WORKLOAD EVALUATION OF SECTORIZED AIR TRAFFIC CONTROL AND STREAM MANAGEMENT

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Abstract

Stream management is a novel air traffic control operational concept in which controllers control streams of aircraft that are functionally equivalent, rather than being responsible for "aircraft in airspace." One of the potential benefits of stream management is workload reduction for the same amount of aircraft handled. An adaptation of the dynamic density workload measure was used to evaluate stream management operations against current sector based control. This evaluation is completed using FACET software and ASDI data. Stream visualizations and data analysis demonstrate the advantages of stream operations.

1. Introduction

Dynamic airspace research is designed to address three limitations of the current sector based air traffic control, specifically to a) balance controller workload, b) accommodate route flexibility, and c) integrate automated separation assurance [1]. Currently, the primary approaches of dynamic airspace design involve modifying sector boundaries with or without "playbook options," or segregating tubes of airspace within existing sector constructs. However, such approaches do not address all three limitations noted above. Some problems cannot be essentially solved under sectorized air traffic control.

A new concept, called "stream management" has been proposed. Under stream management, controllers would be assigned a "stream" of aircraft consisting of functionally equivalent aircraft, i.e. aircraft that will be handled together in the same pattern if they are within one stream. An example of a stream in en route airspace would be aircraft that are utilizing the same routing and are destined for the same geographic area, while in a TRACON a stream can be defined as the aircraft utilizing the same arrival gate and destined for the same runway. (The rough protocol of streams has been applied in the Traffic Management Advisor system already [2-3].) This concept would effectively eliminate the concept of sectors, since controllers would be responsible for the stream regardless of where that stream was located geographically. While this seems, at first, a somewhat radical departure from current operations, stream management in a TRACON would be roughly equivalent to a combined feeder-final operation that is used in some TRACONs, i.e., SoCal TRACON.

One major benefit mechanism of stream management would be to balance workload among controllers; instead of having one controller manage a large number of aircraft and another controller manage almost none, streams could be assigned to controllers to maintain each controller's workload balanced. In this paper, in order to evaluate stream management, estimates of workload under stream management scheme were compared with that of sector-based control. The entire framework of the workload evaluation on both schemes is explicitly illustrated. ASDI data, FACET software, MySQL database and Matlab were utilized in implementation.

The rest of this paper is organized as follows. We first discuss the concept of stream management, followed by a description of workload measures used to assess controller workload in Section 2. In Section 3, the streams are first identified and visualized in Chicago (ORD) TRACON. The workload evaluation method is then applied in San Diego (SAN) area, which is part of the Southern California TRACON (SCT). We show the results and discussions in Section 4. Section 5 concludes the paper.

2. Background

A. Stream Management Concept

Currently, controllers manage a sector of airspace. Within this sector controllers are required to accept aircraft as they enter the sector, perform merging and spacing of converging aircraft, ensure proper separation of crossing aircraft, direct aircraft along a trajectory, keep aircraft avoided from ground obstacles and restricted airspace, and hand aircraft off to the next controller when they leave the sector. Substantial local knowledge is necessary to manage a sector, thus reducing the flexibility of which sectors a controller can manage. Communication across sectors, particularly when those sectors are in different facilities, can create significant workload, so control actions that require such coordination are sometimes avoided even if such actions would benefit individual aircraft.

An alternative to controlling “aircraft in airspace” is the concept of stream management. In en route airspace, controllers under stream management would be responsible for similarly bound aircraft on a similar route, and would therefore primarily be responsible for merging and spacing; responsibility for separating crossing traffic and obstacle clearance would be delegated to automation. Since merging and spacing is generally a more manageable task for controllers, they may be able to handle more aircraft, which would reduce the number of handoffs required and minimize coordination across facilities. In a TRACON, where there is already limited crossing traffic, the concept of stream management is very similar to the combined feeder-final operation utilized in some facilities. Therefore, the concept may be easier to adapt to a TRACON initially, and the benefit found in the TRACON would likely be exceeded in en route airspace. For that reason, we are initially focusing on implementing the concept within a TRACON environment.

One proper definition of a stream is that it is composed of aircraft that have the same engine type, destination airport, and arrival gate. This is chosen to be consistent with the current definition of a stream in the FAA’s Traffic Management Advisor (TMA) system, which is currently implemented in every en route air traffic control center (Center) in the U.S. National Airspace System (NAS). (Several streams can be handled together as one “super stream.”) However, a wide variety of other possible definitions for streams could be adopted.

As mentioned, the mature concept for stream management would delegate some tasks to automation. For example, separation between crossing streams and with the terrain would be handled by automated separation assurance. It is therefore not expected that this concept could achieve full maturity until such technology is fielded; this technology is required in order to meet NextGen implementation goals by year 2025. In such a system, a controller’s responsibility will be reduced to spacing and sequencing of aircraft within their streams. Because of this, only limited specialized knowledge may be required, giving more flexibility to assigning controllers, and the communication needs between streams may become minimal.

Implementing stream management will address limitations of sector management with the following benefit mechanisms:

a) The shift to stream management may allow workload to be better balanced across controllers than in current sector operations.

b) Controllers may have more flexibility with aircraft routing, as they are no longer confined by sector boundaries.

c) The integration of automated separation assurance under the stream management concept will allow higher airspace capacity while maintaining a similar controller workload relative to current sector operations.

B. Workload Measure

Several metrics are currently used to measure or control air traffic controller workload. The simplest of these is a traffic count, as compared to the Monitor Alert Parameter (MAP) assigned for each sector as the maximum allowable traffic count; the FAA monitors the predicted aircraft count for all sectors using the Enhanced Traffic Management System (ETMS) and reroutes aircraft to avoid sectors exceeding their MAP number [4]. (Typically, controllers are expected to handle on the order of 13 aircraft at any given time, with substantial variation based on the difficulty of the traffic flow through the sector.) ATWIT is a real-time measure taken during air traffic control tasks, typically only during simulations [5]. Post-hoc workload can be taken using instruments such as the NASA task load index (TLX) [6]. Model-based measures, which could be applied to predicted traffic or recorded traffic files, include various methods that can be used to compute a complexity metric referred to as dynamic density [7-8]. Dynamic density is defined as the collective effect of all factors, or variables, that contribute to sector level air traffic control complexity or difficulty. Since this work was conducted using a recorded traffic file, a measure of dynamic density was used.

Since each metric in [7-8] has certain limitations within itself, a new metric for both sector based and stream based management is developed by applying the most essential components shared by all metrics. The need for the comparison between sector based control and stream management is to evaluate how controller workload and responsibilities will change with the implementation of stream management. In next section, the demonstration that controller workload is reduced with stream operations acts as a foundation of support that higher capacity airspace may not be possible with current sector operations.

3. Method

In this paper, the authors' first focus is on the definition of streams. After the stream definition is obtained, the controllers' workload comparison is performed between sector and stream based air traffic management.

A. Operational considerations

Prior to this analysis, SCT SAN controllers were interviewed to obtain insight into the operations of the facility. It was learned that SCT SAN is divided into six sectors. Each of the six sectors may be controlled by an individual controller. Combinations of different sectors may exist based upon operational needs or staffing availability. Thus, in this paper the authors are investigating how the controllers workload will change with stream based operations especially in SCT SAN area.

B. Stream Visualization

First of all, in order to observe the streams in a TRACON, the FACET visualization of Aircraft Situation Display to Industry (ASDI) data for B737-300 with jet engine into ORD (Chicago O'Hare Airport) on March 26, 2007 is plotted.

Chicago TRACON spans approximately 45 miles from the ORD airport, which has four STARs and two RNAV STARs (Figure 1).

There are 77 flights of B737-300 entering ORD on March 26, 2007. In Figure 2 shown below, four metering fixes (KRENA, NEWRK, HALIE, PAPPI) are illustrated and four streams can be defined by these four metering fixes.

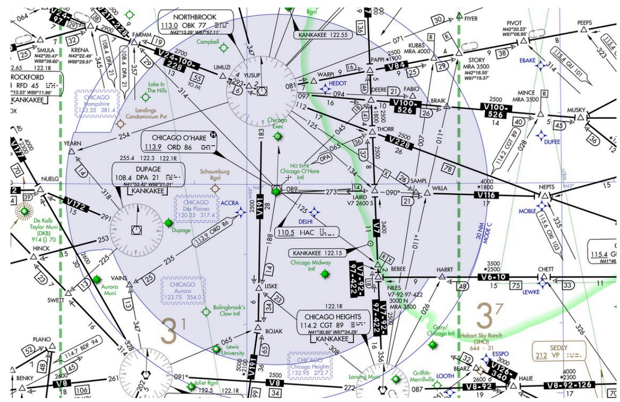

Figure 1 Chicago TRACON on aeronautical chart.

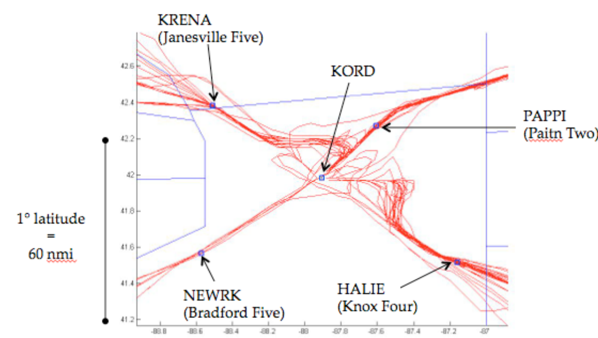

Figure 2 Four arrival streams to KORD are visualized.

After we take a first look of streams in a TRACON, the detailed stream definition is introduced in Section 3.C.

C. Definition of streams

As mentioned in Section 3.A, Aircraft Situation Display to Industry (ASDI) data on March 26, 2007 is used to analyze flights arriving in Southern California TRACON (SCT), San Diego (SAN) area. The ASDI tracking data is used as input for the Future Air traffic management Concepts Evaluation Tool (FACET) software [9] and the output from FACET is parsed by destination airport or runway, arrival gate (metering fix or metering boundary) and engine type (jet, turboprop or prop). An example of several streams of jet aircraft arriving at KSAN can be seen in Figure 3.

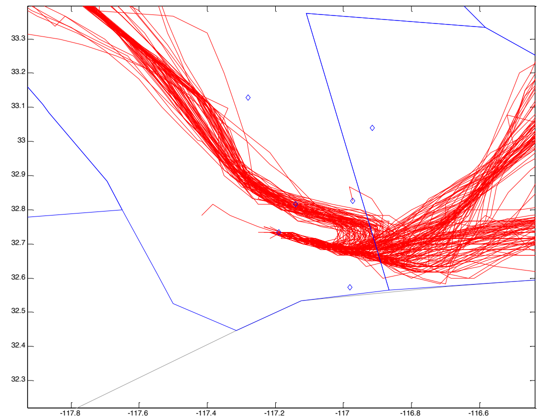

Figure 3 Arrival jet streams to KSAN.

From the flight plan data in ASDI, we extract the metering fix of each aircraft, which is used to set the stream configurations together with engine type and destination airport. From the tracking data in ASDI, we perform the stream visualization and workload evaluation analysis.

Aircraft are grouped with arrival gates by evaluating common arrival routes, whether through a meter fix or a standard terminal arrival route (STAR), or commonly vectored routes. After aircraft trajectories were grouped into streams by their destination airport, engine type, arrival gate; the streams were integrated into super-streams to calculate the overall workload complexity.

D. Workload evaluation

a) FACET playback

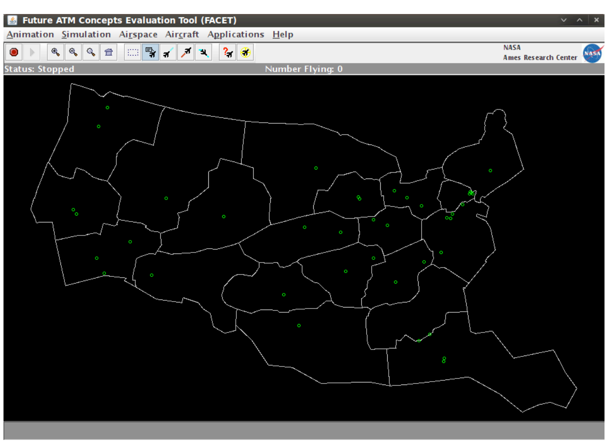

Figure 4 FACET software GUI.

First we use playback mode in FACET software (see Figure 5) to rerun the ASDI tracking data. The reason we perform the tracking data playback is because FACET provides more attributes to facilitate workload calculation. i.e., FACET adds altitude speed, heading, heading rate information that will be used in several dynamic density metrics and it outputs which sector and which center an aircraft is in at any time. The sector and center information will be used in workload evaluation for sectorized air traffic control.

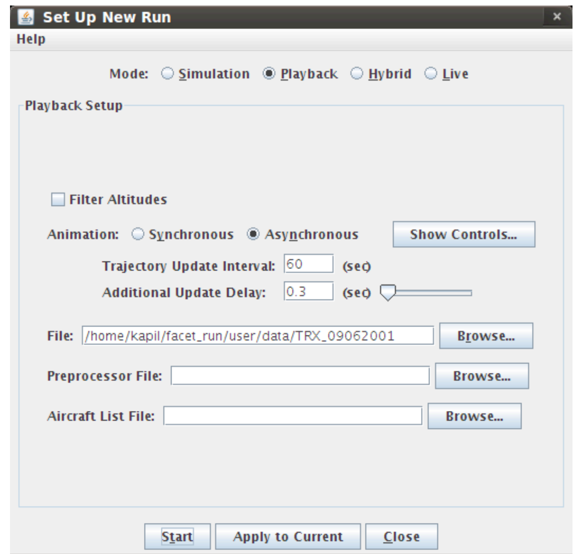

Figure 5 Playback mode interface in FACET.

b) MySQL database

Although the output from FACET playback contains more useful attributes, its file format is in plain text, in which the information is not easy to retrieve and manipulate. Therefore we use MySQL database to store and manage the FACET output.

```
mysql> describe Data20070326;
+-------------+-------------+------+-----+---------+-------+
| Field       | Type        | Null | Key | Default | Extra |
+-------------+-------------+------+-----+---------+-------+
| ACID        | int(11)     | YES  |     | NULL    |       |
| ACTYPE      | varchar(50) | YES  |     | NULL    |       |
| Orig        | varchar(20) | YES  |     | NULL    |       |
| Dest        | varchar(20) | YES  |     | NULL    |       |
| CurrentTime | double      | YES  |     | NULL    |       |
| Lat         | double      | YES  |     | NULL    |       |
| Lon         | double      | YES  |     | NULL    |       |
| Speed       | double      | YES  |     | NULL    |       |
| Sector      | int(11)     | YES  |     | NULL    |       |
| Center      | int(11)     | YES  |     | NULL    |       |
| Head        | double      | YES  |     | NULL    |       |
| HeadRate    | double      | YES  |     | NULL    |       |
| Alt         | double      | YES  |     | NULL    |       |
| AltSpeed    | double      | YES  |     | NULL    |       |
+-------------+-------------+------+-----+---------+-------+
14 rows in set (0.21 sec)
```

Figure 6 Build a MySQL table.

ACID	ACTYPE	Orig	Dest	CurrentTime	Lat	Lon	Speed	Alt	AltSpeed	Head	HeadRate	Sector	Cente
15491	A320	KIAD	KORD	40806	41.24999999...	-86.0166666...	421	25000	0	278.5012356...	4.860763533...	290	3
15491	A320	KIAD	KORD	40866	41.30000000...	-86.1666666...	421	25000	0	278.5033797...	4.860800954...	290	3
15491	A320	KIAD	KORD	40926	41.33333333...	-86.3166666...	416	24000	0	286.6362998...	5.002747188...	290	3
15491	A320	KIAD	KORD	40986	41.36666666...	-86.4499999...	411	21900	0	290.3882891...	5.068231755...	290	3
15491	A320	KIAD	KORD	41046	41.4	-86.5833333...	393	20000	0	287.4923175...	5.017687515...	290	3
15491	A320	KIAD	KORD	41106	41.43333333...	-86.7	356	17200	0	288.5116803...	5.035478751...	290	3
15491	A320	KIAD	KORD	41166	41.45	-86.8333333...	356	14900	0	289.6530822...	5.055399973...	290	3
15491	A320	KIAD	KORD	41226	41.48333333...	-86.9499999...	356	12600	0	284.9954450...	4.974108868...	290	3

Figure 7 Example MySQL query results.

We create a database in MySQL and build a table with attributes described in Figure 6. The attributes include Aircraft ID, Aircraft Type, Origin Airport, Destination Airport, Current Time, Latitude, Longitude, Ground Speed, Altitude, Altitude Speed, Heading, Heading Change Rate, Current Sector, and Current Center. Then the plain text output from FACET is loaded into this table. This data was then cross referenced against another table of all possible aircraft types in ASDI data, which provides the engine type according the aircraft type.

Now the queries can be performed to retrieve data. We list the query result in Figure 7 of the aircraft with computer ID 15491 when it is in sector 290. Please notice FACET has a mapping from the real sector names to its own sector indices, e.g., Sector 290 in Figure 7 is Sector ZAU35 in Chicago center. Another note is that the update rate of ASDI data is one minute, which is our result resolution in this paper. Higher resolution data and CTAS software [10] will be used in our future work.

c) Matlab with MySQL interface

In order to visualize streams or compute the workload, we use the Matlab's Database Toolbox and MySQL Connector/J to build the interface.

First of all, more streams are identified in San Diego area. San Diego International Airport (KSAN) is the larger airport with two runways 9 and 27. From Figure 8 we can observe that relatively huge mount of jet streams arrive in KSAN and the traffic finally merge into north stream and east stream.

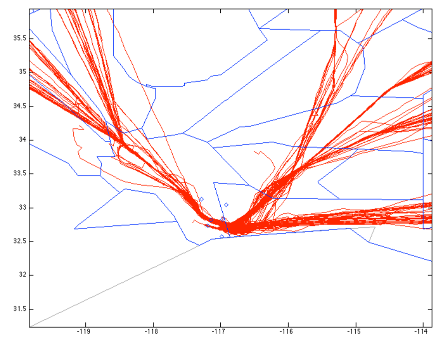

Figure 8 All jet streams into KSAN.

Most aircraft of the turboprop stream into KSAN departure from KLAX (Los Angeles) with tower en route control (TEC) in low altitude (see Figure 9).

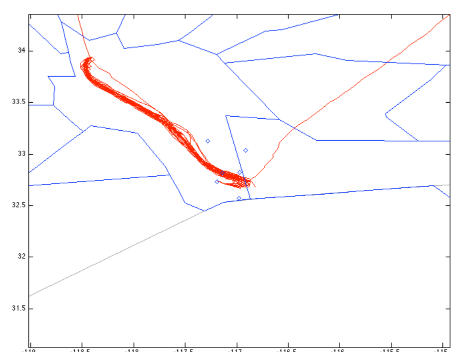

Figure 9 All turboprop streams into KSAN.

Since KSAN is an international airport, there are very few prop traffic. They do not follow STAR or TEC (see Figure 10).

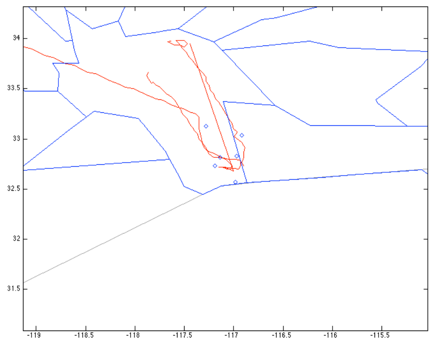

Figure 10 All prop streams into KSAN.

In addition, the streams into Montgomery Field Airport (KMYF) are plotted. KMYF is a smaller airport so there is more traffic in turboprop and prop streams coming in (see Figure 11, Figure 12 and Figure 13).

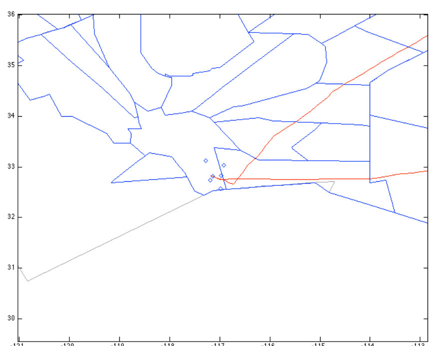

Figure 11 All jet streams into KMYF.

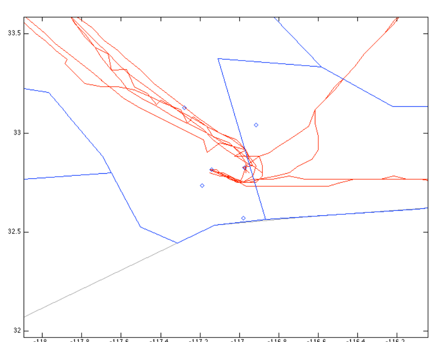

Figure 12 All turboprop streams into KMYF.

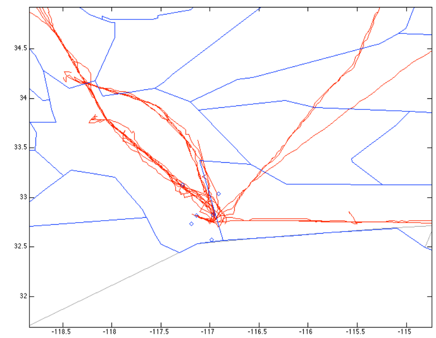

Figure 13 All prop streams into KMYF.

d) Workload calculation

According to the ASDI data and the existed metrics, we select those factors that can be calculated based on ASDI data and design our own metric for both sector based control and stream based control.

The complexity calculation utilized is an adapted version of dynamic density. Dynamic density is calculated as a weighted sum of a number of factors including aircraft count, heading change, speed change, altitude change, and others. To ensure a fair comparison, only variables that are relevant in both sector-based and stream management control were utilized. The weightings of the factors were set in two ways; the first method utilized a regression weighting in [8], and the second was based on subject matter experts (SME) defining the weighting as in [6]. Eq. (1) is our dynamic density where W1-W4 are the regression or SME weightings and N, NH, NS, NA are the factors that define dynamic density within a sector.

$$\text{Dynamic Density} = W_1 \bullet N + W_2 \bullet NH + W_3 \bullet NS + W_4 \bullet NA \qquad (1)$$

where

N = aircraft count

NH = heading change

NS = speed change

NA = altitude change

For sector based management, Eq. (1) is used to calculate the dynamic density in each sector for the whole day of Mar 26, 2007 first. And the total dynamic density will be the summation of all the sectors. The aircraft in each sector are identified according to the "Current Sector" attribute as shown in Figure 7.

For stream based management, the dynamic density in each stream is first calculated and then all the stream dynamic densities are accumulated. The aircraft in each stream are identified by their destination, engine type and arrival gate as described in Section 3.C.

4. Results

The aircraft tracking data are analyzed in both stream management scheme and sector based control scheme. The metric is re-designed and applied.

For the data file of March 26, 2007, the regression weighting for dynamic density resulted a complexity measure of 16,429 for sector-based control and a complexity measure of 12,460 for stream management, with a reduction of 24%. Using the SME-weighted dynamic density equations, the complexity measures were 28,836 and 23,550 for sector-based control and stream management respectively, for a reduction of 18%.

This apparent reduction in complexity may be a result of shifting from manual responsibility to automated responsibility for interacting streams.

5. Conclusion

The stream definition is proposed and the visualization helps better understand the stream management concept. A complete complexity measure procedure from ASDI data to workload evaluation for both sector based control and stream management is presented in this paper, where FACET, Database and Matlab are utilized. In order to accommodate both traffic management schemes, a dynamic density adaption is introduced. The results show that shifting from sector based control to stream management indeed reduces the overall workload, which makes the stream management become a potential framework for higher density operations in future air transportation systems.

Acknowledgments

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