Applications of a Terminal Area Flight Path Library

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Abstract

Air traffic operations in a Terminal Radar Approach Control (TRACON), the airspace surrounding a busy commercial airport, are quite dynamic. As arrival flights approach their landing runways, air traffic controllers apply speed, altitude, and heading directives to effect safe and orderly merging of converging air traffic flows.

In some simulation models involving air traffic movement, a simplifying assumption has aircraft flying along straight-line paths in the TRACON. A direct path in the TRACON is simple to represent, but lacks fidelity with the real world. This path simplification is a limitation in modeling terminal area operations, and is a constraint when evaluating technological or operational changes in the terminal domain. As a remedy, we have created a library of TRACON paths using observed operational data. Collected data consists of ordered: latitude/longitude/altitude/time observations at 5-second intervals, from arrival fix to runway, or from runway to departure fix. Flow-specific geographic depictions of flight paths often show a wide splay, especially during busy periods when more extensive maneuvers are needed for merging and spacing. This diversity of paths implies additional flying time, and important noise and emissions impacts can be represented by sampling from this library. Employing higher fidelity TRACON paths is expected to improve accuracy in modeling flight delay and environmental impacts in the terminal area.

Introduction

The National Airspace System (NAS) is the collection of all aviation and air traffic resources in the U.S., including airports, runways, airspace, navigation equipment, and the air traffic management system. The system is exceedingly complex. Policy makers at the Federal Aviation Administration (FAA) rely on simulation models of the NAS to abstract and simplify problems and situations, in an attempt to answer questions regarding operation of the NAS, e.g., automation enhancements or safety. Many of these simulation models utilize a software module known as a *trajectory modeler* to build aircraft flight profiles, i.e., time-ordered sequences of position and altitude information. Typically a trajectory modeler uses aircraft flight plan data identifying route of flight, take-off time, and aircraft type, and performs an estimation process, using nominal assumptions about climb performance, aircraft loading (and hence take-off weight), etc. The accuracy of the resultant flight trajectories is important to the accuracy of the broader results of the simulation model.

However, part of the flight's planned path is not included in the flight plan: the path in the departure and arrival airport region. This is because the terminal paths are not known at the time of filing the flight plan: it is unknown what runway configuration (i.e., the set of active runways) the airport will be in, as that is mostly a function of wind speed and direction, which are dynamic and can often change over the course of the day.

Trajectory modelers often simply assume that paths in the TRACON are straight and direct: on departures, going from the airport reference point ("ARP", the official airport location, expressed in latitude/longitude, often the geometric center of the landing area) to the first named departure fix in the flight plan; on arrivals, proceeding from the arrival fix directly to the ARP. To improve on this part of the trajectory modeling, we have created a library of TRACON paths, taken from real-world data. We describe below how we derive this library, and then present two applications of the library.

Data Capture and Processing

A service called the National Offload Program (NOP), which is operated by the FAA, collects NAS operational data daily. One of the data items collected is flight tracks for TRACONs. Flight tracks contain identifying flight number and flight status (arrival, departure, or overflight) as well as position reports including (latitude, longitude, altitude, and time-of-report). TRACON paths are extracted from these files, connecting runway and arrival or departure fix.

The term "arrival fix" is not rigorously defined or used in air traffic management, so it was necessary that we identify appropriate fixes, approximately on the TRACON boundary. In some earlier work [DeArmon et al., 2009], merging points for an airport's arrival fleet were identified via a custom-designed clustering algorithm. The algorithm begins by overlaying an imaginary grid on the subject area, then tallying trajectory transits through grid cells, for a full day of flight trajectories. Grid cells with high counts are next identified and a network of links is constructed to connect them, creating a "tree" of merge nodes. Figure 1 displays arrival fixes for Chicago O'Hare International Airport (ORD) as filled, red triangles on the inner-most circle.

The term "departure fix" is likewise not rigorously defined, and it was necessary to determine a reasonable set of fixes to end the TRACON paths for departures. A procedure of examining departure trajectories en masse, looking for named fixes on or near the TRACON lateral boundary was developed, and works well, as verified by subject matter experts and by visual assessment.

As mentioned above, simple trajectory modeling makes the ARP a single location from which departures emanate and to which arrivals converge. We improve on that simplification by applying some geometric logic to determine runway usage per the actual flight track in question. Three metrics are computed for each track at 100' above ground (see Figure 2, with the metrics annotated): the path angle difference from the runway centerline (DELHD), the distance from the centerline (OFFC), and the distance from the runway end (DIST). A score is computed using these three metrics, and an accurate runway assignment results (as validated via visual assessment).

Using the arrival and departure fix locations, a file of NOP flight tracks for an airport (typically a full day, represented by scores of megabytes of data) is processed. A proximity test is performed to associate a flight with an arrival or departure fix. The runway assignment logic is applied to determine runway usage. Stored data are organized by: date, airport, fix, runway configuration, and runway.

Applications of the TRACON Path Library

The detailed TRACON flight paths captured in the TRACON path library are envisioned to be of importance for terminal area studies that are sensitive to aircraft flight path information. Here we describe two such applications, where the TRACON path library is expected to advance existing modeling approaches in the terminal area. The first application pertains to delay modeling, while the second application is focused on fuel burn, emissions, and noise modeling in the terminal domain. The following discussions describe these applications in greater detail.

Improved Transit Times for TRACON Arrivals

MITRE uses an internally-developed discrete event simulation model known as *systemwide*Modeler [Kuzminski, 2008] to analyze the impact of operational changes on the NAS. It was suspected that *systemwide*Modeler's TRACON arrival flight transit times were modeled to be too short. Since the path being used was a straight line, with no imputed TRACON delay, the air traffic control (ATC) directed maneuvers to effect merging and spacing were not accounted for. While the entire solution to this problem has not been completed yet, the work described here defines the initial logic for enhancing terminal area delay modeling using the TRACON path library.

For a given combination of fix/runway/configuration, the library is scanned for associated paths. The paths are considered as a set, the transit time of each is determined, and the list of transit times is sorted lowest to highest. The 10th percentile transit time is selected as a reasonable time to represent unimpeded flight for the combination, i.e., assuming the flight could expedite its trip from fix to runway end, and have no interactions with other aircraft or obstructions.

Next, a new trajectory point is created, called a "contention point", at 5 nautical miles from the runway end, along the runway centerline. (This distance from the runway end is somewhat arbitrary. It need not coincide with any particular point along the final approach path − it is merely a common point, close to landing, for arrival flights using the runway.) For all flights for this fix/runway/configuration, their trajectory is modified as follows: instead of flying straight to the ARP, the flight flies directly to the contention point, then directly to the runway end. However, the 10th percentile unimpeded flight time is apportioned between the two segments: fix to contention point, contention point to runway end. It is planned that the contention point will be a shared resource for the set of flights on this runway. As a resource in the simulation model, it has finite capacity, and, when over-subscribed, delay will be assigned to flights using a first-come-first-served queue.

There exists already in the model mechanisms for modeling queuing for a landing runway, and for modeling ATC workload in the en route domain (increased ATC workload implies increased delay). The use of the contention point as a shared resource will allow for the representation of TRACON delay due to ATC merging and spacing activities in TRACON airspace, as distinct from runway landing capacity alone.

See Figures 3 and 4 for examples. The multi-colored sinuous lines are individual flight tracks. The slightly thicker black line is the two segments just described, with the angle apex being the contention point.

Environmental Modeling

We are currently pursuing a project to use data from *systemwide*Modeler to assess noise, emissions, and fuel burn impacts of aviation on a NAS-wide level. We will use the output from the *systemwide*Modeler as input to the FAA's Aviation Environmental Design Tool (AEDT, see [Iovinelli, 2009]) to model environmental consequences of operational changes in the NAS. *Systemwide*Modeler considers ATC workload and capacity of resources and estimates flight-by-flight delay. Flights with delay will spend more time generating noise and emissions, and are therefore an appropriate input source. As indicated previously, *systemwide*Modeler provides high fidelity flight track information in the enroute portion of a flight, with simplified terminal area tracks. While emissions and fuel burn estimation for the terminal area may be conducted with simplified arrival and departure paths (given accurate time-of-transit), noise estimation is strongly driven by the precise location of the aircraft. As such, this TRACON library will provide key terminal area input to the AEDT model, supplementing flight track information from *systemwide*Modeler to improve noise, emissions, and fuel burn modeling in the terminal area.

Noise studies require that the analyst specify a dispersion of tracks to represent a realistic spread or splay of actual track paths. Typically, the analyst would assess a visual representation of many tracks, select characteristic nominal paths or "backbones", and then figure a way to specify the variation about the backbone created by ATC maneuvers for merging and spacing. Figure 5 notionally shows one way to specify track dispersion – establishing a backbone, and then the one-sigma and two-sigma envelopes about it. Sigma is one standard deviation of the set of distances of individual tracks from the backbone, measured perpendicular to the backbone. Since we plan to model the entire NAS (and the top 35 airports in detail), this manual approach to path specification is not practicable.

We plan instead to perform random sampling of the TRACON path library and use radar paths. Figure 6 is a plot of departure paths, randomly selected from many sample days. The multi-colored lines are observed departure paths from departure runway to fix. For contrast, the simpler direct ARP-to-fix lines are overlaid. It is assumed that random sampling of the TRACON path library will fairly represent true airspace usage, for many combinations of fix/runway/configuration, giving rise to improved estimates for environmental impacts.

Next Steps

The next steps in these two applications are to exercise the TRACON path library in the applications previously mentioned and explore other potential application areas. For *systemwide*Modeler, we will implement the feature of improved arrival flight TRACON transit times, using the stratagem of the geometrically-constructed contention point. For the environmental modeling, we will use random sampling to create realistic airspace usage, with the intent of more accurate environment impact results.

Another potential application area for the TRACON path library is modeling terminal area NextGen operational improvements. These include use of advanced procedures such as RNAV/RNP procedures, optimal profile descents (OPDs), operations for closely spaced parallel runways, as well as decision support tools such as the Relative Position Indicator (RPI) that can modify terminal area operations relative to current practices. Having a TRACON path library with high-fidelity flight path information may be of value to evaluating proposed NextGen initiatives.
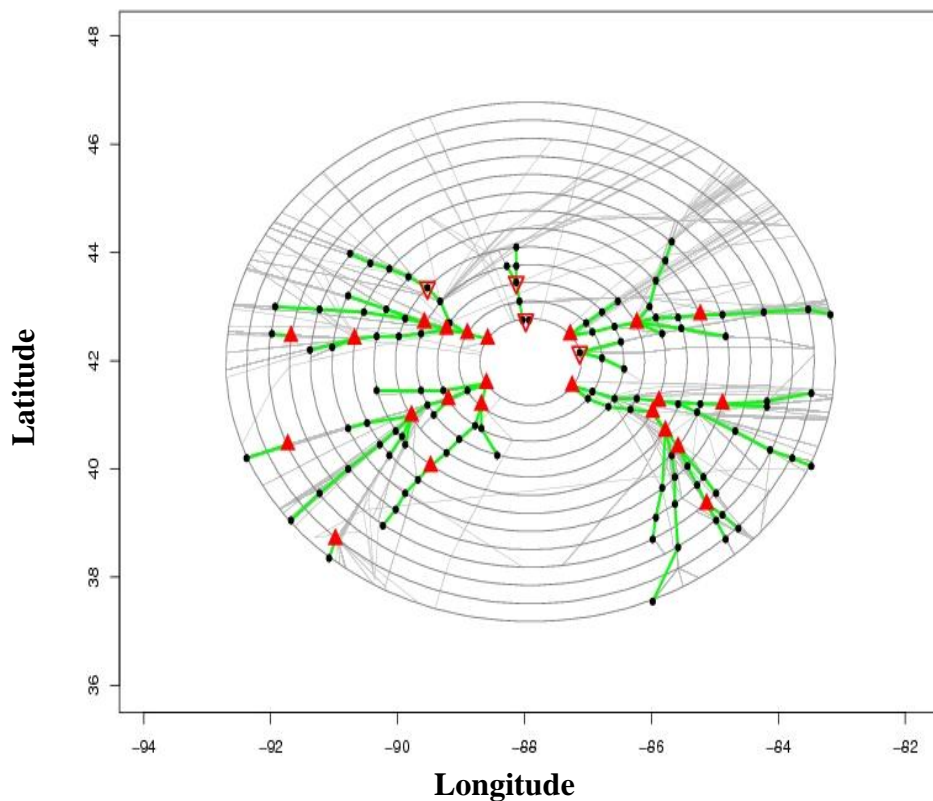

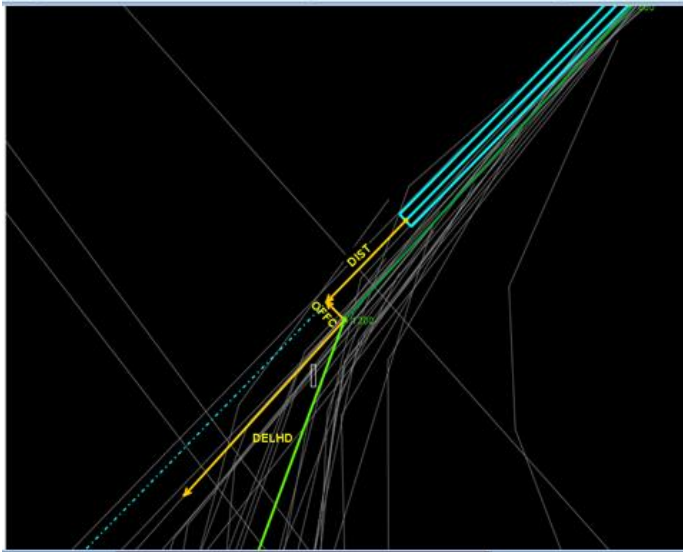Figure 1: Merge Tree Constructed for Arrivals to Chicago O'Hare Airport (ORD).

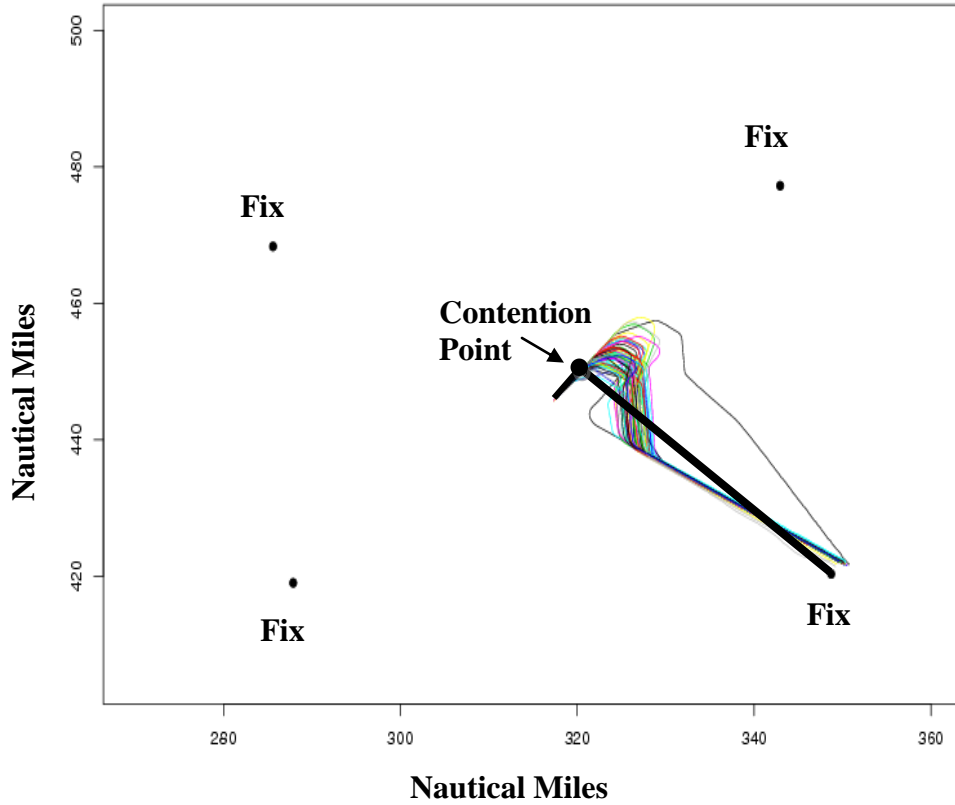Figure 2: Three Parameters Used to Determine Runway Assignment of a Flight

Figure 3: Arrival paths from fix to runway, with super-imposed nominal path, Chicago O'Hare Airport (ORD). (Black filled circles represent arrival fixes; multi-colored lines are flight tracks. The thicker black line is the two new trajectory segments with contention point at the apex of the angle. Axes are not in equivalent scaling.)
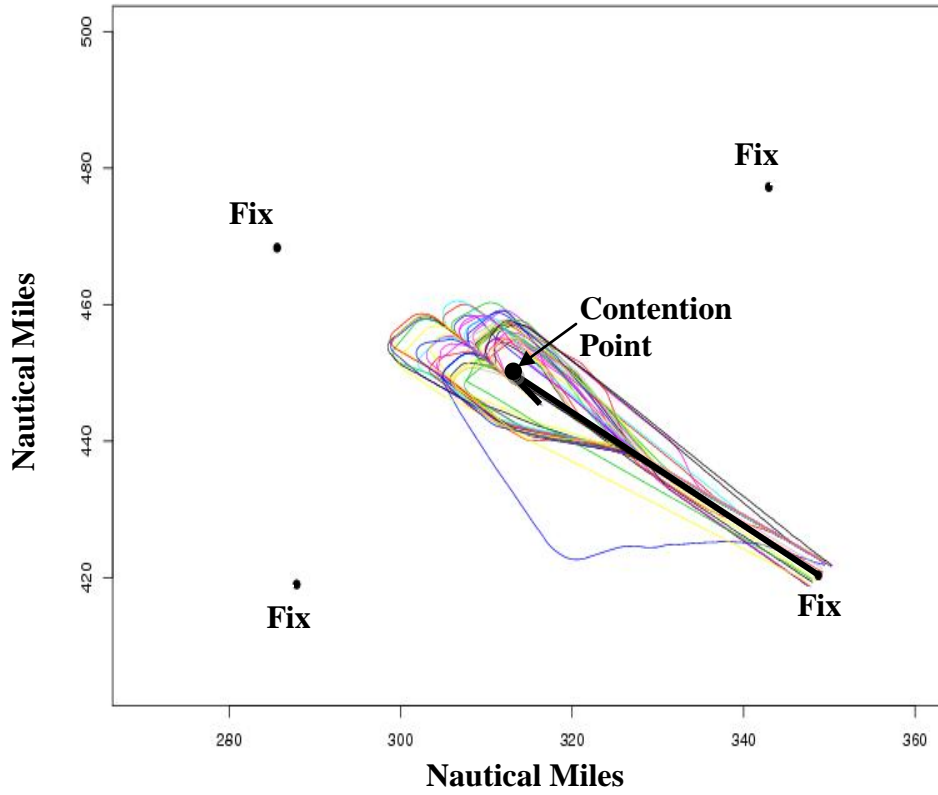
Figure 4: Arrival paths from fix to runway, with super-imposed nominal path, Chicago O'Hare Airport (ORD). (Black filled circles represent arrival fixes; multi-colored lines are flight tracks. The thicker black line is the two new trajectory segments with contention point at the apex of the angle. Axes are not in equivalent scaling.)
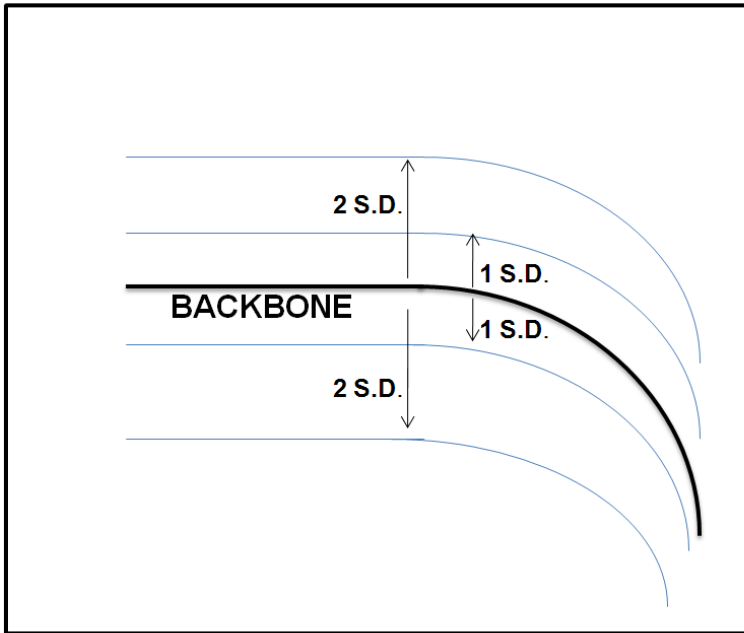
Figure 5: Notional diagram of designing path "backbone", plus specification of spread using Standard Deviations (S.D.)
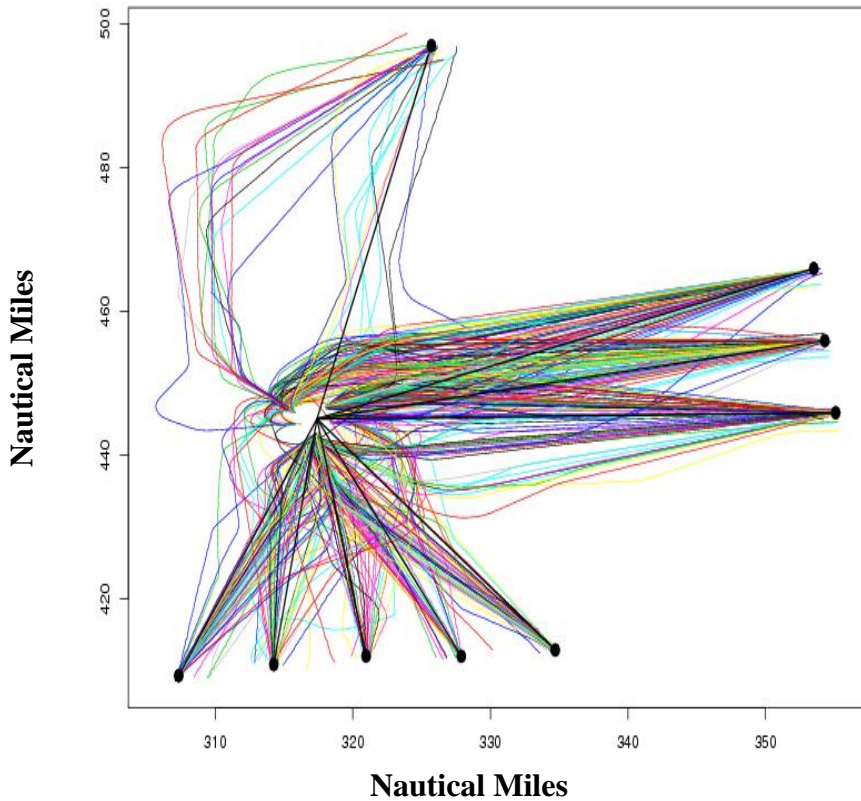
Figure 6: Departure Paths from Multiple Runways over Many Days, Chicago O'Hare Airport (ORD) (Black filled circles represent departure fixes; black lines connect the airport to the departure fix directly; axes are not equally-scaled).

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