A METHODOLOGY FOR AIRPORT ARRIVAL FLOW ANALYSIS USING TRACK DATA – A CASE STUDY FOR MDW ARRIVALS

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Abstract

Traffic flow in the Terminal Radar Approach Control Facilities (TRACON) is a significant factor in determining airport throughput capacity and airline operational efficiency. In recent years the availability of high fidelity terminal area track data has made it possible to increase the granularity of airport and airspace performance analysis.

This paper describes a methodology for airport arrival flow analysis using National Offload Program (NOP) track data. The analysis provides insight into track distances flown and track time for alternate terminal arrival flows (i.e. from the final waypoint in the Standard Terminal Arrival Route (STAR) to the runway threshold via a type of approach).

The methodology is applied to 35 days of NOP track data for Chicago TRACON (C90) for arrivals into MDW. Arrivals into MDW landing to the north-west on 31C and to the north-east on 4R exhibit the shortest average track distance (28.42 NM and 29.81 NM.). Arrivals landing to the south-east on 13C exhibit the highest mean track distance of 38.9 NM. Track distance/time is least for VFR approaches onto all runways. When IMC conditions exist, RNP approaches provide 6-10% savings in track distance/time over ILS approaches. One unexpected result is that RNP approaches exhibit the same variance in track distance/time as ILS approaches. The variance in RNP approaches occurs on the downwind and turn-to-base, while the variance on the ILS approach occurs by "tromboning" on the base leg and the turn to final.

Introduction

The flow of traffic in the terminal area is a significant factor in determining the airport capacity and airline operation efficiency. The relative position of the final waypoint on the Standard Terminal Arrival Route (STAR) and runway determines the track distance/time in the TRACON and the resulting flow onto the runway. Operational efficiency is maximized when the arrival flow crosses the final waypoint on the STAR and flies a straight course onto the runway. TRACON flows that require turns to line-up for the final approach segment add vector complexity and result in increased track distance/time, and more importantly increased variance in track distance/time resulting in lost runway productivity.

The choice of approach procedure also affects the track distance/time and their variability. VFR approaches generally result in shortest track distance/time with low variability. ILS approaches during Instrument Meteorological Conditions (IMC) require a 10-14 NM final approach leg and increased variance as flights are vectored to the base leg and the turn-to-final to capture the localizer.

Required Navigation Performance (RNP) approaches with RNP 0.3 and Radius to Fix (RF) capability are designed to provide a precise, curved flight path that can be used instead of ILS approaches [1]. These approaches, developed by Alaska Airlines in 1996 to improve access and schedule reliability to its airports (surrounded by mountains and having complex wind patterns) [2], have been deployed worldwide [3][4][5]. The Federal Aviation Administration (FAA) has published RNP approach procedures for 97 airports in the U.S [6]. These approaches reduce track distance/time in the TRACON and have the potential to reduce variability in track distance/time.

This paper describes a methodology for airport arrival flow analysis using National Offload Program (NOP) track data to: (1) characterize TRACON flows, and (2) to compute TRACON flow performance statistic (i.e. μ and σ for track distance and track time). An arrival flow refers to the flow of traffic from the final waypoint on the STAR to the runway threshold via an approach-type.

A case study of TRACON flows to Chicago Midway International Airport (MDW) is presented. MDW is one of 97 airports where a RNP procedure has been published. It is also a Southwest hub, and the airline currently does carry out limited number of RNP procedures. Analysis of 35 days of NOP track data identifies the following characteristics:

- Arrivals into MDW landing to the north-west on 31C exhibit the shortest average track distance (28.42 NM.).
- Arrivals landing to the south-east on 13C exhibit the highest mean track distance of 38.9 NM.
- Track distance/time is least for VFR approaches onto all runways.
- When IMC conditions exist, RNP approaches provide 6-10% savings in track distance/time over ILS approaches.
- RNP approaches exhibit the same variance in track distance/time as ILS approaches. The variance in RNP approaches occurs on the downwind and turn-to-base, while the variance on the ILS approach occurs by "tromboning" on the base leg and the turn to final.

These results have implications for the benefits of RNP equipage for airports with RNP procedures. The results also indicate an opportunity to leverage RNP capabilities by addressing the excess variability in track distance/time that occurs prior to the turn-to-base.

It should be noted that the use of RNP approaches into MDW 13C during IMC allows the simultaneous use of MDW 13C for arrivals and ORD 22L for departures. If the ILS is required for arrivals into MDW 13C, either the arrivals or departures must be held-up (as these procedures share the same airspace) resulting in flights delays.

This paper is organized as follows: the next section describes the methodology for characterizing the TRACON flows using surveillance track data, the following section describes the results of a case-study analysis of Chicago MDW, finally the Conclusions section describes the implications of these results and future work.

Methodology

This section describes the data used, the algorithm for TRACON flow characterization, and the computation of performance metrics.

Data Used

This analysis uses the National Offload Program (NOP) data. The NOP service operated by the FAA. It collects NAS operational data daily. One of the data items collected is flight tracks for Terminal Radar Approach Control Facilities (TRACONs). Flight tracks contain identifying flight number and flight status (arrival, departure, or over flight) as well as position reports including (latitude, longitude, altitude, and time-of-report) [7].

Flow Characterization

The flows are characterized by specifying a direction, runway, and arrival approach procedure. This is done by studying the runway configuration and published arrival procedure for the airport.

For example, at MDW there are ten runways, as shown in Figure 1. Out of these, runway 13C, 31C and 4R have ILS. Runway 13C has an RNP approach as well. In IMC, the arrivals into MDW are restricted (depending on the wind conditions) to one of the three ILS runways.

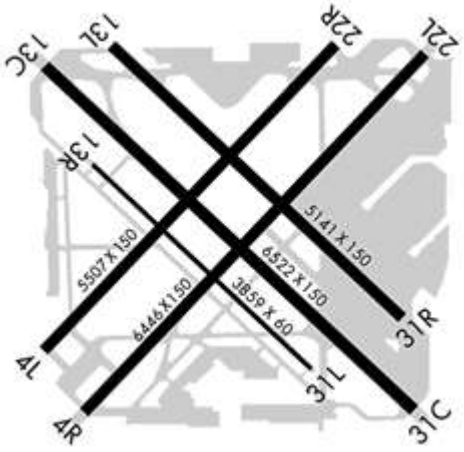

Figure 1. MDW runway Configuration (Source:airnav.com)

For arrivals into MDW, there are three STARs one from the west and two from the east. The two STARs (one RNAV and one conventional) from the east terminate at Chicago Heights VORTAC

(CGT), and the STAR from the west terminates at Joliet VORTAC (JOT). These are shown in Figure 2. These two waypoints feed traffic into the terminal area at MDW.

The number and the location of the final waypoint on the STAR with respect to the runways determine the direction from which the traffic flows in. These combined with the runway and arrival approach procedure characterize various TRACON flows. For instance, at MDW flights flying-in from JOT for an ILS approach onto runway 13C are assigned to "W 13C ILS" flow. Similarly "E 13C RNP" flow will consist of flights flying in from the CGT (east waypoint) onto runway 13C for an RNP approach.

Figure 2. Location of the Final Waypoint on the STAR w.r.t the Airport (MDW).

Flow Assignment

Tracks are assigned to flows based on proximity to certain fixes along a procedure. A similar approach is used in [8].

The methodology for assigning tracks for flows at MDW is as follows.

Step1: Filter out MDW arrivals track from rest of the data.

The NOP data has tracks information for the whole TRACON. Before tracks are assigned to flows, relevant data is filtered. A sample plot of unprocessed NOP data is shown in Figure 3.

The algorithm for assigning tracks as airport arrivals is as follows,

a. Sort each track by time.
b. Get the first and last hit for each track.
c. Determine the top left and bottom right corner of the airport, by adding and subtracting 0.05 degrees from the coordinated of the airport. This will be the boundary of the airport.
d. If the first hit is within the airport boundary then assign flight track as departure else assign flight track as arrival.

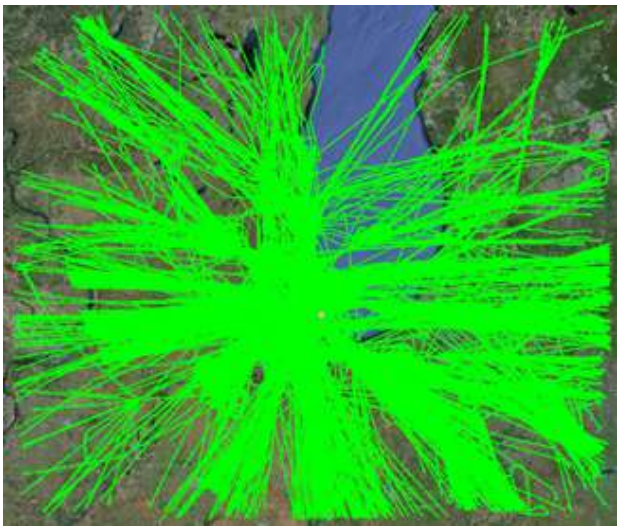

Figure 3. Unprocessed NOP data.

Step2: Assign track to runways.

The algorithm for assigning track to a runway is as follows,

a. Get the first two radar hit for the departure track and last two hits for the arrival track, call it sub-track.
b. For each sub-track calculate the distance from each runway's centerline.
c. For each sub-track calculate the heading, and compare it to each runway's alignment.
d. Assign the sub-track to the runway with the minimum distance and difference in heading.

Step3: Assign track Direction and Approach Procedure Type

After assigning runways, each arrival track is assigned a Direction and Approach Procedure Type.

To assign Direction, rectangular boundaries are defined (by the two co-ordinates upper left and lower right) to capture flow coming in from each direction. Flight tracks are assigned direction based on the rectangular boundary crossed.

The approach procedure characterizes the approach of an aircraft from the final waypoint on the STAR to the runway threshold. In this analysis, flight tracks are assigned to one of four approach procedure types, ILS, RNP, Visual and Straight Approach (SA). The SA approach procedure is assigned to a track when it is not possible characterize a track as ILS, RNP or Visual. This happens when the final waypoint on the STAR is aligned with the runway and the aircraft flies a straight course onto the runway.

The tracks are categorized as ILS, RNP or Visual approach procedure based on the maneuver's proximity to a predetermined fix along the approach. For each procedure a fix and proximity threshold is defined. If a flight track is within the proximity threshold of the fix then it is assigned the respective procedure. Figure 4, shows an example of how direction and arrival approach procedure is assigned to flight landing on runway 13C at MDW.

Figure 4. Example for how Direction and Arrival Procedure is assigned to Tracks

Performance Metrics

The performance metrics computed for each flow are, track distance and track time. The track distance is measured in nautical miles and track time in minute. Track distance/time is the distance/time from the final way point on the STAR to the runway threshold. Since not all the tracks pass directly over the this waypoint, a perpendicular (as shown in Figure 5) is drawn across the flow to mark the start.

Flight tracks with excessive vectoring in the terminal area are not included in the track distance/time statistics. The excessive vectoring is defined by cumulative turn angle (in either direction) of more the 330-450 degrees. The cumulative turn angle threshold is set based on the length of the approach from the final waypoint on the STAR to the runway threshold. A total of 287 tracks were filtered out based on this criterion. Figure 5, shows a sample of tracks that were filtered out.

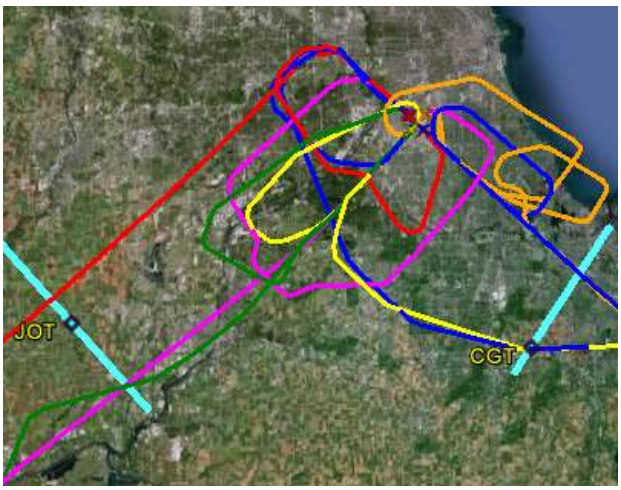

Figure 5. Tracks with excessive vectoring in terminal area.

Results

Thirty five days of NOP track data for Chicago TRACON (C90) are analyzed. The days are selected from year 2010, 2011 and 2012, to cover various meteorological conditions and runway configurations at MDW.

TRACON Arrivals Flows at MDW

Of the 9306 arrival track analyzed, 9265 tracks are successfully assigned to 21 identified flows (see Table 1). Forty-one tracks could not be assigned because of incomplete track information.

In Table 1, the flows are arranged by Direction, followed by Runway and Arrival

Approach Procedure. A total of 5109 tracks are assigned to various flows from the East, the remaining 4197 tracks are assigned to various flows from the West.

Table 1. Flows at MDW

Direction	Runway	Procedure	Count
E	13C	ILS	815
E	13C	RNP	77
E	13C	Visual	577
E	13L	Visual	5
E	22L	Visual	722
E	22R	Visual	65
E	31C	SA	1502
E	4L	Visual	35
E	4R	ILS	1235
E	4R	Visual	58
E	NA	SA	18
W	13C	ILS	587
W	13C	RNP	101
W	13C	Visual	511
W	13L	Visual	6
W	22L	Visual	617
W	22R	Visual	66
W	31C	ILS	1133
W	31C	Visual	38
W	31R	Visual	1
W	4L	Visual	34
W	4R	SA	1080
W	NA	SA	23

Flows onto runway 31C from the East and runway 4R from the West, have not been characterized as ILS, RNP or Visual, as flights fly a straight course onto the runway from the final waypoint on the STAR. Such flows are labeled as Straight Approach (SA).

Major flows from the East are "E 13C ILS", "E 13C RNP", "E 13C Visual", "E 4R Visual", "E 4R ILS", "E 31C SA" and "E 22L Visual". A sample of these flows along with the legend is shown in Figure 6.

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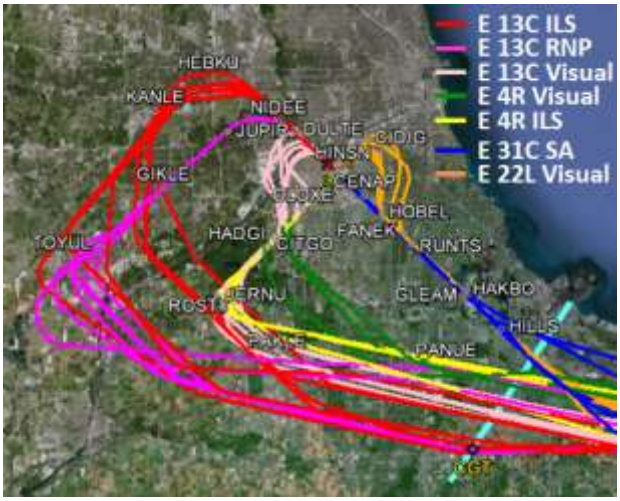

Figure 6. Sample Flows from the East

Major flows from the West are "W 13C ILS", "W 13C RNP", "W 13C Visual", "W 4R SA", "W 31C Visual", "W 31C ILS" and "W 22L Visual". A sample of these is show in Figure 7.

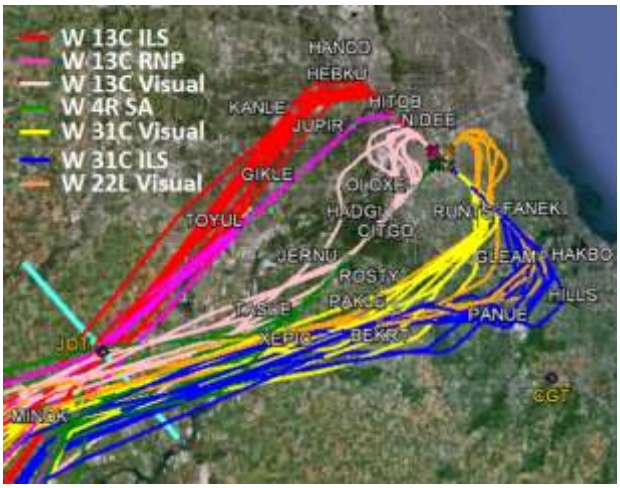

Figure 7. Sample Flows from the West

Track distance and Track Time Statistics

The statistics for track distance and track time are shown in Table 2 and Table 3. The Track distance is measured in nautical mile and Track time is measure in minutes. The statistics are for 8977 flight tracks, i.e., after filtering out 41 tracks that were not assigned to any flow, and 287 flights that had excessive vectoring in the terminal area.

Table 2. Track distance Statistics (Nautical Mile)

Runway						Procedure						Flow					
Rwy	Count	Min	Max	Mean	SD	Pro	Count	Min	Max	Mean	SD	Dir	Count	Min	Max	Mean	SD
13C	2622 (29%)	22.97	102.66	38.90	7.68	ILS	1371 (15.2%)	30.57	102.66	43.19	7.38	E	800 (8.9%)	30.57	102.66	48.09	5.75
												W	571 (6.3%)	33.77	55.43	36.33	1.97
						RNP	173 (1.9%)	32.14	65.04	38.49	7.28	E	76 (0.8%)	37.35	65.04	45.62	5.05
												W	97 (1.1%)	32.14	48.93	32.91	1.80
						Visual	1078 (12%)	22.97	54.17	33.51	3.62	E	571 (6.3%)	22.97	54.17	33.10	4.54
												W	507 (5.6%)	29.78	43.77	33.97	2.06
13L	9 (0.1%)	29.88	35.50	32.64	1.88	Visual	9 (0.1%)	29.88	35.50	32.64	1.88	E	3	29.88	32.70	31.24	1.41
												W	6	30.97	35.50	33.34	1.76
22L	1202 (13%)	16.41	79.38	30.21	13.40	Visual	1202 (13%)	16.41	79.38	30.21	13.40	E	713 (7.9%)	16.41	73.91	19.49	2.34
												W	489 (5.4%)	34.39	79.38	45.84	4.59
22R	115 (1.3%)	17.35	64.04	31.09	14.41	Visual	115 (1.3%)	17.35	64.04	31.09	14.41	E	64 (0.7%)	17.35	21.86	18.69	0.96
												W	51 (0.6%)	35.84	64.04	46.65	5.33
31C	2616 (29%)	15.28	77.31	28.42	15.08	SA	1477 (16.4%)	15.28	72.31	15.64	2.30	E	1477 (16.4%)	15.28	72.31	15.64	2.30
						ILS	1101 (12.2%)	36.65	77.31	45.29	5.24	W	1101 (12.2%)	36.65	77.31	45.29	5.24
						Visual	38 (0.4%)	32.78	40.67	35.96	1.23	W	38 (0.4%)	32.78	40.67	35.96	1.23
31R	1	41.84	41.84	41.84	0.00	Visual	1	41.84	41.84	41.84	0.00	W	1	41.84	41.84	41.84	0.00
4L	68 (0.8%)	23.04	39.34	30.81	3.37	Visual	68 (0.8%)	23.04	39.34	30.81	3.37	E	35 (0.4%)	23.04	39.34	31.49	4.02
												W	33 (0.4%)	28.54	38.90	30.09	2.35
4R	2344 (26%)	19.54	60.47	29.81	3.73	ILS	1224 (13.6%)	23.57	57.66	30.61	4.46	E	1224 (13.6%)	23.57	57.66	30.61	4.46
						Visual	58 (0.6%)	19.54	24.72	21.97	1.35	E	58 (0.6%)	19.54	24.72	21.97	1.35
						SA	1062 (11.8%)	28.00	60.47	29.32	1.80	W	1062 (11.8%)	28.00	60.47	29.32	1.80

Table 3. Track Time Statistics (Minute)

Runway						Procedure						Flow					
Rwy	Count	Min	Max	Mean	SD	Pro	Count	Min	Max	Mean	SD	Dir	Count	Min	Max	Mean	SD
13C	2622 (29%)	6.13	29.69	11.47	2.68	ILS	1371 (15.2%)	8.63	29.69	12.8	2.63	E	800 (8.9%)	8.63	29.69	14.34	2.31
												W	571 (6.3%)	8.70	17.63	10.63	1.06
						RNP	173 (1.9%)	8.18	19.89	11.3	2.58	E	76 (0.8%)	11.05	19.89	13.67	2.05
												W	97 (1.1%)	8.18	15.00	9.49	0.93
						Visual	1078 (12%)	6.13	21.63	9.81	1.61	E	571 (6.3%)	6.13	17.43	9.89	1.83
												W	507 (5.6%)	7.33	21.63	9.73	1.33
13L	9 (0.1%)	8.37	12.86	9.66	1.38	Visual	9 (0.1%)	8.37	12.86	9.66	1.38	E	3	8.99	9.85	9.30	0.48
												W	6	8.37	12.86	9.85	1.68
22L	1202 (13%)	4.54	28.74	8.8	3.08	Visual	1202 (13%)	4.54	28.74	8.8	3.08	E	713 (7.9%)	4.54	28.74	6.55	1.14
												W	489 (5.4%)	8.50	21.69	12.07	1.83
22R	115 (1.3%)	4.91	17.43	9.28	3.43	Visual	115 (1.3%)	4.91	17.43	9.28	3.43	E	64 (0.7%)	4.91	8.75	6.49	0.81
												W	51 (0.6%)	8.50	17.43	12.79	1.88
31C	2616 (29%)	4.22	30.19	8.72	3.84	SA	1477 (16.4%)	4.22	21.51	5.7	0.81	E	1477 (16.4%)	4.22	21.51	5.7	0.81
						ILS	1101 (12.2%)	9.07	30.19	12.8	2.38	W	1101 (12.2%)	9.07	30.19	12.8	2.38
						Visual	38 (0.4%)	8.58	10.89	9.18	0.43	W	38 (0.4%)	8.58	10.89	9.18	0.43
31R	1	11.2	11.2	11.2	0	Visual	1	11.2	11.2	11.2	0	W	1	11.20	11.20	11.20	0.00
4L	68 (0.8%)	6.96	14.41	10	1.66	Visual	68 (0.8%)	6.96	14.41	10	1.66	E	35 (0.4%)	6.96	14.41	10.42	1.82
												W	33 (0.4%)	7.43	13.38	9.56	1.37
4R	2344 (26%)	5.4	21.99	9.33	1.79	ILS	1224 (13.6%)	6.49	21.99	9.76	2.06	E	1224 (13.6%)	6.49	21.99	9.76	2.06
						Visual	58 (0.6%)	5.4	8.163	6.68	0.52	E	58 (0.6%)	5.4	8.163	6.68	0.52
						SA	1062 (11.8%)	6.38	17.76	8.97	1.21	W	1062 (11.8%)	6.38	17.76	8.97	1.21
NA	41 (0.5)	5.16	28.43	11.1	5.86	SA	41 (0.5%)	5.16	28.43	11.1	5.86	E	18 (0.2%)	5.16	8.14	6.15	0.87
												W	23 (0.3%)	10.01	28.43	15.03	5.08

The two tables show track distance/time statistics by runway, by procedure, and by flow. The table show the count/percentage of tracks assigned to each runway, procedure and flow, along with the minimum, maximum, mean and standard deviation. For the 35 days analyzed, runways 13C, 31C, 4R and 22L put together accounted for 98% of the arrivals.

The performance of the runways in terms of mean track distance/time is as follow. The ranking of runways in terms of mean track distance/time is 31C, 4R & 22L and 13C. The track distance to runway 31C is the shortest, with the mean track distance of 28.42 NM. Distance to 4R, 22L and 13C are longer by 1.4, 1.8 and 10.5 NM respectively.

The track time to runway 31C is the shortest, with mean track time of 8.72 minute. The track time to runways 22L, 4R, and 13C are longer by 0.1, 0.6 and 2.7 minute respectively. The ranking in terms of track distance/time standard deviation from least to worst is 4R, 13C, 22L and 31C.

A closer look at individual procedures show operational efficiency is maximized when the arrival flow crosses the final waypoint on the STAR and flies a straight course onto the runway. Runway 31C has a straight approach from the East and runway 4R has a straight approach from the West. The track distance/time for these straight procedures is shorter by 20-30% than other procedures (ILS or visual) from the respective direction.

For major flows from the East the track distance/time ranking is shown in Table 4 and Table 5. The SA onto 31C is the shortest with mean track distance/time of 15.64 NM /5.7 minute. The ILS onto 13C is the longest with the mean track distance/time of 48.1 NM/ 14.34 minute, which amounts to 30 NM/ 9 minutes in excess track distance/time.

Table 4. East Flow Track Distance (NM)

Dir/Rwy/Pro			Count	Min	Max	Mean	SD
E	31C	SA	1477	15.28	72.31	15.64	2.30
E	22L	Visual	713	16.41	73.91	19.49	2.34
E	4R	Visual	58	19.54	24.72	21.97	1.35
E	4R	ILS	1224	23.57	57.66	30.61	4.46
E	13C	Visual	571	22.97	54.17	33.10	4.54
E	13C	RNP	76	37.35	65.04	45.62	***5.05***
E	13C	ILS	800	30.57	102.66	48.09	***5.75***

Table 5. East Flow Post Track Time (min)

Dir/Rwy/Pro			Count	Min	Max	Mean	SD
E	31C	SA	1477	4.22	21.51	5.70	0.82
E	22L	Visual	713	4.54	28.74	6.55	1.14
E	4R	Visual	58	5.40	8.16	6.68	0.52
E	4R	ILS	1224	6.49	21.99	9.76	2.06
E	13C	Visual	571	6.13	17.43	9.89	1.83
E	13C	RNP	76	11.05	19.89	13.67	***2.05***
E	13C	ILS	800	8.63	29.69	14.34	***2.31***

For major flows from the West the track distance/time ranking is shown in Table 6 and Table 7. The SA onto 4R is the shortest with mean track distance/time of 29.32 NM/ 9 minute. The ILS onto 31C and Visual onto 22L have the longest track distance/time of 45 NM/13 minute, which amounts to 15 NM/ 4 minute in excess track distance/time.

Table 6. West Flow Track Distance (NM)

Dir/Rwy/Pro			Count	Min	Max	Mean	SD
W	4R	SA	1062	28.00	60.47	29.32	1.80
W	13C	RNP	97	32.14	48.93	32.91	***1.80***
W	13C	Visual	507	29.78	43.77	33.97	2.06
W	31C	Visual	38	32.78	40.67	35.96	1.23
W	13C	ILS	571	33.77	55.43	36.33	***1.97***
W	31C	ILS	1101	36.65	77.31	45.29	5.24
W	22L	Visual	489	34.39	79.38	45.84	4.59

Table 7. West Flow Track Time (min)

Dir/Rwy/Pro			Count	Min	Max	Mean	SD
W	4R	SA	1062	6.38	17.76	8.97	1.21
W	31C	Visual	38	8.58	10.89	9.18	0.43
W	13C	RNP	97	8.18	15.00	9.49	***0.93***
W	13C	Visual	507	7.33	21.63	9.73	1.33
W	13C	ILS	571	8.70	17.63	10.63	***1.06***
W	22L	Visual	489	8.50	21.69	12.07	1.83
W	31C	ILS	1101	9.07	30.19	12.75	2.38

The visual approaches have shorter track distance/time compared to corresponding ILS and RNP approaches (except for track distance of RNP onto 13C from West).

The RNP approach onto runway 13C is shorter than the corresponding ILS approach by 6% for flows from the East, and by 10% for flows from the West.

For flows from the East, the variance of the RNP flow is almost as high as the ILS approach, despite the accuracy of the RNP procedure. The variance in RNP approaches occurs on the downwind and turn-to-base, while the variance on the ILS approach occurs by "tromboning" on the downwind, base leg and the turn to final.. This is better understood from Figure 8 and Figure 9.

Figure 8 – All track for "E 13C ILS" flow

Figure 9 – All tracks for "E 13C RNP" flow

The flows onto runway 13C from the West are efficient and have lower variance compared to the flows from the East. This is shown in Figure 10 and Figure 11. The x-axis is the track distance and the y-axis is the normalized frequency. The vertical line marks the mean of the distribution. In Figure 10, the track distance distribution about the mean is wide spread and has a fat tail. This is caused by the vectoring in the terminal (shown in Figure 8 and Figure 9).

In Figure 11, the Track Mile distribution about the mean is tight, especially for the RNP flow. This is better understood from Figure 12, which shows all the 97 track for RNP flow onto runway 13C.

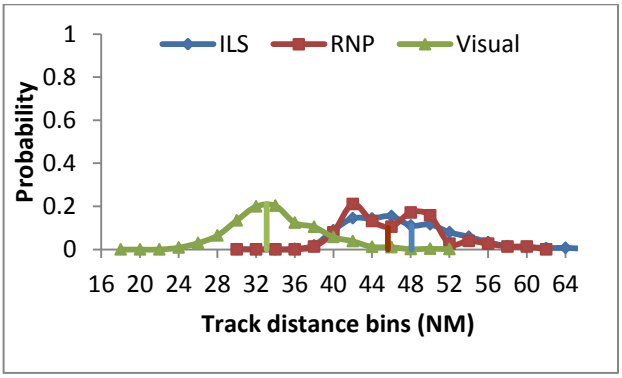

Figure 10 – PDF of Track Mile for 13C flows from the East

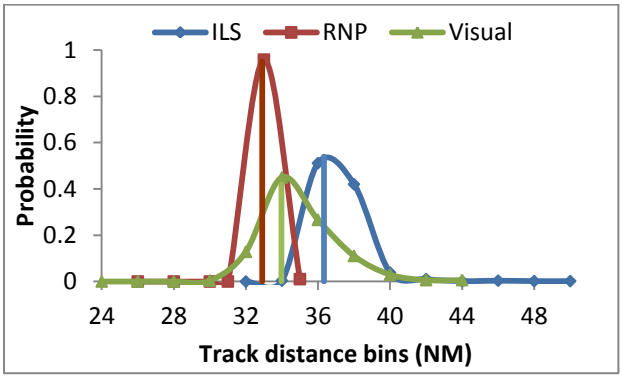

Figure 11 – PDF of Track Mile for 13C flows from the West.

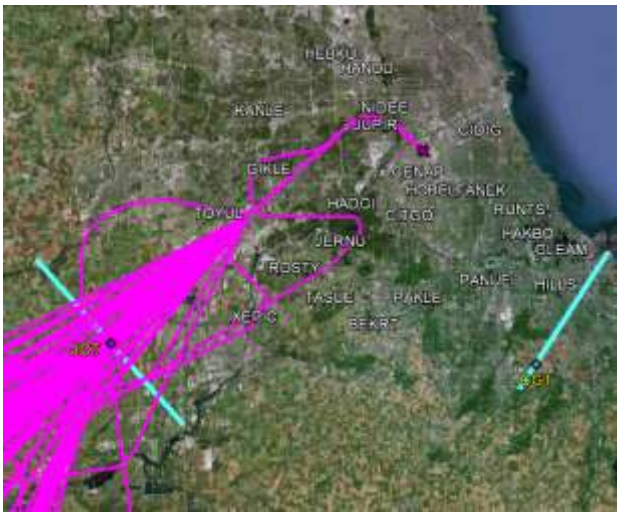

Figure 12 – RNP flows onto runway 13C from the East.

Conclusions and Future Work

This paper presents a methodology for (1) characterizing and assigning TRACON arrival flows analysis using National Offload Program (NOP) track data, and (2) computing TRACON arrival flow performance metrics.

A case-study analyzed 35 days of NOP track data for Chicago TRACON (C90). For MDW 21 flows are identified and, 95% of the 9306 arrival tracks analyzed are successfully assigned to these flows. For each flow track distance/time metrics are computed and their statistics tabulated.

The results show, runway 31C has the lowest mean Track Mile of 28.42 NM and runway 13C has the highest mean Track Mile of 38.9 NM. There are track distance/time savings in VFR approaches. When IMC conditions exist, RNP approaches

provide 6-10% savings in track distance/time over ILS approaches. Another interesting finding is that despite the accuracy of the RNP technology, the "vectors" between the final waypoint on the STAR and the start of the RNP approach introduce as much variation in track distance/time as the ILS approaches.

While RNP approach procedures are in place, majority of the airlines are yet to invest in the avionics required to fly them, as the benefits of RNP approach for improving terminal flow efficiency is not clearly established. However, Southwest Airlines has taken the lead to equip with RNP with the goal to improve flight efficiency in the terminal area. In 2007, Southwest Airlines contracted with GE Aviation – formerly known as Naverus – to develope tailored RNP approach procedures for all its hubs [3]. The cost of this transformation is estimated at $175 million [3]. Based on the demonstration flights the new procedures are expected to reduce fuel burn and emissions by six percent per flight leg on an average [10]. This amounts to 90.6 million less gallons of fuel and 1.9 billion pounds less CO_2 emission annually [10]. The results in this paper confirm a 6-10% savings in track distance/time for RNP approach over the ILS approach.

Future Work

The next steps are:

1. To build a fuel burn model using track data while taking into consideration the flight trajectory (i.e. level and descending) in the terminal area.
2. To estimate the impact of Flight Vectoring (Go Around and Holding) on fuel burn.
3. To build a model to estimate the benefits of RNP approach to an airline.

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References

[1] GE Aviation, "Required Navigation Performance | GE Aviation Systems | GE Aviation." [Online]. Available: http://www.geaviation.com/systems/products-and-services/performance-based-navigation/learning-rnp.html. [Accessed: 07-Feb-2013].

[2] Federal Aviation Administration, "Facility Orientation Guide, Juneau Air Traffic Control Tower." 2009.

[3] D. Hughes, "RNP with a Difference," *Aviation Week & Space Technology*, vol. 169, no. 23, 15-Dec-2008.

[4] GE Aviation, "GE Aviation's PBN Services Professional Resume, Version1." Feb-2011.

[5] Airservices Australia, "Brisbane Green," 2008.

[6] Honeywell, "Required Navigation Performance - Authorization Required," 2012.

[7] J. DeArmon, A. Mahashabde, W. Baden, and P. Kuzminski, "Applications of a Terminal Area Flight Path Library," 2011.

[8] S. Dorfman, J. Daily, T. Gonzalez, and G. S. Kondo, "NAS-wide vertical profile analysis: Level segments in arrival and departure flows," in *Integrated Communications, Navigation and Surveillance Conference (ICNS), 2012*, 2012, pp. D6–1.

[9] M. Enriquez,"Identifying Temporally Persistent Flows in the Terminal Airspace via Spectral Clustering." The MITRE Corporation, 2013.

[10] J. Martin, "Testimony of Captain Jeff Martin." Southwest Airlines Co., 29-Jul-2009.