i-1)->mp(i)} - delay_{mp(i-1)->mp(i-1)} \).
   This is the flight’s earliest time-of-arrival at MP(i) that allows it to still meet the next terminal meter point’s STA (\( STA_{mp(i-1)} \)). This is how the segment absorbs the remaining delay caused by the downstream merge points.

3) Previously scheduled STA \( STA_{mp(i)} \).
   If an STA has been assigned to the terminal meter point in the previous iteration then the PTA for this terminal meter point cannot be earlier than the previously scheduled STA \( STA_{mp(i)} \). This is because the \( STA_{mp(i)} \) might be delayed due to a scheduling conflict or was adjusted in Step 5.

Step 4: Schedule the PTA \( T_{mp(i)} \) at the terminal meter point MP(i) to produce STA \( STA_{mp(i)} \)
The scheduler identifies the earliest available arrival time at the terminal meter point MP(i), but no earlier than the PTA. The separation distance constraint for the terminal meter point is enforced. For example, \( STA_{mp(i)} \) will have (at least) the minimum required separation between it and the flight ahead and between it and the flight behind.

Step 5: Adjust merge points STA between current merge point and runway.
Each time an STA is scheduled at a new terminal meter point, MP(i), the separation constraint at the MP(i) can potentially delay the flight such that it is impossible to arrive at the next downstream terminal meter point at its previously assigned STA. This step performs the STA adjustment to ensure the downstream terminal meter point STA is feasible. Given \( STA_{mp(i)} \), make sure that:
\[
T_{mp(i)->mp(i-1)} <= STA_{mp(i-1)} - STA_{mp(i)} <= T_{mp(i)->mp(i-1)} + delay_{mp(i-1)->mp(i-1)}
\]
for all terminal meter points to the runway.
The scheduled flying time between consecutive terminal meter points should be greater or equal to the nominal duration; and lesser or equal to the maximum segment duration (nominal segment duration + segment delay). If there is a violation, the STA_{mp(i-1)} is adjusted such that the condition is satisfied.

**Step 6: Assign the adjusted runway STA to runway PTA.**

If any of the terminal meter point STAs have been adjusted in Step 5, the flight needs to be rescheduled from its runway PTA to account for terminal meter point separation constraint and runway scheduling constraints. Rescheduling from the runway will enforce all the constraints again.

**Step 7: Delay Feedback to meter fix.**

When all the terminal meter points are scheduled, the TRACON has absorbed all the delay it can absorb. Any remaining delay is distributed to the ARTCC by incrementing the MF STA by the unabsorbed amount of delay. If the new meter fix STA does not violate any ARTCC scheduling constraints, this flight has completed its scheduling. Otherwise, a new meter fix STA is generated and the flight is added back to the scheduling list. It will be selected again at a later time according to DP order-of-consideration logic for TRACON scheduling.
Appendix A: ATD-1 Software Development Note

A1 Introduction
The goal of ATD-1 was to provide precision arrival flight schedules in the terminal area. TMA is already a well-established tool to provide the arrival schedule to en route controllers. Naturally, ATD-1 could use output from TMA as one of the inputs to the terminal area schedule. It was obvious that the output from ATD-1 can also be a good input to the TMA en route schedule. Thus, some type of integration would be desired. TMA already utilizes an existing terminal area model to help produce the ARTCC arrival schedule. TMA models airport configuration, airport acceptance rate, runway acceptance rate, TRACON acceptance rate, landing separation distance, terminal area delay, and nominal terminal arrival routes. The ATD-1 development approach is to improve TMA’s terminal area model and be an extension to TMA. The area of improvements for TMA’s terminal area model was identified:

1) Detailed altitude and speed restrictions for the nominal interior route.
2) Provide realistic schedules at the terminal meter points along the nominal interior route.
3) Improve the TRACON delay model.

With these considerations and three improvements in mind, ATD-1 simulation software was developed as an incremental addition to TMA.

A2 Functional modification
1) Better speed restrictions for nominal interior route.
TMA implements TRACON terminal speed restrictions as a series of path distance to runway and speed pairs for all nominal interior routes (e.g., 2NM/170CAS, 15NM/200CAS, 45NM/250CAS). ATD-1 needs a better model. ATD-1 creates all new nominal interior route definition with detailed nominal and slow speed restrictions at all the relevant waypoints along an arrival route. Aircraft of different engine types can have different route/speed/altitude restrictions. For each flight arriving on a particular route, ATD-1 generates nominal and slow trajectories based on the speed profile. A corresponding decision tree is created to map the route to selection criteria. The route is defined in site_adapt_dir/system/atc_proc_definitions file (See Attachment 2), the decision tree is defined in site_adapt_dir/system/atc_proc_tree file (See Attachment 3) for Example of files. The following PRs enabled this functionality:

AFPRS00010913
Extracting ETA for all waypoints along the route.
Add FAST_TRACON_TIME and SLOW_TRACON_TIME in AC property for analysis results extraction.
AFPRS00011765
lib_message/WaypointEtaListStructure has memory leak

AFPRS00011077
SDO TRACON trajectory request does not pass correct cur_cas/cur_mach to the GenAlt interface

AFPRS00011212
Add SDO terminal meter point speed profile file to ZLA_TFAS adaptation

AFPRS00011233
Create SDO categories for TRACON
(This approach was abandoned later for ATC procedure approach, but some of the incremental changes might still be useful to ATC procedure approach)

AFPRS00011428
Debug SDO TRACON trajectory in RA with ZLA_TFAS adaptation

AFPRS00011748:
Generate TRACON route with ATC procedure-based initial route and degree of freedom.

AFPRS00012036
Add aircraft on route as an evaluation to category decision tree. Also get slow profile ground speed for applying terminal meter point separation.

AFPRS00012218
Improve the logic to setup slow profile ETA.

AFPRS00012304
Tune the logic of using ATC procedure waypoint restrictions.

AFPRS12473 (new, added June 11, 2011)
Give a unique id to each analysis request and it’s result. This fixes a bug of corruption in analysis result node when multiple analysis requests’ results were residing in same analysis result list. This may not be a problem for RTMA, because trajectory interceptor introduced the possibility for analysis request to be out of sequence.

2) Improve TRACON delay distribution model
The TRACON Delay Distribution model in TMA is an adapted number of seconds of delay that any flight should be able absorb in the TRACON before feedback to ARTCC airspace. ATD-1 developed an individual flight’s delay distribution model based on its aircraft type, engine type, selected nominal interior route, speed restrictions along the route, and weather condition. This was achieved by calculating the difference in each route segment’s flying duration between the flight’s nominal and slow speed profile trajectories. The result
of this calculation resulted in ETAs for all waypoints along the route, each segment's flight duration, and amount of time the flight can absorb along the segment without vectoring.

**AFPRS00011349**  
Add terminal meter point to CTAS  
This PR setup a terminal meter point file in system directory  
`site_adapt_dir/system/merge_points`. Created a class in the lib that will read in terminal meter points contained in this file (See Attachment 1) for an example of terminal meter point file.

**AFPRS00011386**  
Calculate the control time range of TRACON segment, delay time in the segment between nominal and slow speed profile trajectories.

**AFPRS00011395**  
RA extracts and sends terminal meter point ETAs to CTAS

### 3) Merge point scheduling algorithm and delay distribution

Terminal meter point scheduling is a way to generate schedules for points along terminal arrival route. The detailed understanding of the arrival flight's terminal route trajectory based on nominal and slow profile enabled a more accurate terminal arrival model. With the knowledge of flight's individual route segment’s flying duration and segment delay capability, the scheduling algorithm was able to produce realistic schedule at terminal meter points and absorb the appropriate amount of delay.

**AFPRS00011414**  
Terminal meter point scheduling algorithm, and setting up terminal meter point for schedule in DP. This is the core PR for implementing terminal meter point scheduling algorithm in CTAS. This PR extended the ETA and STA classes to add terminal meter point values. The Schedule class was extended to add terminal meter points as schedule reference point. The Schedule class also integrated terminal meter point scheduling algorithm with the runway scheduler.

**AFPRS00011997**  
Apply slow profile ground speed for terminal meter point separation distance.

**AFPRS00011902**  
Inconsistency of `flow_parameter_sets` parameter during airport configuration changes

**AFPRS00011980**  
Super stream separation distance list handling problem

**AFPRS00012062**  
[DP] fix super stream class flow list handling problem
AFPRS00012216  
[DP] terminal meter point scheduling generate negative MF delay

AFPRS00012235  
Correct the wrong index used in eta_copy_merge_point()

AFPRS00012262  
[DP] terminal meter point scheduling triggers "waypoint delay < 0' messages

4) **Changes that ATD-1 depended on but not core to the main algorithm.**  
TS was modified to generate continues decent profile trajectory with 2.4 degree glide slope. TS was also modified to hold speed restriction until its time to capture next speed restriction. ATD-1 does not use (and does not require) the TSS GenAlt interface. The GenAlt interface allows TMA to specify more complicated trajectory definitions to be synthesized. Earlier documentation suggested, in error, that the GenAlt interface was an ATD-1 requirement.

Adding timeline to TGUI to display terminal meter point schedule.

Sending terminal meter point sequence, schedule and delay to Host.

Adding ability for TGUI to set terminal meter point separation matrix and buffer.
Attachment 1: Example of terminal meter point file

# comment start with #
# meter points for LAX's terminal scheduling
SADDE LUVYN MINZA SEAVU MADOW JETSA EAGULL RUSTT TRTLE WYVIL DYLAN FIM BAYER CLUSTR PDZ
Attachment 2. Example of atc_proc_definitions file

# atc_proc_definitions 07/02/2010
ZLA_TFAS
# (Lines beginning with '#' are comments and are ignored.)
# Revision History
# 20100702 ddu initial setup.

# atc procedure definitions added for initial test.

JET_LAX_24R_GRAMM

JET_LAX_24R_KONZL

JET_LAX_24R_LAADY

JET_LAX_24R_DEANO

JET_LAX_24R_PIRUE

JET_LAX_24R_SHIVE

JET_LAX_25L_GRAMM

JET_LAX_25L_KONZL

JET_LAX_25L_LAADY

JET_LAX_25L_DEANO

JET_LAX_25L_PIRUE

JET_LAX_25L_SHIVE
JET_LAX_25L_SXC

NONE_JET_LAX_25L_GRAMM

NONE_JET_LAX_25L_KONZL

NONE_JET_LAX_25L_LAADY

NONE_JET_LAX_25L_DEANO

NONE_JET_LAX_25L_PIRUE

NONE_JET_LAX_25L_SHIVE

NONE_JET_LAX_25L_SXC

EMPTY
Attachment 3. Example of atc_proc_tree file

# atc_procedure_tree , tree used to find atc procedure
    ZLA_TFAS
# (Lines beginning with '#' are comments and are ignored.)
# Revision History
# 20100702 ddu initial setup
# Tree structure added for initial test.

criteria WHICH_ENGINE {
    value JET
}
criteria WHICH_DESTINATION {
    value LAX
}
criteria WHICH_RUNWAY {
    value 24R
}
criteria AIRCRAFT_IN_GO_AROUND{
    value YES
    # Which /p runway is used as which runway flight is from
    criteria WHICH_FP_RUNWAY {
        value 25L
        category JET_LAX_25L_24R_GO_AROUND
        value 24R
        category JET_LAX_24R_24R_GO_AROUND
        value DEFAULT
        category JET_LAX_24R_24R_GO_AROUND
    }
    value DEFAULT
}
criteria WHICH_ARRIVAL_METER_FIX {
    value GRAMM
    category JET_LAX_24R_GRAMM
    value KONZL
    category JET_LAX_24R_KONZL
    value LAADY
    category JET_LAX_24R_LAADY
    value DEANO
    category JET_LAX_24R_DEANO
    value PIRUE
    category JET_LAX_24R_PIRUE
    value SHIVE
    category JET_LAX_24R_SHIVE
    value SXC
    category JET_LAX_24R_SXC
    value DEFAULT
    category EMPTY
}
value 25L
criteria AIRCRAFT_IN_GO_AROUND{
    value YES
    # Which /p runway is used as which runway flight is from
    criteria WHICH_FP_RUNWAY {
        value 25L
        category JET_LAX_25L_24R_GO_AROUND
        value 24R
        category JET_LAX_24R_25L_GO_AROUND
        value DEFAULT
        category JET_LAX_25L_25L_GO_AROUND
    }
    value DEFAULT
}
criteria WHICH_ARRIVAL_METER_FIX {
    value GRAMM
}
category JET_LAX_25L_GRAMM
value KONZL

category JET_LAX_25L_KONZL
value LAADY

category JET_LAX_25L_LAADY
value DEANO

category JET_LAX_25L_DEANO
value PIRUE

category JET_LAX_25L_PIRUE
value SHIVE

category JET_LAX_25L_SHIVE
value SXC

category JET_LAX_25L_SXC
value DEFAULT

category EMPTY

}
value DEFAULT

category EMPTY

}
value DEFAULT

category EMPTY

}

# end of WHICH_ENGINE
References


Title of Package: (edit)
ATD-1 TMA DOCUMENTS FOR APPROVAL (NINE DOCUMENTS)
Routernumber: 21936

Group this package under:
HQ_ARMD_ASP

Routing Package Administrator: Angela Boyle (edit)
Comments: (edit)

****URGENT REQUEST TO COMPLETE APPROVAL PROCESS FOR THE TMA DOCUMENTS PRIOR TO FRIDAY MORNING, SEPTEMBER 27, 2013****

Nine items enclosed:
1. ATD-1 Scheduling Algorithm Overview Version 2.0 (HSwenson & LChen, September 2013) / 7.01 ATD1-TMAlgDescription-20130913-V2.0.pdf

2. Controller Managed Spacing Tool Advisory Algorithm (CLee & LChen, September 2013) / 7.02 ATD1-CMSAlg-201309-Rev-.pdf

3. Overview of TMA RNP Route Processing (SChan, September 2013) / 7.03 ATD1-RNPRouteProcessing-201309-Rev-.pdf

4. Overview of RTMA Trajectory Synthesis Changes (SChan, September 2013) / 7.04 ATD1-TSSoftwareChanges-201309-Rev-.pdf

5. Overview of RTMA Dynamic Planner Changes (LChen, September 2013) / 7.05 ATD1-RTMADynPlannerChanges-201309-Rev-.pdf

6. STARS-RTMA Functional Description (Cisek, September 2013) / 7.06 ATD1-STARS-RTMAFuncDesc-201309-Rev-.pdf


8. Staggered Parallel Approaches Algorithm in TMA (LChen, September 2013) / 7.08 ATD1-StaggerAlgorithmTMA-201309-Rev-.pdf


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Add File

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