BEACON CODE USAGE STATISTICS

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Abstract

Beacon codes are a set of limited National Airspace System (NAS) resource. Currently, the beacon code allocation process is based upon the concept of discreet beacon code assignment to each ARTCC (Air Route Traffic Control Center). This allocation process is done according to the rules published in NBCAP (National Beacon Code Assignment Plan).

In this paper, the distribution of codes to the ARTCCs is presented. Also, Host data is analyzed to demonstrate the utilization of codes through the day with varying level of traffic. This analysis is supposed to help identify beacon code bottlenecks in the NAS. There are two kind of bottlenecks studied:

(i) ARTCCs which run out of beacon codes most frequently due to high demand/traffic.

(ii) ARTCCs where maximum instances of enroute beacon code reassignment occurs due to conflict with another aircraft using the same beacon code. These kinds of beacon code reassignments are undesirable as it increases pilot/controller workload during hand-off.

5 months of HOST data from 1st August to 31st December 2007 is analyzed. Individual beacon code utilization statistic for each of the 20 ARTCCs in the CONUS is reported for the 5 month period. On select days for which radar track data is available, the correlation of the code utilization with the traffic level in the corresponding ARTCC is also presented. This analysis provides the foundation of exploiting the inherent structure of NAS traffic to enable a more efficient beacon code assignment, i.e. with fewer beacon code reassignments and more efficient distribution of the Beacon Codes among the ARTCCs.

Introduction

A flight is assigned its first beacon code by the Host Computer System (HCS) of the Center it is departing from. Ideally, flights will fly from their origin to their destination using the same code for the duration of their flights. However, because there are more flights in need of codes at any point in time than there are codes available, and traffic levels are growing, each code has to be assigned to more than one flight (while still ensuring unique code assignment within a center). Due to this shortage of available codes, when aircraft cross center boundaries along its route, there is a possibility that the code it is using is already in use by some other flight in the facility it is approaching. The HCS in this case must reassign the flight entering the center a new beacon code. This process is known as code reassignment.

Code Reassignment requires voice communication to request the new transponder setting. As a result, these actions lead to increased workload of air traffic controllers and pilots (in addition to other tasks to be completed as part of a standard hand-off procedure). For this reason, code reassignments are undesirable and should be minimized.

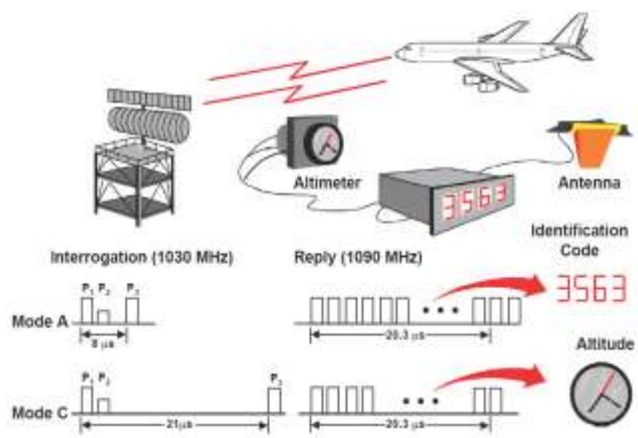


Figure 1: ATCRBS system working. Ref: Surveillance Tools for Distributed Air/Ground Traffic Management (Steven R. Bussolari, MIT, Lincoln Labs)

The primary goal of NBCAP (National Beacon Code Allocation Plan) is to efficiently manage the beacon code set as a limited National Airspace System (NAS) resource. The NBCAP is based upon the concept of discrete beacon code assignments to each ARTCC so that codes can be adapted and assigned by a computer to a flight plan according to a specific procedure. Ideally, each ARTCC should be allocated enough exclusive code blocks so that each aircraft could be given a computer assigned unique discrete code which would not be duplicated anywhere in the NAS. The intent would thereby, allow all aircraft to proceed from departure to destination using the same discrete code. Unfortunately, duplicate computer code assignments are unavoidable because of the limited number of code subsets available, the number of ARTCC's, and the volume of traffic. To minimize the impact of duplicate computer assignments, careful analysis of code utilization statistics is required to ensure appropriate facility assignments. Therefore, ARTCC facility assignments are managed from the national level.

The objective of this research is to analyze historical Host data to identify ARTCCs with Beacon Code shortage and reassignment problems.

This paper is organized as follows: In the following section, the functioning of ATCRBS is described. Next, relevant previous work is discussed followed with the data sources and analysis. Finally, the implications of these results are discussed in the conclusion section.

How ATCRBS Works

ATCRBS is an acronym for Air Traffic Control Radar Beacon System. It is a system used in ATC to enhance surveillance radar monitoring and separation of aircraft [1][2][3].

ATCRBS consists of transponders (in aircraft) and Secondary Surveillance Radar (SSR) which is co-located with the Primary Surveillance Radar (PSR) on the ground. The SSR located at the ATC site, transmits interrogations and listens for replies. Transponders located on the aircraft receive interrogations, decode it and respond with requested information (mode 1,2,3/A,C).

As shown in Figure 1, ATCRBS interrogator at the ATC facility on ground periodically interrogates aircraft on a frequency of 1030 MHz. Aircraft receiving this interrogation reply with the requested information (altitude and/or identification) after a 3 micro second delay. The interrogator then decodes the reply and identifies the aircraft.

When an aircraft receives a mode 3/A interrogation, the reply expected is a Beacon/Squawk code. Current mode 3/A transponders installed on aircraft are designed to transmit four octal digits, resulting in a total of 8^4 = 4096 possible beacon codes. Many of the codes are reserved for special uses such as military operations, which further reduces the number of codes available for use by civilian aviation. The National Beacon Code Allocation Plan (NBCAP) established by DoT/FAA order 7110.66D [4] permanently allocates the remaining beacon codes to the ARTCC's. The controller uses the beacon code as the unique identifier for flights within a center boundary. In order for the controller to uniquely identify and address each aircraft it is necessary to ensure that all aircraft flying within the area of responsibility of that controller are uniquely identifiable, i.e. each aircraft within that center has a unique beacon code.

Previous Work

Geographic Beacon Code Allocation study by Lucic et al [5] includes statistic on Beacon Codes reassignments. There is no previous work on the statistic of code utilization.

Srl No.	Date	Total # of Reassignments
1	11/22/2000	8381
2	12/20/2000	7649
3	1/24/2001	7014
4	4/19/2001	7943
5	5/17/2001	7950
6	11/26/2003	9333
7	12/18/2003	8972
8	1/23/2004	7512
9	2/13/2004	9865
10	3/12/2004	9560
11	4/29/2004	9726
12	5/27/2004	9612
13	7/1/2004	9472
14	8/6/2004	9204
15	9/10/2004	9041
16	10/20/2004	8888
17	11/19/2004	9628

Figure 2: Number of Beacon Code Reassignments in NAS

Figure 2 shows the number of beacon code reassignment instances in the entire NAS for 17 days.

These numbers are very similar to the ones obtained by the analysis of 153 days of HOST data even though the data used in this study is for 2007. This shows that there has been close to no change in the frequency of beacon code reassignment in the NAS in the last decade.

Data Sources

The data used in this study was obtained from HOST data which is recorded for every ARTCC in the NAS. The data extracted spans over a period of 183 days from 1st August, 2007 to 31st December 2007. There are two types of data:

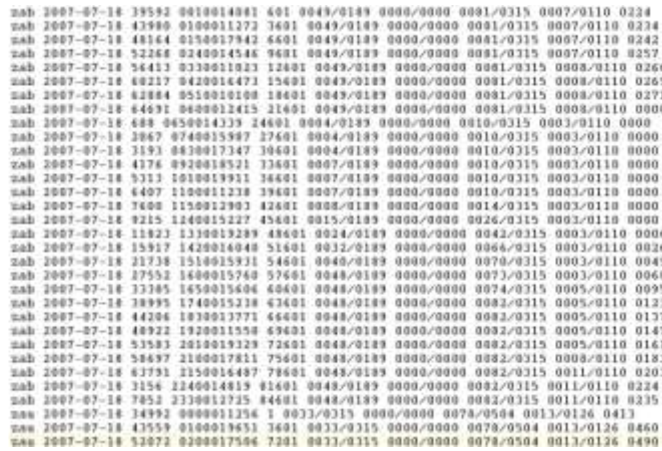
A. *Utilization Beacon(UB) Message*

Each ARTCC has one entry (row) for every hour of the day. A snapshot of the data is shown in **Figure 3**. The following fields are used:

i. Center ID: 3 letter ARTCC code. Eg: ZAB – Albuquerque Center.
ii. Date
iii. Block
iv. Time(hhmmssxxxx): The first 6 letters are time in the hhmmss format.
v. Time converted to seconds starting at midnight on 1st August 2007.
vi. Peak Number of Internal Primary and Secondary Codes and the total number of adapted codes.
vii. Peak Number of Internal Tertiary Codes and the total number of adapted codes.
viii. Peak Number of External Primary and Secondary Codes and the total number of adapted codes.
ix. Peak Number of External Tertiary Codes and the total number of adapted codes.
x. Number of Code Reassignments since midnight.

B. *Beacon Reassignment(BA) Message*

A snapshot of the data is shown in **Figure 4**. Each row corresponds to an instance of Beacon Code Reassignment.



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zab 2007-07-18 39592 0010014081 601 0049/0189 0000/0000 0001/0315 0007/0110 0224
zab 2007-07-18 43980 0100011272 3601 0049/0189 0000/0000 0001/0315 0007/0110 0234
zab 2007-07-18 48164 0150017942 6601 0049/0189 0000/0000 0081/0315 0007/0110 0242
zab 2007-07-18 52268 0240014546 9601 0049/0189 0000/0000 0081/0315 0007/0110 0257
zab 2007-07-18 56413 0330011023 12601 0049/0189 0000/0000 0081/0315 0008/0110 0266
zab 2007-07-18 60217 0420016473 15601 0049/0189 0000/0000 0081/0315 0008/0110 0269
zab 2007-07-18 62884 0510010108 18601 0049/0189 0000/0000 0081/0315 0008/0110 0271
zab 2007-07-18 64691 0600012415 21601 0049/0189 0000/0000 0081/0315 0008/0110 0000
zab 2007-07-18 688 0650014339 24601 0004/0189 0000/0000 0010/0315 0003/0110 0000
zab 2007-07-18 2067 0740015987 27601 0004/0189 0000/0000 0010/0315 0003/0110 0000
zab 2007-07-18 3193 0830017347 30601 0004/0189 0000/0000 0010/0315 0003/0110 0000
zab 2007-07-18 4176 0920018521 33601 0007/0189 0000/0000 0010/0315 0003/0110 0000
zab 2007-07-18 5313 1010019911 36601 0007/0189 0000/0000 0010/0315 0003/0110 0000
zab 2007-07-18 6407 1100011238 39601 0007/0189 0000/0000 0010/0315 0003/0110 0000
zab 2007-07-18 7600 1150012903 42601 0008/0189 0000/0000 0014/0315 0003/0110 0000
zab 2007-07-18 9215 1240015227 45601 0015/0189 0000/0000 0026/0315 0003/0110 0000
zab 2007-07-18 11823 1330019289 48601 0024/0189 0000/0000 0042/0315 0003/0110 0006
zab 2007-07-18 15917 1420016048 51601 0032/0189 0000/0000 0066/0315 0003/0110 0026
zab 2007-07-18 21738 1510015931 54601 0040/0189 0000/0000 0070/0315 0003/0110 0049
zab 2007-07-18 27552 1600015760 57601 0048/0189 0000/0000 0073/0315 0003/0110 0068
zab 2007-07-18 33385 1650015606 60601 0048/0189 0000/0000 0074/0315 0005/0110 0095
zab 2007-07-18 38995 1740015238 63601 0048/0189 0000/0000 0082/0315 0005/0110 0123
zab 2007-07-18 44206 1830013771 66601 0048/0189 0000/0000 0082/0315 0005/0110 0137
zab 2007-07-18 48922 1920011558 69601 0048/0189 0000/0000 0082/0315 0005/0110 0147
zab 2007-07-18 53583 2010019329 72601 0048/0189 0000/0000 0082/0315 0005/0110 0161
zab 2007-07-18 58697 2100017811 75601 0048/0189 0000/0000 0082/0315 0008/0110 0183
zab 2007-07-18 63791 2150016487 78601 0048/0189 0000/0000 0082/0315 0011/0110 0203
zab 2007-07-18 3156 2240014819 81601 0048/0189 0000/0000 0082/0315 0011/0110 0224
zab 2007-07-18 7852 2330012735 84601 0048/0189 0000/0000 0082/0315 0011/0110 0235
zau 2007-07-18 34992 0000011256 1 0033/0315 0000/0000 0078/0504 0013/0126 0413
zau 2007-07-18 43559 0100019651 3601 0033/0315 0000/0000 0078/0504 0013/0126 0460
zau 2007-07-18 52072 0200017506 7201 0033/0315 0000/0000 0078/0504 0013/0126 0490
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Figure 3: Snapshot of Utilization Beacon(UB) Host Data

The following fields are used:

i. Center ID: 3 letter ARTCC code. Eg: ZAB – Albuquerque Center.
ii. Date
iii. Block
iv. Time (hhmmssxxxx): The first 6 letters are time in the hhmmss format. The remaining 4 letters are irrelevant for the purpose of this analysis.
v. Call sign of Flight 1: The flight identifier of flight which is already using the corresponding Beacon Code.
vi. Call sign of Flight 2: The flight identifier of flight whose beacon code needs to be reassigned due to potential conflict with beacon code of flight 1.
vii. Computer Identifier of Flight 1.
viii. Computer Identifier of Flight 2.
ix. Beacon Code of Flight 1(In use).
x. Beacon Code of Flight 2(Reassigned).
xi. Origin of Flight 1.
xii. Origin of Flight 2.
xiii. Destination of Flight 1.
xiv. Destination of Flight 2.

zab	2007-07-18	39242	0006163454	376	SWA2301	SWA2721	082	695	7334	0727	SAN	SAN	BNA	PHX
zab	2007-07-18	39902	0014174729	057	AWE369	N453AM	453	012	1546	0753	PHX	XNA	SMF	AMA
zab	2007-07-18	40596	0021055711	1265	AWE92	USA1561	326	197	4172	0721	PHX	PIT	PDX	PHX
zab	2007-07-18	41488	0031407169	1900	N390JK	UPS305	275	422	1741	2636	GRD	MMCU	AMA	KELP
zab	2007-07-18	41954	0037107941	2230	COA427	N424QS	901	929	7222	2647	SAN	SNA	EWR	GGG
zab	2007-07-18	42479	0043228820	2602	AAL2452	AAL1324	170	154	7226	2646	LAX	SNA	DFW	DFW
zab	2007-07-18	42576	0044218991	2671	AWE399	AAL2450	572	175	7371	1603	IAH	LAX	PHX	DFW
zab	2007-07-18	43084	0050069821	3006	COA541	N425AP	041	606	7370	2657	LAX	GTU	IAH	TDW
zab	2007-07-18	43543	0055050577	3305	AWE663	JBU411	279	103	1327	1620	MKE	BOG	PHX	SAN
zab	2007-07-18	43572	0055230620	3323	BTA2609	DOOM95	301	663	0710	1625	KIAH	BAD	MMCU	BAD
zab	2007-07-18	43781	0057400954	3460	COA1609	SWA330	021	657	7313	2654	IAH	LAX	SAN	TUS
zab	2007-07-18	44001	0100161313	3616	UAL1497	N6111V	168	714	7213	2616	KORD	YUM	KPHX	FFZ
zab	2007-07-18	44590	0106522309	4012	SWA1220	N715LM	251	030	1055	2605	LAX	HII	HOU	ELP
zab	2007-07-18	44857	0110062734	4206	DAL1127	FFT059	045	556	1467	0764	TPA	DEN	SLC	PHX
zab	2007-07-18	46845	0134055791	5645	USA1511	AWE600	672	190	3324	0737	CLT	EWR	PHX	PHX
zab	2007-07-18	47359	0140306628	6030	NWA101	AAL1716	377	433	1352	1634	MEM	LAX	LAX	STL
zab	2007-07-18	47853	0146177441	6377	SWA693	NWA174	669	954	1623	1641	PHX	MEM	AUS	LAS
zab	2007-07-18	48234	0150538071	6653	SWA693	NWA174	669	515	1623	0724	PHX	MEM	AUS	LAS
zab	2007-07-18	48990	0200069300	7206	AAL1701	SWA765	855	728	3612	2645	DFW	BWI	PHX	PHX
zab	2007-07-18	49170	0202059590	7325	COA435	USA715	425	506	2711	2654	IAH	PHL	SAN	LAX
zab	2007-07-18	49172	0202069602	7326	AWE33	AWE44	269	094	2061	2657	LAX	CLT	PHX	PHX
zab	2007-07-18	49262	0203149739	7394	CYO277	COA150	458	606	7251	0765	SNA	IAH	ELP	ONT
zab	2007-07-18	49419	0205069987	7506	SWA399	N136DR	306	603	2605	2613	PHX	AMA	SMF	AMA
zab	2007-07-18	49709	0200300518	7710	TRS57	N904JR	713	239	6373	1657	ATL	SFO	SFO	HOU
zab	2007-07-18	49851	0210170757	7817	WOA0971	MXA999	562	709	7273	1662	KIAH	KLAS	PHNL	MMMX
zab	2007-07-18	50290	0215351454	0135	N560WW	UAL703	131	337	0535	2671	LBB	IAD	PPA	ABQ
zab	2007-07-18	50715	0221062119	0466	N299SC	AWE412	173	543	3727	0751	APA	SFO	SGR	PHX
zab	2007-07-18	50859	0223052338	0505	SWA3072	DAL557	031	521	6703	1676	LAS	CVG	BNA	SAN
zab	2007-07-18	51093	0225552736	0755	DAL1107	NKS706	245	407	4152	4111	ATL	DTW	LAX	LAX
zab	2007-07-18	51209	0227162911	0036	COA361	FDX1351	636	921	7331	0720	IAH	LGB	SFO	MEM

Figure 4: Snapshot of Beacon Reassignment (BA) Host Data

C. *DoT/FAA Order JO 7110D*

The current allocation of Beacon Codes to each ARTCC is published in FAA Order JO 7110D.

D. *ETMS 4-D Trajectory Data*

ETMS (Enhanced Traffic Management System) data for 5 days of 2007 spanning different seasons was used in this analysis to validate the BC reassignment and utilization statistic from the Host data using a NBCAS(National Beacon Code Assignment Simulator – to be discussed in Section III).

FID	Time	ACID	AcType	Ori	Dest	Lat	Lon	Alt
547236635	28893	AAL256	B752	ORD	EINN	2906	3674	370
547236635	28953	AAL256	B752	ORD	EINN	2909	3662	370
547236635	29013	AAL256	B752	ORD	EINN	2912	3648	370
547236635	29073	AAL256	B752	ORD	EINN	2915	3634	370
547236635	29133	AAL256	B752	ORD	EINN	2918	3621	370
547236635	29193	AAL256	B752	ORD	EINN	2921	3609	370
547238499	30582	AAL900	B772	SAEZ	MIA	1427	4703	400
547238499	30642	AAL900	B772	SAEZ	MIA	1435	4706	400
547238499	31422	AAL900	B772	SAEZ	MIA	1515	4776	179
547238499	31482	AAL900	B772	SAEZ	MIA	1520	4781	158
547238499	31542	AAL900	B772	SAEZ	MIA	1525	4786	138
547238499	31602	AAL900	B772	SAEZ	MIA	1529	4791	138
547238499	31662	AAL900	B772	SAEZ	MIA	1533	4797	106
547238499	31722	AAL900	B772	SAEZ	MIA	1536	4802	101
547238499	31782	AAL900	B772	SAEZ	MIA	1538	4807	90
547238499	31842	AAL900	B772	SAEZ	MIA	1541	4811	81
547238499	31902	AAL900	B772	SAEZ	MIA	1542	4815	75
547238823	29100	COA30	B762	SBGR	EWR	1550	3936	360
547238823	29700	COA30	B762	SBGR	EWR	1626	3971	360
547238823	29820	COA30	B762	SBGR	EWR	1634	3974	360
547238823	30360	COA30	B762	SBGR	EWR	1699	4005	360

Figure 5: Snapshot of enroute ETMS data

The 5 days of 2007 for which ETMS data was used are:

3rd January (Winter), 11th April (Spring), 26th July (Summer), 21st November(Thanksgiving) and 19th December(Winter). A snapshot of the data is shown in Figure 5.

The data has 48966 tracks (each track is one flight leg). It also includes international and cargo flights. Military flights are not included in this data as they have their own reserved set of beacon codes. The following fields were used:

i. FID – this field is the unique identifier for a flight leg.

ii. Time – Time in seconds from 12 AM GMT on the corresponding date.

iii. ACID – Airline assigned aircraft ID. Eg: AAL900

iv. AcType – Aircraft Type. Eg: B752

v. Ori – 3 or 4 letter ICAO code for origin airport. Eg: ORD

vi. Dest – 3 or 4 letter ICAO code for destination airport.

vii. Lat – Latitude of the aircraft at the corresponding time in minutes. Eg: 2906 represents 2906/60 ~ 48.43 degree North

viii. Lon – Longitude of the aircraft at the corresponding time in minutes. Eg:3674 represents 3674/60 ~ 61.23 degrees West.

ix. Alt – Represents the flight altitude level.

Analysis and Results

A. *Beacon Code Allotment for each ARTCC*

Figure 6 shows the distribution of Beacon Codes to all the 20 ARTCCs in the CONUS according to DoT/FAA Order JO 7110D. The blue and magenta bars are for external and internal codes respectively. Both charts in Figure 6 show the same information (number of codes); the top chart is sorted by number of external codes and the bottom one is sorted by internal codes. ZMA (Miami Center) is the center with the highest number of external beacon codes allocated to it (1118 codes). ZHU (Houston Center) has the highest number of internal beacon codes (567 codes).

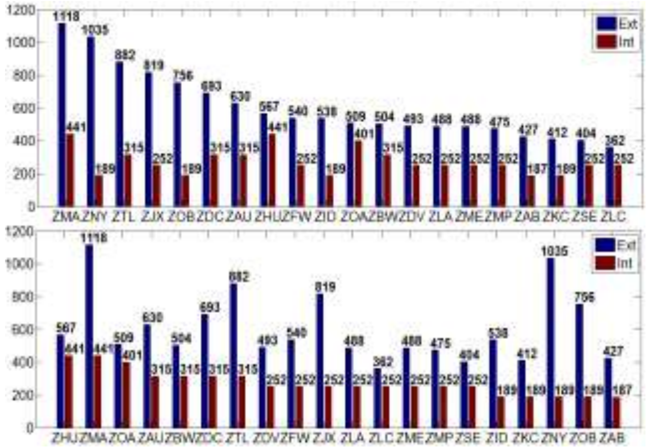

Figure 6: Distribution of Beacon Codes by ARTCC

B. Beacon Code Utilization from HOST Data

Host UB(Utilization Beacon) data has information on the number of codes in each category(external, internal, primary, secondary, tertiary) that are being used for each hour of the day.

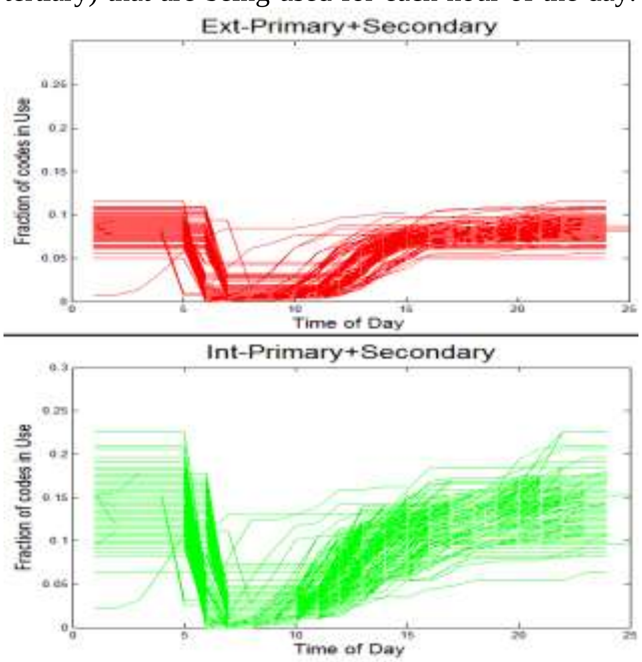

Figure 7: ZTL Code Utilization for External (Top figure) and Internal (Bottom figure) Primary and Secondary Codes for 153 days of 2007

Figure 7 shows the fraction of codes being utilized by the ZTL ARTCC for all the 153 days as a function of time. The top and bottom figure shows the utilization in External and Internal categories respectively. The maximum code utilization in the external and internal category for ZTL for the 153 days of Host Data analyzed is 0.116 and 0.225 respectively.

Figure 8 shows a histogram with maximum code(External) utilization fraction during each day on x-axis and number of days (out of population of 153) on y-axis. The mean and median of this histogram is 0.0089 and 0.088 respectively.

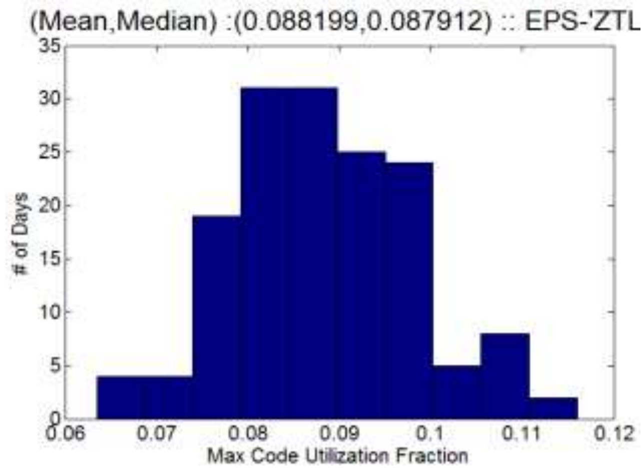

Figure 8: Histogram of Max Code Utilization Fraction for ZTL (External Codes)

Figure 9 shows a similar histogram as Figure 8 but for the Internal Code category. The mean and median in this case is 0.153 and 0.156 respectively.

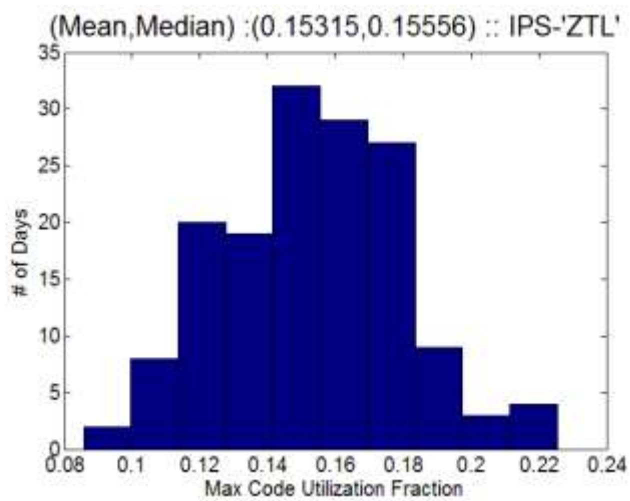

Figure 9: Histogram of Max Code Utilization for ZTL (Internal Codes)

The plots and histograms shown in Figure 7, Figure 8 and Figure 9 were done for all the 20 ARTCCs. A summary of the mean and median of maximum code utilization fraction per day for each of the 20 ARTCCs is shown in Table 1 and Figure 10 shows that ZHU had the highest code utilization in the internal category of 0.529. ZLC had the highest code utilization in the External category of 0.389.

C. Beacon Code Reassignment from HOST Data

Every row of the Host BA (Beacon Code Reassignment) data corresponds to an instance of Beacon Code Reassignment in the NAS. Figure 11 shows the number of Beacon Code Reassignments in NAS for each of the 153 days in HOST data analyzed. The mean number of reassignments is 7642 and the median is 7768. It can be observed in Figure 12 that the number of BC reassignments on a given day is mostly in the 8000-9000 range. It was also derived from the ETMS data processing (to be discussed in following section) that there are on an average approximately 73000 hand-offs (ARTCC boundary crossing instances) per day in NAS. As a result, the probability of a pilot having to change his code when crossing an ARTCC boundary is about 9-10% ([8000 to 9000]/[70000-75000]).

Table 2 for External and Internal Beacon codes respectively. In both the tables the last column shows whether or not the Kolmogorov-Smirnov test rejects the null hypothesis that the Max Utilization Fraction is normally distributed with p-value of 0.05.

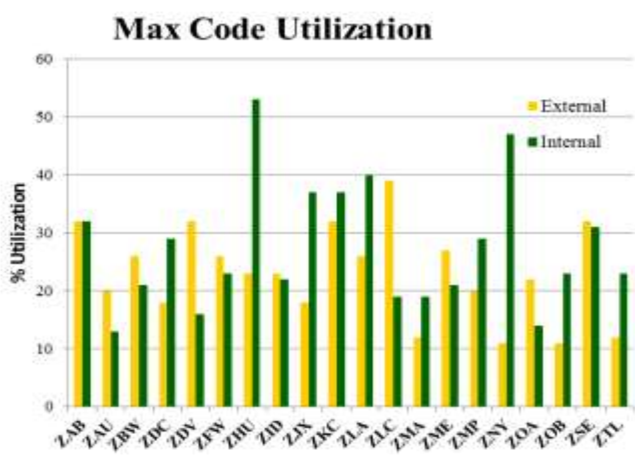

Figure 10: Maximum Code Utilization for each of the 20 ARTCCs (for 153 days of Host Data)

Table 1: Max Utilization Fraction for External Primary and Secondary Codes for 153 days of 2007 (Host Data)

ARTCC	Max of Max	Median	Mean	Normally Distributed (Kolmogorov-Smirnov Test with p = 0.05)
ZAB	0.321	0.289	0.289	Yes
ZAU	0.198	0.154	0.157	Yes
ZBW	0.265	0.195	0.19	Yes
ZDC	0.176	0.162	0.164	No
ZDV	0.317	0.263	0.26	Yes
ZFW	0.265	0.221	0.222	Yes
ZHU	0.227	0.197	0.197	Yes
ZID	0.227	0.198	0.2	Yes
ZJX	0.176	0.133	0.131	Yes
ZKC	0.317	0.282	0.283	Yes
ZLA	0.265	0.264	0.265	No
ZLC	0.389	0.295	0.286	No
ZMA	0.122	0.09	0.087	No
ZME	0.267	0.233	0.241	No
ZMP	0.204	0.167	0.164	Yes
ZNY	0.115	0.106	0.107	No
ZOA	0.222	0.184	0.183	Yes
ZOB	0.11	0.086	0.087	No
ZSE	0.317	0.253	0.25	Yes
ZTL	0.116	0.088	0.088	Yes

Figure 10 shows that ZHU had the highest code utilization in the internal category of 0.529. ZLC had the highest code utilization in the External category of 0.389.

D. Beacon Code Reassignment from HOST Data

Every row of the Host BA (Beacon Code Reassignment) data corresponds to an instance of Beacon Code Reassignment in the NAS. Figure 11 shows the number of Beacon Code Reassignments in NAS for each of the 153 days in HOST data analyzed. The mean number of reassignments is 7642 and the median is 7768. It can be observed in Figure 12 that the number of BC reassignments on a given day is mostly in the 8000-9000 range. It was also derived from the ETMS data processing (to be discussed in following section) that there are on an average approximately 73000 hand-offs (ARTCC boundary crossing instances) per day in NAS. As a result, the probability of a pilot having to change his code when crossing an ARTCC boundary is about 9-10% ([8000 to 9000]/[70000-75000]).

Table 2: Max Utilization Fraction for Internal Primary and Secondary Codes for 153 days of 2007 (Host Data)

ARTCC	Max of Max	Median	Mean	Normally Distributed (Kolmogorov-Smirnov Test with p = 0.05)
ZAB	0.317	0.219	0.233	No
ZAU	0.127	0.089	0.089	Yes
ZBW	0.21	0.113	0.105	No
ZDC	0.292	0.218	0.219	Yes
ZDV	0.163	0.117	0.119	No
ZFW	0.234	0.168	0.171	Yes
ZHU	0.529	0.499	0.529	No
ZID	0.217	0.134	0.132	Yes
ZJX	0.365	0.258	0.27	No
ZKC	0.37	0.262	0.286	No
ZLA	0.397	0.314	0.313	Yes
ZLC	0.19	0.143	0.151	No
ZMA	0.193	0.116	0.111	No
ZME	0.206	0.145	0.159	No
ZMP	0.286	0.225	0.238	No
ZNY	0.466	0.261	0.243	No
ZOA	0.137	0.099	0.102	Yes
ZOB	0.233	0.179	0.18	Yes
ZSE	0.313	0.237	0.246	No
ZTL	0.225	0.153	0.156	Yes

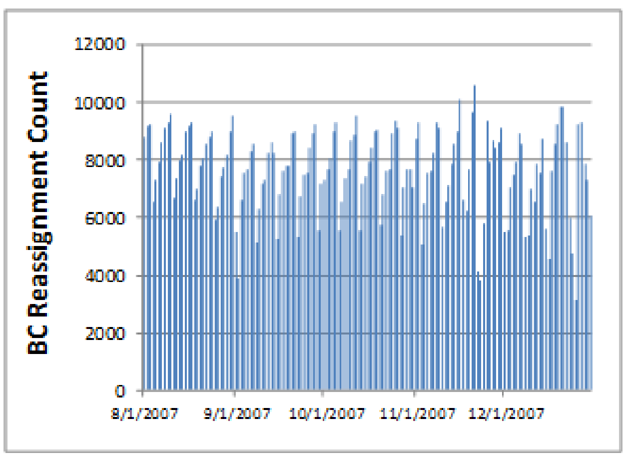

Figure 11: Number of Beacon Code Reassignments in the NAS for each of the 153 days in HOST data

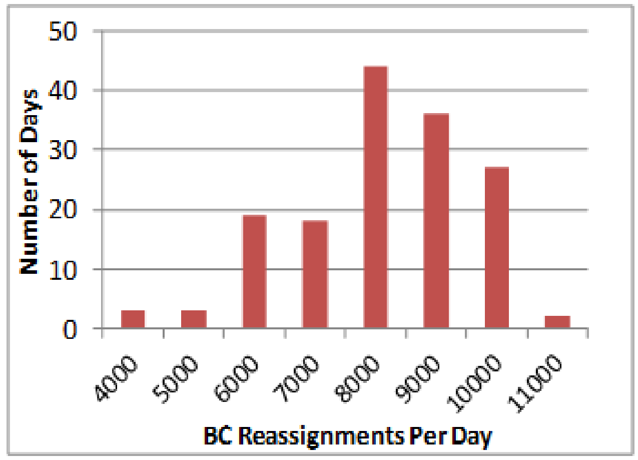

Figure 12: Histogram of BC Reassignments for 153 days of HOST Data

E. Beacon Code Reassignment Statistic from ETMS Data

Figure 13 shows the number of Hand-Offs and beacon code reassignment instances from the ETMS data for 5 days. The number of Hand-Offs ranges from approximately 70000 to 75000. The probability of beacon code reassignments (shown as red squares) ranges from 9-10%.

Figure 13: Beacon Code Hand-Off and Reassignments from ETMS Data

F. Beacon Code Utilization and Reassignment using the NBCAS (National Beacon Code Assignment Simulator)

NBCAS is a simulator designed to mimic current day NAS beacon code allocation process. There are certain limitations on exactly reproducing the day-to-day operations due to the current unavailability of data such as flight cancellation ground delay and flight cancelation. As shown in Figure 14, NBCAS has two major inputs, track data and beacon code allocation rules. The source of track information is historical ETMS TZ hits and beacon code allocated rules are obtained from FAA NBCAP Order JO 7110.66D.

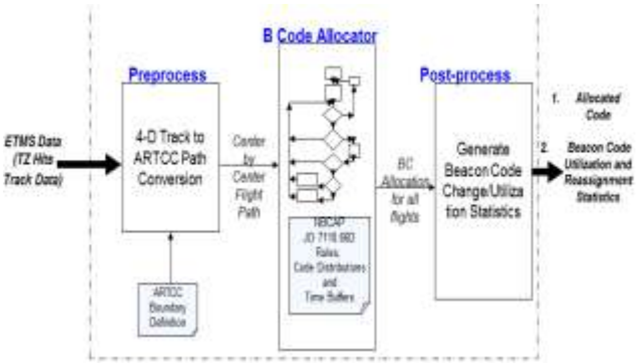

Figure 14: NBCAS (National Beacon Code Assignment Simulator) Block-Diagram

(i) Preprocessor: ETMS has 4-D flight trajectories. In order to be able to convert a given flight track into a sequential list of ARTCCs traversed, the boundary crossing points (time and location) is extracted from the TZ hits. This can be done using point in a polygon method. Once the boundary crossing time in known, the result is exported into a separate data structure where each track is stored as a sequential list of ARTCCs traversed along with the entry and exit time for each center along its path.

(ii) B Code Allocator: The NBCAS assigns codes to aircraft according to the rules described in DoT/FAA Order JO 7110D. Input to this process is preprocessed data which is 4-D track data converted to ARTCC-by-ARTCC path data with entry and exit time for each ARTCC on the path of individual aircraft.

The time-increment for the current NBCAS plan is 5 minutes, i.e. code allocation is done for every 5 minute interval. For every flight active in the NAS (active = requiring beacon code) during the current time period, it is first checked whether the current ARTCC for that flight is the same as the ARTCC that flight was in during the previous time step, in other words, whether or not the flight has crossed an ARTCC boundary or if it has just become active. In either case it needs to be assigned a code. If the flight is crossing into another ARTCC then the code that the flight is already assigned is checked for conflict against the flights already active in the following ARTCC. If there is no 'code conflict' the flight just keeps its old code. Otherwise, a new code is to be assigned to this flight from the code bucket of the entering ARTCC. The code assignment is done in the order primary, secondary and tertiary. The primary and secondary list is searched in cyclic order and the tertiary codes, if needed, are searched in top-down order. It must be noted here that flights which are active in the current time step but would disappear (land and no longer need a code) in the next time step are recorded in an array which is checked after each time period to release the codes corresponding to such flights at the end of current time step.

(iii) Post-processor: After the B-Code Allocator module allocates code to individual flights according to rules of NBCAP, the post-processor module calculates statistic on the allocated codes. The statistics are produced in the same format as reported in HOST data to enable easy comparison and also facilitate the validation of the NBCAS implementation.

Figure 15 shows for ZDC, a comparison of code assignment through NBCAS for July 26th through NBCAS(two plots on Left hand side) and the actual code assignment recorded in the HOST data(plots on RHS) for both external(top) and internal(bottom) category. It can be observed that for both the external and internal codes, the utilization plot (red line) follow the same trend and values through the day for both NBCAS output and the Host UB data. This means that code assignment through NBCAS is fairly accurate for both internal and external code categories.

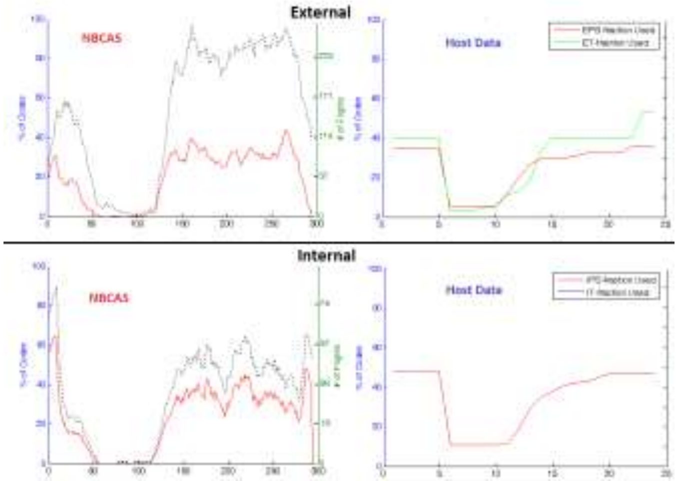

Figure 15: Comparison of NBCAS Output and Host Data for ZDC July 26, 2007

Conclusions

Of the 153 days of Host data of latter half of 2007 analyzed, ZHU ARTCC has the maximum code utilization in the internal category of 0.529. In the external category of codes, ZLC has the highest code utilization in the External category of 0.389.

The mean number of Beacon Code Reassignments in NAS for 153 days in HOST data analyzed is 7642 and the median is 7768. The number of BC reassignments on a given day is in the 8000-9000 range. From the ETMS Hand-Offs data the number of hand-offs in a day is observed to be approximately 73000. Using this as the denominator it can be concluded that the probability of a pilot having to change his code when crossing an ARTCC boundary is about 9-10% ([8000 to 9000]/[70000-75000]).

The NBCAS developed from the implementation of rules in DoT/FAA Beacon Code Order JO7110D is validated by successfully comparing its output with the Host Data for the corresponding days. Using this simulator, different Beacon Code assignment strategies can be tested out and compared with the baseline for current and futuristic traffic levels.

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