

# Air Traffic Sector Configuration Change Frequency

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**A Mixed Integer Linear Programming method is used for creating sectors in Fort Worth, Cleveland, and Los Angeles centers based on several days of good-weather traffic data. The performance of these sectors is studied when they are subjected to traffic data from different days. Additionally, the advantage of using different sector designs at different times of day with varying traffic loads is examined. Specifically, traffic data from 10 days are used for design, and 47 other days are played back to test if the traffic-counts stay below the design values used in creating the partitions. The primary findings of this study are as follows. Sectors created with traffic from good-weather days can be used on other good-weather days. Sector configurations created with two hours of traffic can be used for 6 to 12 hours without exceeding the peak-count requirement. Compared to using a single configuration for the entire day, most of the sector-hour reduction is achieved by using two sector configurations—one during daytime hours and one during nighttime hours.**

## I. Introduction

Airspace sectors have evolved over decades to assist the human controller organize flights for safe and efficient operations through the airspace. Unfortunately, the resulting sector design's inflexibility makes it difficult for it to adapt to changing weather and traffic conditions. With limited means for redistributing capacity in the airspace, traffic flow management techniques, such as delaying aircraft on the ground, are employed to reduce traffic in the affected airspace. Since this leads to delays, reconfiguring the airspace to dynamically adjust its capacity to where and when it is most needed has been proposed as an alternative.<sup>1</sup> This objective motivated the development of several airspace partitioning techniques.<sup>2-9</sup>

This paper examines whether airspace partitions created with several days of data are robust, where robust means that they can be used on other similar days, and it examines the benefit of using different partitions at different times of the day. The focus of earlier airspace partitioning research was on partitions generated with at most one-day of traffic data; the issue of whether the partitions could be used with traffic data from other days was not of concern. The benefit, measured by reduced sector-hours, of using different configurations generated by combining sectors and by combining altitude slices has been examined in Refs. 10 and 11, respectively. This same metric has been used here to show the tradeoff between reduced sector-hours and the number of times the partitions are changed in a day.

The Mixed Integer Linear Programming (MILP) method described in Ref. 9 is used with traffic data from ten high-volume low-delay days to design sectors in Fort Worth, Cleveland and Los Angeles centers. These centers were chosen because they are located in different regions of the U. S. and experience very different traffic patterns. A comparison of peak traffic-counts in the sectors for traffic from 57 days including the ten days used in the design shows that the sector configurations in these centers are robust. Results show that sector configurations created with two-hour traffic data can be used for duration of six to twelve hours without exceeding the peak traffic-count requirement. Most of the sector-hour reduction is obtained by using one sector configuration during the daytime hours and one during the nighttime hours compared to using a single configuration for the entire day. Further reduction is achieved if three sector configurations are used during the day.

Section II describes the actual air traffic dataset consisting of 57 high-volume low-delay days, out of which, ten days are used for creating the sector configurations. The entire dataset is used for evaluating the sector configurations. Section III discusses the MILP method, and Section IV describes the robust sectorization and

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validation method for creating sectors. Validation results are discussed in Section V. Tradeoff between sector-hours and the number of configuration changes is discussed in Section VI, and the paper is concluded in Section VII.

## II. Air Traffic Dataset

The analysis and results discussed in this article are based on air traffic data from high-volume low-delay days. High-volume traffic is usually associated with weekdays. Delays are low on days on which the flights are relatively unaffected by weather and congestion caused rerouting and ground holds. Most aircraft stay on their filed route of flight and are on-time with respect to their schedule. To identify such days, delay data for all the days in 2007 were obtained from the Federal Aviation Administration’s Air Traffic Operations Network (OPSNET) database. The days were then categorized based on total domestic departure-counts and total time delay in minutes using the multiple-metric K-Means classification method described in Ref. 12. Days were separated into nine groups based on the combination of traffic-volume (“low-volume,” “medium-volume,” “high-volume”) and delay (“low-delay,” “medium-delay,” and “high-delay”). Figure 1 shows the scatter plot of the 57 days that were selected for this study. Ten of the 57 days, marked in circles, were used for designing the sectors. We will refer to these days as the training set. The ones marked with triangles are the remaining 47 days that were used for evaluating the robustness of these sectors, referred to as test days.

Figure 2 shows the average, upper and lower bounds of the number of aircraft in the Fort Worth Center airspace as a function of time for the ten training days. The numbers of training and test days for each day of the week are listed in Table 1. Aircraft position data from the ten training days for each two-hour time period were used in the MILP sector design method, described in Ref. 9, to create 12 sector configurations spanning the 24-hour time period. The MILP sector design method is briefly discussed next.

## III. Mixed Integer Linear Programming Method

The MILP method discussed in this section assumes a hexagonal tessellation of the airspace. Such a tessellation with tiles marked with numbers uniquely identifying them is shown in Fig. 3. Tiles marked with the letter “s” are special tiles called “seed” tiles.

The setup phase of the algorithm counts the total number of aircraft located within the tile along with the total number of aircraft that cross each of the six sides of the tile for the duration of interest. The direction of tile boundary crossing is ignored. The seed tiles are also selected at this point.

The optimization process clusters the hexagonal tiles together to form sectors by using a connection variable that represents a directional link between two tiles. This variable contains not only the identity of the linked tiles, but also the accumulated sum of aircraft counts of every tile upstream of that link. This accumulation of aircraft counts

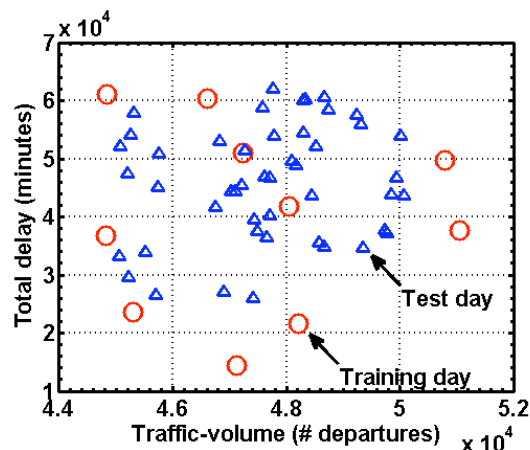


Figure 1. High-volume low-delay days.

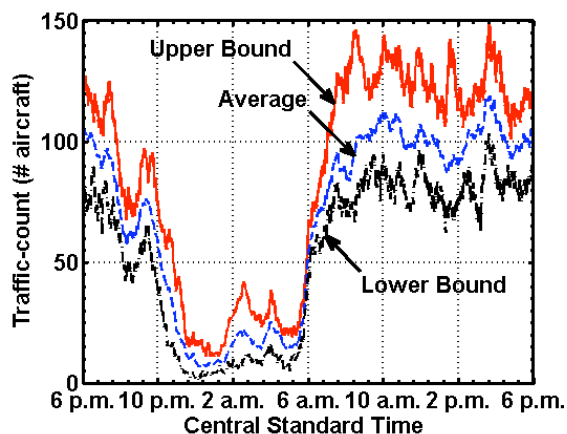


Figure 2. Upper and lower bounds.

Table 1. Numbers of training and test days corresponding to days of the week.

Day of week	Training days	Test days
Monday	2	5
Tuesday	3	15
Wednesday	1	14
Thursday	1	9
Friday	3	4
<b>Total</b>	<b>10</b>	<b>47</b>

is terminated at the “sink” tile, which is selected during the optimization process from among the pre-determined seed tiles. In this way, the value of the final link going into the sink tile, plus the sink tile’s aircraft count equals the total aircraft count of that cluster of tiles. Figure 3 shows a notional solution of the optimization in which the directions of the links between adjacent tiles, all the way to the sink tile 1 are marked with arrows. All the tiles that contribute links to a particular sink tile,  $\hat{s}$ , are said to belong to one region (sector) of airspace. Note that sink tile does not refer to an actual destination of aircraft. Rather it is a mathematical construct to aid in the formulation of the optimization problem.

The solution phase of the algorithm is implemented by six basic constraints and an optimization function. The first constraint ensures that the link variable captures the accumulated number of aircraft upstream in the contiguous cluster of tiles. This is basically a conservation of aircraft constraint between a tile’s incoming links, the one outbound link, and its own contribution of aircraft counts. The second constraint predicates that the total number of aircraft captured by the sum of incoming links to a sink tile, plus its own contribution of aircraft counts is constrained to be within 5% of the average number of aircraft, where the average number of aircraft is the sum of the number of aircraft in all tiles for the duration of interest divided by the desired number of sectors. This constraint leads to the creation of sectors with nearly equal numbers of aircraft. The third constraint asserts that the number of sink tiles should equal the desired number of sectors. The fourth constraint establishes that all non-sink tiles (including seed tiles that do not end up becoming sinks) have a single outbound link to an adjacent tile. The fifth constraint specifies that there is no outbound link from a sink tile. Finally, one of the most compelling reasons for using this method of tile clustering is that tile contiguity can be enforced by only allowing links to be formed between adjacent cells. This is the sixth constraint. In practice, this constraint can be implicitly enforced in the data structure utilized by the other constraints.

The optimization function consists of the sum of the weighted outbound link values from each tile to its adjacent tiles. The weights are given by the boundary crossing counts computed during the setup phase. These weights are used to ensure that the link directions resulting from minimization of the optimization function are aligned along the major flows seen in the air traffic data. Other details of the MILP method are given in Ref. 9. A notional solution of the optimization shown in Fig. 3 can be viewed as a Directed Acyclic Graph (DAG) rooted at the sink tile 1 in Fig. 4. The graph is directed because the outbound links are defined from a tile to its adjacent tile; it is acyclic because

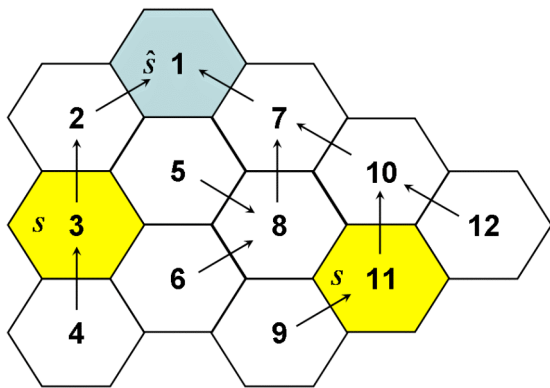


Figure 3. Tessellation of the airspace.

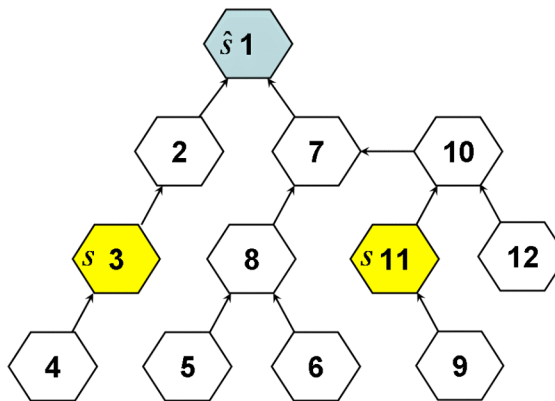


Figure 4. Directed Acyclic Graph resulting from optimization.

single outbound-links (no backward links between adjacent tiles), conservation of aircraft, and single sink tile per sector prevent the formation of loops. Once the tiles are associated with sectors, a boundary smoothing algorithm described in Ref. 9 is used for generating the final sector boundaries.

#### IV. Robust Sectorization and Validation

This section describes the method for designing sectors using several days of air traffic data, selecting few sector configurations for the 24-hour period, and validating the design. The design is validated by playing back the test traffic data through the designed sectors and determining that the design criteria are not violated. The method is summarized in a block diagram in Fig. 5. The examples and results presented in this and subsequent sections are based on high-altitude traffic, which is above 24,000 feet altitude.

The first step of the robust sectorization method consists of initializing time,  $t$ . Next, the time-interval  $T$  is initialized to a two-hour period of the day, for example 0:00 to 2:00 coordinated universal time (UTC) (6 p.m. to 8 p.m. central standard time (CST)) in step 502. Note that 5 in 502 refers to Fig. 5. The desired number of sectors,  $m$ , is initialized to two sectors in step 503. Aircraft position data within the specified  $T$  are used in the MILP based sector design method, discussed in Section III, in step 505. Computation of the total number of aircraft in the tiles and the numbers crossing the tile boundaries is accomplished by processing ten days of traffic data, one day at a time, in the setup phase of the MILP algorithm. This is possible because counts from two days can be obtained by adding the counts from the first day to those from the second day. The solution phase of the MILP algorithm is then run based on the parameters obtained from the setup phase to partition the airspace into  $m$  sectors.

Traffic data used in the MILP algorithm are then played back through the  $m$  sectors output by the MILP algorithm to generate a histogram of the sector traffic-counts in step 506. An example of such a histogram for Fort Worth Center airspace partitioned into two sectors for the 6 p.m. to 8 p.m. CST time-interval is shown in Fig. 6. The minimum and maximum numbers of aircraft during this interval were 23 and 81. This example shows that the traffic-counts in a sector can be unacceptably high when airspace is partitioned into few sectors. To ensure that the traffic-counts stay below a specified threshold in most instances, the airspace needs to be partitioned into more sectors. This is the motivation for step 508 that increases  $m$  by two. The previous steps are repeated to create histograms of the type in Fig. 6. Step 507 transfers control to Step 509 once the nine histograms are obtained with airspace partitioned into two through 18 sectors.

The sector selection step 509 is used to select a sector configuration with the appropriate number of sectors for the chosen  $T$ . The sector cumulative frequency is computed for each of the nine histograms by summing the frequency along the traffic-count bins. The cumulative frequency graph for the histogram in Fig. 6 is shown in Fig.

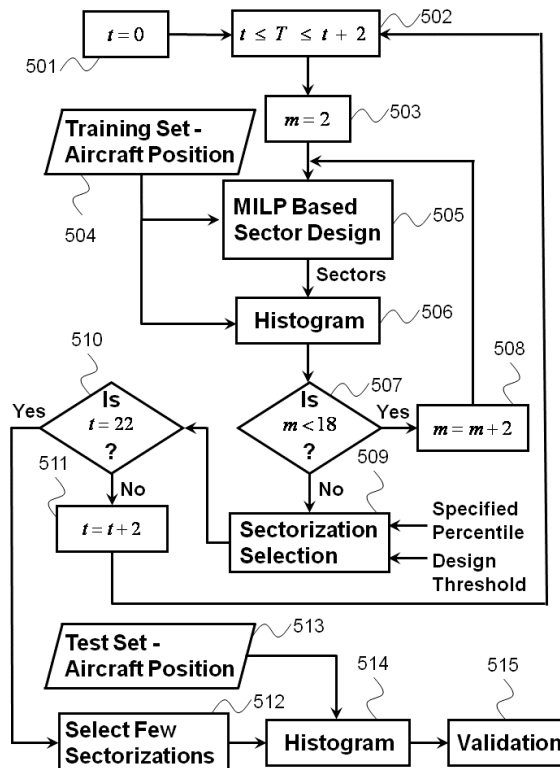


Figure 5. Robust sectorization and validation method.

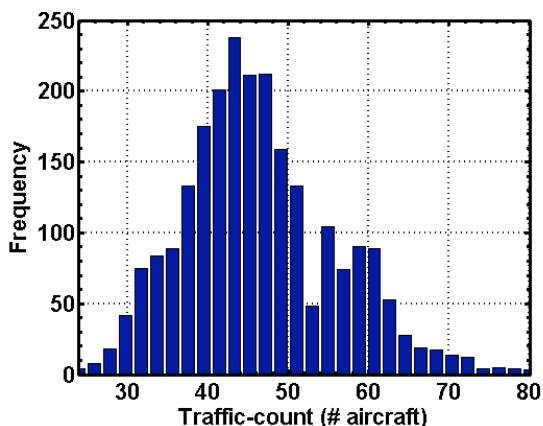


Figure 6. Histogram of traffic-counts during the two-hour period with Fort Worth Center airspace partitioned into two sectors.

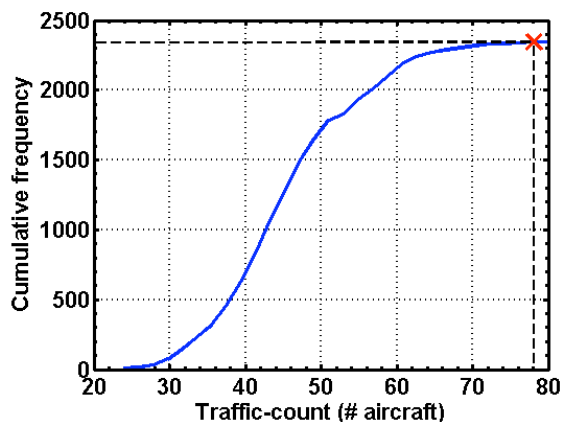


Figure 7. Cumulative frequency of traffic-counts during the two-hour period with Fort Worth Center airspace partitioned into two sectors.

7. The last value of the graph in Fig. 7 is 2346, which is the total number of traffic-count samples in Fig. 6. Based on the last value, the 99.9 percentile value is 2344. The traffic-count corresponding to 2344 is 78 aircraft. This location is marked by an 'x' in Fig. 7. The central idea here is that if the Fort Worth Center airspace were to be partitioned into two sectors during the 6 p.m. to 8 p.m. CST time-interval, the probability is 99.9 percent that the traffic-count would be at or below 78 aircraft in a sector. Lower percentile values can be chosen to remove outlier traffic-count values.

The process of computing the cumulative frequency and selecting a traffic-count value corresponding to the specified percentile is repeated for each of the nine sector configurations. The values obtained for the nine sector configurations for the first two-hour time period (6 p.m. to 8 p.m. CST) are shown in Fig. 8. The number of sectors needed for ensuring 99.9% probability of traffic-counts staying below a specified traffic-count threshold can be obtained from the data presented in this figure. For example, at least 12 sectors would be needed if a threshold of 20 aircraft were chosen. This example shows that given a percentile value and a design threshold, a sector configuration can be chosen for the time-interval of interest.

Step 510 checks if a sector configuration has been selected for the last two-hour interval. If not,  $t$  is incremented by two-hours in step 511, and a new time-interval is determined in step 502. The entire process discussed thus far is repeated for this new time-interval. The result is a selection of 12 sector configurations, one for each two-hour time-interval, in step 509. Figure 9 shows a bar chart of the number of sectors in the configurations selected in the Fort Worth Center. Observe that the number of sectors correlates to the traffic-count shown in Fig. 2.

In step 512, two or three sector configurations are chosen from the available 12. This selection is accomplished by organizing the configurations into a few groups and then identifying one representative configuration for each group. The K-Means algorithm discussed in Ref. 12 is used to organize the configurations into groups based on the number of sectors. For example, sector configurations for the first, second, and tenth two-hour time periods shown in Fig. 9 are placed in the first group, 3<sup>rd</sup> through 6<sup>th</sup> are placed in the second group and the remaining are placed in the third group, when three groups are desired. Based on these three groups, the sector configuration for the first two-hour period (6 p.m. to 8 p.m. CST) is selected for the duration of the first four-hours from 6 p.m. to 10 p.m. CST. Similarly, the sector configuration of six sectors for the 4 a.m. to 6 a.m. time-interval is applied for the eight-hour period spanning the 10 p.m. to 6 a.m. interval. Finally, the third configuration of 16 sectors for the 10 a.m. to 12 p.m. time interval is selected for the twelve-hour period from 6 a.m. to 6 p.m. CST. Note that the sector configuration for the tenth two-hour time period (12 p.m. to 2 p.m. CST) is a member of the first group since it has twelve sectors, but it lies between two members of the third group (10 a.m. to 12 p.m. and 2 p.m. to 4 p.m. configurations). Regardless, the representative member of the third group is used to cover this interval. Selected sector configurations and durations of their application for the Cleveland, Los Angeles and Fort Worth Centers are summarized in Table 2.

Once representative sectors are selected in step 512, histograms of the type given in Fig. 6 are created for them in step 514 using aircraft position data from training set and test set days derived from step 513. In step 515 the

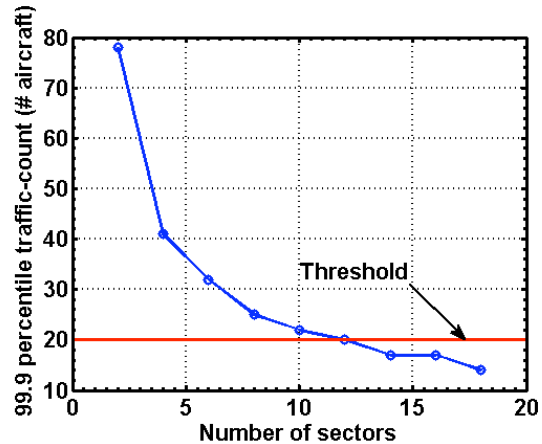


Figure 8. 99.9 percentile traffic-counts during the two-hour period with nine different configurations of Fort Worth Center airspace.

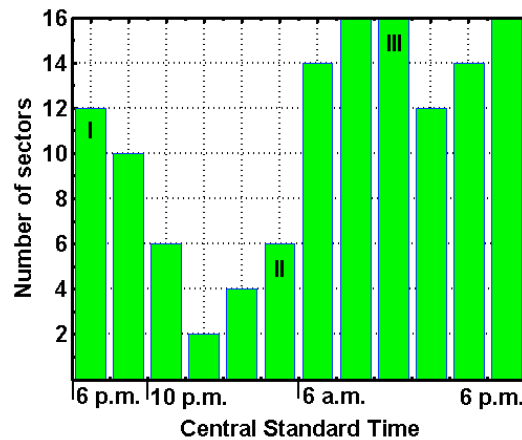


Figure 9. Selected sector configurations of the Fort Worth Center airspace for the two-hour time-intervals.

Table 2. Selected sector configurations for Cleveland, Fort Worth and Los Angeles centers.

Configuration		Center		
		Cleveland	Fort Worth	Los Angeles
I	Selected config.	7 p.m. – 9 p.m. EST	6 p.m. – 8 p.m. CST	4 p.m. – 6 p.m. PST
	Number of sectors	14	12	12
	Duration	7 p.m. – 11 p.m. EST	6 p.m. – 10 p.m. CST	4 p.m. – 12 a.m. PST
II	Selected config.	3 a.m. – 5 a.m. EST	4 a.m. – 6 a.m. CST	12 a.m. – 2 a.m. PST
	Number of sectors	6	6	4
	Duration	11 p.m. – 5 a.m. EST	10 p.m. – 6 a.m. CST	12 a.m. – 4 a.m. PST
III	Selected config.	3 p.m. – 5 p.m. EST	10 a.m. – 12 p.m. CST	12 p.m. – 2 p.m. PST
	Number of sectors	16	16	14
	Duration	5 a.m. – 7 p.m. EST	6 a.m. – 6 p.m. CST	4 a.m. – 4 p.m. PST

cumulative frequency values are computed based on the histograms provided by step 514 (see Fig. 7). These values are then used for determining traffic-counts corresponding to the percentile value (for example, 99.9) used in the design. The sector design is validated by determining if this traffic-count is above or below the specified threshold capacity value (for example, 20 aircraft) used in design.

## V. Validation Results

Results of validation using three sector configurations of the Fort Worth, Cleveland and Los Angeles centers listed in Table 2 are described in this section.

The three sector configurations of the Fort Worth Center are shown in Figs. 10-12. Traffic data from the ten training and 47 test set days were played back through these configurations for the time durations noted in Table 2 to compute traffic-counts in the sectors. Histograms were then created with these traffic samples. Cumulative frequency values were computed using these histograms, and 99.9 percentile traffic-counts were determined.

Figure 13 shows the histogram of 162,204 traffic-count samples for the Sector Configuration I shown in Fig. 10. The maximum number of aircraft in a sector was found to be 28 aircraft. The 99.9 percentile traffic-count was found to be 20 aircraft; it is marked by the vertical line in Fig. 13. Observe that the value of 20 aircraft is same as the

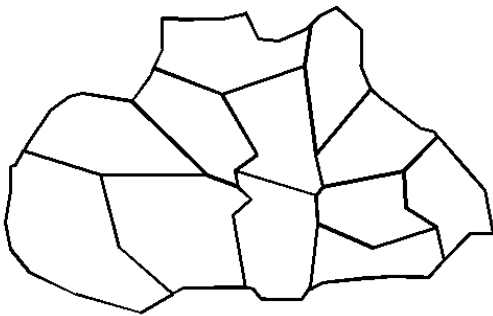


Figure 10. Fort Worth Sector Configuration I based on 6 p.m. to 8 p.m. CST traffic data from training set days.

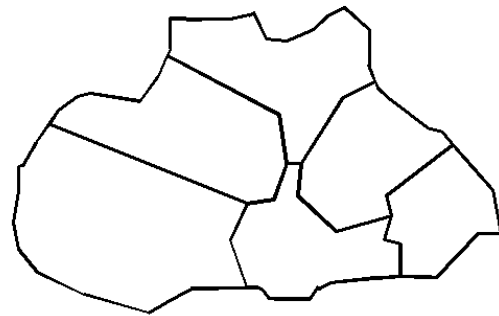


Figure 11. Fort Worth Sector Configuration II based on 4 a.m. to 6 a.m. CST traffic data from training set days.

design threshold value in Fig. 8, therefore the sector configuration in Fig. 10 can be applied for the 6 p.m. to 10 p.m. CST duration. This example shows that a sector configuration developed with traffic data from a smaller time-interval can be applied to a larger time-interval without violating the design criteria.

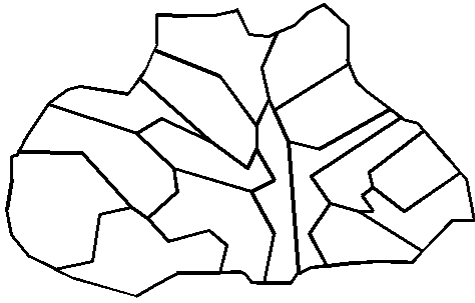


Figure 12. Fort Worth Sector Configuration III based on 10 a.m. to 12 p.m. CST traffic data from training set days.

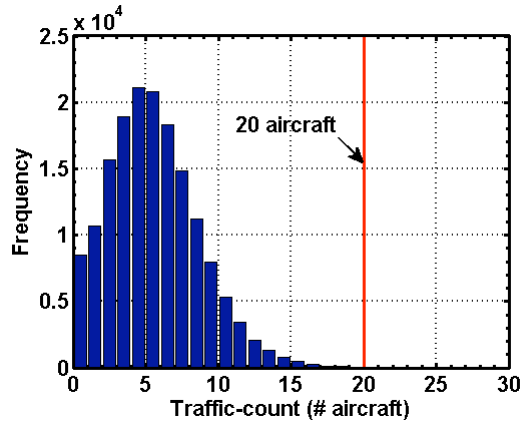


Figure 13. Histogram of traffic-counts from 6 p.m. to 10 p.m. CST with Fort Worth Center Configuration I.

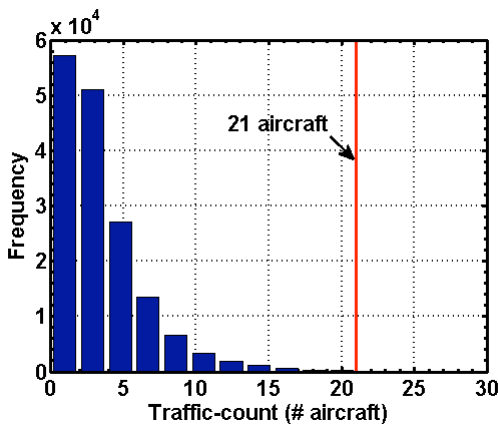


Figure 14. Histogram of traffic-counts from 10 p.m. to 6 a.m. CST with Fort Worth Center Configuration II.

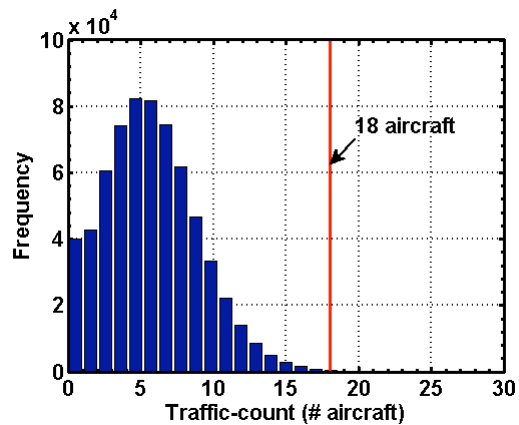


Figure 15. Histogram of traffic-counts from 6 a.m. to 6 p.m. CST with Fort Worth Center Configuration III.

Figures 14 and 15 show histograms derived from traffic data from the 57 days and the sector configurations II and III shown in Figs. 11 and 12. Total numbers of traffic-count samples were 163,158 and 653,632, and the peak traffic-counts in a sector were 42 and 31 aircraft for these two sector configurations, respectively. The 99.9 percentile traffic-counts were determined to be 21 and 18 as shown in Figs. 14 and 15. Although the 99.9 percentile traffic-count value of 21 for Configuration II was found to be one above the design value, instances of traffic-count of 21 were found to be small with 99.87 percentile value of 20 aircraft. Given that the traffic-counts in most instances are at or below the design value, Configuration II and III can be used for the desired eight-hour and twelve-hour periods.

In situations where the traffic-count is forecasted to be much higher than what the sector was designed for, traffic flow management techniques can be used to moderate the demand. The validation results given here suggest that this would be required infrequently.

Validation results for Cleveland, Los Angeles and Fort Worth centers are summarized in Table 3. The last row of

Table 3. 99.9 percentile traffic-counts in the chosen sector configurations for Cleveland, Fort Worth and Los Angeles centers.

Configuration	Center		
	Cleveland	Fort Worth	Los Angeles
I	18	20	17
II	22	21	13
III	18	18	18
III all day	18	17	17



the table lists 99.9 percentile traffic-counts obtained with Sector Configuration III used for the entire day. Cleveland Center and Los Angeles Center results, like the Fort Worth Center results, suggest that sector configurations developed with traffic data from several days over smaller time-intervals can be used over larger time-intervals on similar days of traffic without peak traffic-counts significantly exceeding the design threshold.

## VI. Sector Configuration Change Frequency

Results presented in the previous section indicate that a single sector configuration used during the busy part of the day can be used for the entire day without exceeding the traffic-count limits. These configurations have the most number of sectors compared to other configurations designed for lower traffic-volume. For example, Configuration III shown in Fig. 12 has 16 sectors compared to Configuration II shown in Fig. 11 that has six sectors. Given that each sector requires resources in terms of equipment and air traffic controllers, it is desirable to have as few sectors as possible for handling the expected traffic. Thus, from a resource utilization perspective, sector configurations should be changed as frequently as possible. Although sector configuration change is permitted in the current air traffic control environment, it is difficult to do so frequently because of safety issues of transitioning from one configuration to the next. Change during a busy period is workload intensive because aircraft have to be handed over to neighboring sectors.<sup>11</sup> If done in an uncoordinated manner, aircraft would be within the geometric confines of one sector while being controlled by another sector. Configuration change is difficult even if it is timed with a shift change when a new controller assumes separation responsibility for the sector. Regulations require the sector controller to ensure that the incoming controller has complete situational awareness prior to transfer. This is difficult to achieve if the sector configuration changes upon transfer. Due to these practical impediments, sector configuration change should be considered only when there is a significant benefit.

The number of sector-hours has been proposed as a benefit metric for comparing different sector configurations in Refs. 10 and 11. It is obtained by summing the product of the number of sectors in each time-interval with the time-interval duration in hours. Following this definition, 256 sector-hours are obtained for the sector configuration change strategy in Fig. 9 with 12 sector configurations. If Configuration III (16 sectors) were used in the Fort Worth Center for the entire day, 384 sector-hours would be spent. The ratio of the sector-hours between a single sector configuration and 12 sector configurations changed once every two-hours is therefore 1.5; sector-hours can be reduced by 50%. Several different configuration change schedules for the Fort Worth Center are provided in Table 4. The numbers of sectors for the two-hour periods are shown in the table. The first row indicates that the same configuration is used throughout the day. The last row of the table contains the same information as the bar chart in Fig. 9; it shows that sector configurations are changed 11 times: 16 to 12, 12 to 10, 10 to 6, 6 to 2, 2 to 4, 4 to 6, 6 to 14, 14 to 16, 16 to 12, 12 to 14, and 14 to 16. Similar schedules were also

Table 4. Sector configuration change schedules for Fort Worth Center.

Number of Changes	Change Schedule	Sector-hours
0	16, 16, 16, 16, 16, 16, 16, 16, 16, 16, 16, 16	384
2	16, 16, 6, 6, 6, 6, 16, 16, 16, 16, 16, 16	304
3	12, 12, 6, 6, 6, 6, 16, 16, 16, 16, 16, 16	288
4	12, 10, 6, 6, 6, 6, 16, 16, 16, 16, 16, 16	284
5	12, 12, 6, 4, 4, 6, 16, 16, 16, 16, 16, 16	280
6	12, 10, 6, 4, 4, 6, 16, 16, 16, 16, 16, 16	276
7	12, 12, 6, 4, 4, 6, 16, 16, 16, 14, 14, 16	272
8	12, 12, 6, 4, 4, 6, 16, 16, 16, 12, 14, 16	268
9	12, 10, 6, 4, 4, 6, 16, 16, 16, 12, 14, 16	264
10	12, 10, 6, 2, 4, 6, 16, 16, 16, 12, 14, 16	260
11	12, 10, 6, 2, 4, 6, 14, 16, 16, 12, 14, 16	256

created for Cleveland and Los Angeles Centers, and sector-hours were computed for each schedule.

384 sector-hours were obtained in the Cleveland Center with 16 sectors used for the entire day; 324 sector-hours were obtained with 16 sectors from 5:00 a.m. to 11:00 p.m. and 6 sectors from 11:00 p.m. to 5:00 a.m. EST. For three configuration changes with 14 sectors during 7:00 p.m. to 11:00 p.m., 6 sectors during 11:00 p.m. to 5:00 a.m., and 16 sectors during 5:00 a.m. to 7:00 p.m. EST, 316 sector-hours were obtained. These sector-hours are lower than 435 sector-hours for the current high-altitude operations in the Cleveland Center reported in Ref. 10. On an average 22 sectors are used for daytime (6:00 a.m. to 11:00 p.m. EST) operations and 11 sectors are used for nighttime operations (11:00 p.m. to 6:00 a.m. EST) in the Cleveland Center. Lower sector-hours were obtained in



our study because of the chosen design threshold of 20 aircraft which resulted in 16 sectors for daytime use and 6 sectors for nighttime use.

The results summarized in Fig. 16 show that two configuration changes are needed for reducing the sector-hours from about 50% to 19% in Fort Worth Center, 23% in Cleveland Center and 26% in Los Angeles Center above the minimum sector-hours achievable with the 12 two-hour sectorizations. These results suggest that the current practice in most centers of using one configuration for the daytime hours and one for the nighttime hours is a reasonable one. Sector-hours are further reduced to 20% in Cleveland and Los Angeles Centers and 13% in Fort Worth Center with three configuration changes. If four configuration changes are allowed, the sector-hours are at most 15% above that achieved with the two-hour sectorizations.

In summary, results presented in Table 3 and in Fig. 16 advocate both, from safety (99.9 percentile peak traffic-count) and resource utilization (sector-hours) perspectives, that two to three sectors configurations are adequate for a good-weather day. Significant reduction in sector-hours is obtained by using Configuration III during daytime hours and Configuration II during nighttime hours in the three centers. Further reduction is obtained if Configuration I is used during the times listed in Table 2. Although sector-hours can be reduced even more by changing sector configurations according to Fig. 16, the frequency of change should be guided by practical considerations, especially during busy traffic periods.

## VII. Conclusions

A robust sectorization and validation method for partitioning airspace into sectors based on several days of air traffic data was described in the paper. Traffic data from ten days out of a set of 57 high-volume low-delay days in 2007 were used for designing sectors in the Cleveland, Fort Worth and Los Angeles center airspace for each two-hour period of the day using the method. Of the twelve sector configurations for each day, three were chosen to span the 24-hour time period. Traffic data from the entire dataset were played back through the three selected sector configurations, and histograms of traffic-counts were computed. These distributions show that the probability of traffic-counts exceeding the threshold value used in the sector design is less than one percent. Examples demonstrate that sector configurations created using two-hour time-interval traffic data from several days can be applied over much longer time-intervals from six-hour to 12-hour durations without violating the design criteria. Sector-hours were computed for several sector configuration change schedules to establish a tradeoff with respect to the number of configuration changes during the day. It was determined that most of the benefit as measured by sector-hours is derived by using two configurations, one during daytime hours and one during the nighttime hours. Further benefit is obtained by using one additional configuration.

## VIII. References

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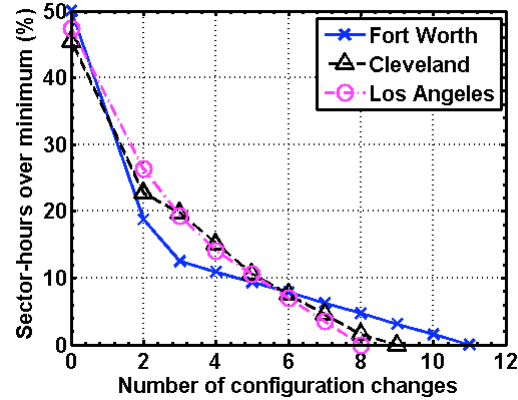


Figure 16. Tradeoff between sector-hours and number of sector configuration changes in Fort Worth, Cleveland and Los Angeles Centers.

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