

Cleveland Center Airspace Redesign Analysis

Michael Drew*

*University of California, Santa Cruz at NASA Ames Research Center,
Moffett Field, CA 94035-0001, USA*

Michael Bloem[†] and Karl D. Bilimoria[‡]

NASA Ames Research Center, Moffett Field, CA 94035-0001, USA

The sectors of Cleveland Air Route Traffic Control Center were redesigned in 2011 in response to changes in air traffic patterns and volume. This paper presents an analysis of that redesign by contrasting the performance of the old design to the new one using historical traffic from the summer of 2010. Multiple workload factors are measured for each sector including one called *sector loading*, which is the sector's peak aircraft count over a 15-minute time interval divided by the sector's capacity, as specified by its Monitor Alert Parameter value. Other factors, like the number of flights near sector boundaries, are used to measure specific controller tasks that contribute to overall workload. Several of the design changes involved splitting busy sectors and combining under-utilized sectors to address traffic load imbalances. By comparing the distributions of these workload factors, the majority of these changes are shown to make the workload in the new sectors more consistent with that of other sectors in the vicinity. Furthermore, many of the changes are shown to improve the balance of workload within areas of specialization.

I. Introduction

EN-route traffic in the U.S. national airspace system is handled by Air Route Traffic Control Centers (ARTCCs). Each ARTCC (or Center) is divided into a small number (typically fewer than 10) of Areas of Specialization (AoS) which are each subdivided into a small number (generally 5 to 10) of sectors. Each sector is operated by a team of one or two (occasionally three) air traffic controllers who are certified to work in an Area. Sectors are designed to distribute workload equitably and to conform with the local traffic flow.¹

Cleveland Center recently redesigned significant portions of their airspace in response to new traffic flow patterns that emerged over the past several years. The two primary factors responsible for these traffic pattern changes were the de-hubbing of Pittsburgh International Airport by US Airways in 2004, and the transition from turbo-prop to regional jet aircraft, which fly at higher altitudes. A team of Cleveland Center staff modified their airspace design to conform with the new traffic patterns. The process for determining this modified airspace design was primarily qualitative, based on the extensive operational knowledge and experience of the redesign team. In order to provide a balanced perspective, an independent quantitative analysis of the airspace design changes was conducted by researchers at the NASA Ames Research Center. This paper documents that effort.

This paper is organized as follows: Section II highlights the most significant airspace design changes that were made and analyzed. Section III details the method used for the airspace analysis. This includes a description of the traffic data used, as well as the metrics and factors used to evaluate the performance of the new design. Section IV presents the major results of the analysis on both an individual sector basis, as well as on a larger regional basis. Section V concludes the analysis of Cleveland Centers airspace redesign effort.

*Research Analyst and Task Manager, Systems Modeling and Optimization Branch, MS 210-8; michael.c.drew@nasa.gov.

[†]Research Aerospace Engineer, Systems Modeling and Optimization Branch, MS 210-10, and Member, AIAA; michael.bloem@nasa.gov.

[‡]Research Aerospace Engineer, Flight Trajectory Dynamics and Controls Branch, MS 210-10; Associate Fellow, AIAA; karl.bilimoria@nasa.gov.

II. Cleveland Center Airspace Changes

Changes to the Cleveland Center airspace design were extensive. Example changes include combining two sectors into one larger sector, splitting sectors horizontally and vertically to form new sectors, and altering the floors and/or ceilings of sectors. Additionally, some Areas gained and/or lost sectors, and one Area was completely redesigned and constructed with entirely new boundaries. These changes were gradually implemented over several months from 2011 into 2012.

While all the changes were simulated and analyzed, only the analysis of a subset consisting of the most major changes is presented in this paper. Listed according to AoS, the subset of changes analyzed in this paper consists of:

- **Area 4:**
 - Sector 45 split horizontally into 45 and 46 (sub-section IV.A).
 - Sector 40 moved into Area 8 (sub-section IV.A).
- **Area 5:**
 - Johnstown TRACON added below Area 5 (sub-section IV.B).
 - Combine sectors 50, 52, 53, 55, and 61 into three sectors (herein called 50, 53, 55) (sub-section IV.B).
 - Restratify and split sector 59 into sectors 59 and 58 (sub-section IV.C).
- **Area 6:** Restratify high and super high sectors (sub-section IV.D).
- **Area 7:** Decommission high sector 74; raise ceiling of lower sectors (sub-section IV.F).
- **Area 8 Low:**
 - Combine sectors 01 and 02 into sector 02 (sub-section IV.E).
 - Combine sectors 05 and 06 into sector 06 (sub-section IV.E).

III. Approach

The method used to evaluate Cleveland Center’s design changes involves comparing the former airspace design (“Old”) to the planned (“New”) one. For both sector designs, the Future ATM Concepts Evaluation Tool (FACET)² is used to record the number of aircraft in each sector (also referred to as the *sector count*), as well as several other workload factors for each sector, using historical traffic from thirty-one days between May and July, 2010. For each day, only the traffic between 6 am and 10 pm EDT is used, which is when most of the traffic occurs. The selected days are all weekdays that were judged to be relatively free of major weather impacts throughout Cleveland Center and nearby airspace, such as that near the major airports along the northern east coast of the US. Sectors should be designed to be robust to weather, for example by being able to facilitate typical weather reroutes, but weather-related factors were not included in this analysis.

A. Sector Loading

The first metric used in the analysis is called *sector loading*. This metric relies on an assumed capacity for each sector for which the published (if available) or estimated sector Monitor Alert Parameter (MAP) is used.¹ The sector loading is found by dividing a sector’s aircraft count by its MAP value. Thus, a value of 1 (or 100%) indicates that the sector is at full capacity. The raw traffic data consists of sector counts recorded every minute over a 16-hour period for 31 days, resulting in nearly 30,000 data points for every sector. Then, the maximum value of these sector count values during every 15-minute interval is recorded. This reduces the data set to roughly 2000 points per sector. Dividing by the sector’s MAP value results in a corresponding set of 2000 sector loading values from the thirty-one selected days.

A typical sector loading distribution plot is shown in Fig. 1. Note that the median value of this sector is shown as is the MAP threshold line at 100%. The orange bar indicates that in roughly 20% of the 2000 data points, this sector has a 15-minute peak loading of between 40 - 50%. Also, for some small but not

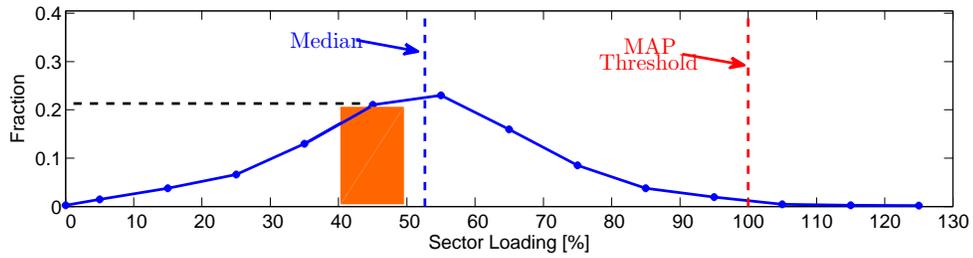


Figure 1. Example Sector Loading distribution.

insignificant part of the time, the sector is over-loaded in that it experiences sector counts exceeding its MAP value.

By comparing the sector loading distributions between the old and new designs (on both an individual basis and Area-wide bases), quantitative insight can be gained into the potential benefit of the new design. For example, sector load distributions that have values beyond 100% loading and/or median lines to the right of about 45% indicate the sector may be over-loaded. Likewise, load distributions with median lines to the left of about 25% suggest the sector is under-loaded. The majority of sectors within Cleveland Center that were subject to the greatest changes fell into these categories before being redesigned. Also, when sector loading distributions are plotted together from multiple sectors within a region (all sectors within an AoS, for example), similar sector loading distributions are preferred because they indicate that workload is well balanced among those sectors.

B. Additional Workload Factors

FACET also computes and records four additional workload factors every minute for every sector. These factors are counts of:

1. Short-term Conflicts
2. Transitioning Flights
3. Flights Near Horizontal Sector Boundaries
4. Vertical Sector Boundary Crossings

Each of these factors are evaluated between the two designs in a manner similar to the sector loading metric. Whereas over fifty factors have been suggested in the literature (see Ref. 3 for example), short-term conflicts, transitioning flights, and handoffs/point-outs were identified by subject matter experts (SMEs) at Cleveland Center as being among the most critical. The last two factors, flights near horizontal sector boundaries and vertical sector boundary crossings, are used as an approximation for handoffs/point-outs. As with sector loading, the maximum values of each factor within each 15-minute interval is used for the analysis.

1. Short-term Conflicts

Short-term conflicts are estimated by projecting each flight in a sector along its current 3D trajectory in 15-second intervals for 5 minutes into the future. A short-term conflict is counted for the sector if any pair of these dead-reckoning predictions originating from the sector results in a loss of separation: aircraft within 5 nmi horizontally and 1000 feet vertically at the same time.

2. Transitioning Flights

The number of transitioning flights within a sector is measured by counting the number of flights ascending or descending faster than 300 ft/min.

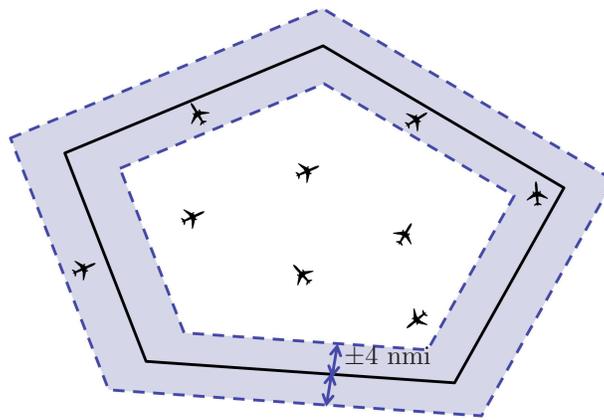


Figure 2. Flights near horizontal sector boundaries.

3. Flights Near Horizontal Sector Boundaries

Figure 2 shows eight flights within and one flight outside of a notional sector. Flights within 4 nmi on either side of the sector's boundaries are counted as boundary flights. In this case, there are four boundary flights at this instant in time. This factor, along with the Vertical Sector Boundary Crossings factor, was programmed as a simple proxy for true boundary crossings and point-outs. Note that this metric does not count flights near vertical boundaries, and that some flights counted as near horizontal boundaries may not actually be point-outs or boundary crossings.

4. Vertical Sector Boundary Crossings

This metric counts flights that have entered or exited each sector during the last minute via the floor or ceiling of the sector as a vertical boundary crossing for that sector.

IV. Results

A comprehensive analysis involving all the previously-discussed metrics was performed on all the design changes listed in Section II. This section highlights the airspace regions and metrics displaying the greatest contrast between the old and new sector designs. Several of the workload factors showed little to no appreciable difference, as the intent of the design change was likely not based on those factors.

A. Area 4

The changes involved with this area include splitting the ultra-high sector 45 into two sectors—45 and 46. Also, low sector 40 is moved out of Area 4 into Area 8. These changes are depicted in Fig. 3.

The Sector Loading distributions for all Area 4 sectors are shown in Fig. 4. The old sector design is shown on top, and the new design is shown on the bottom. Note that sector 45 had been the most congested sector within the area (as demonstrated by its median and distribution being substantially to the right of the other sectors), and that sector 40 had been the least congested sector according to this metric. The bottom plot shows that the distributions in Area 4 match closely, indicating that there is a better balance of sector loading within the area. The resulting median values of sector loading between 30 and 40 percent suggest that the workload conditions for this area are neither too heavy nor too light. Furthermore, there are fewer instances of over-MAP conditions. Also, sector 40 is the only one in Area 4 classified as a low altitude sector. Its transfer out of the area results in a more consistent traffic type in the area as a whole. These reasons justify the decision to split 45 and transfer 40 out of Area 4.

The other four workload factors were also evaluated for the Area 4 changes. Not surprisingly, splitting sector 45 into two sectors significantly reduced the number of short-term conflicts. The performance of sectors 45 and 46 of the new design is shown to be more consistent with the other sectors in the area (see

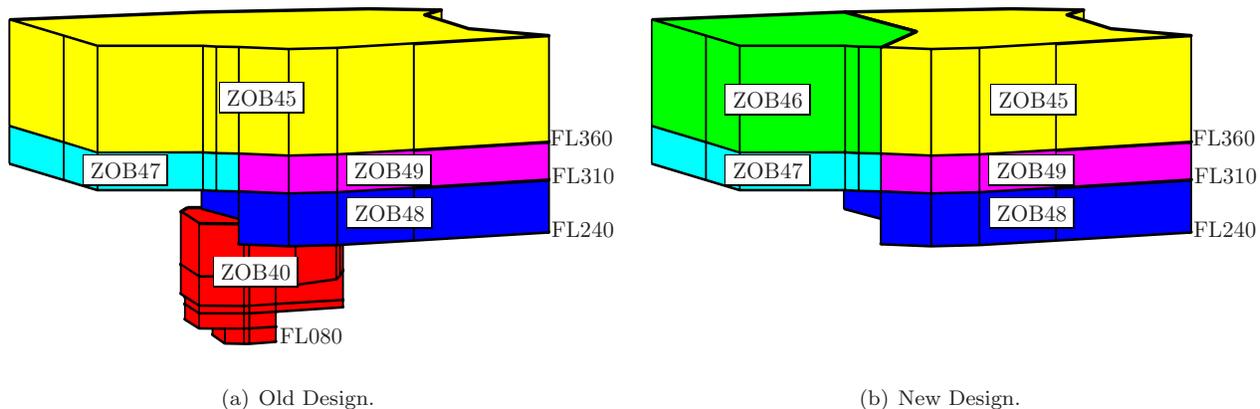


Figure 3. Area 4 Sectors.

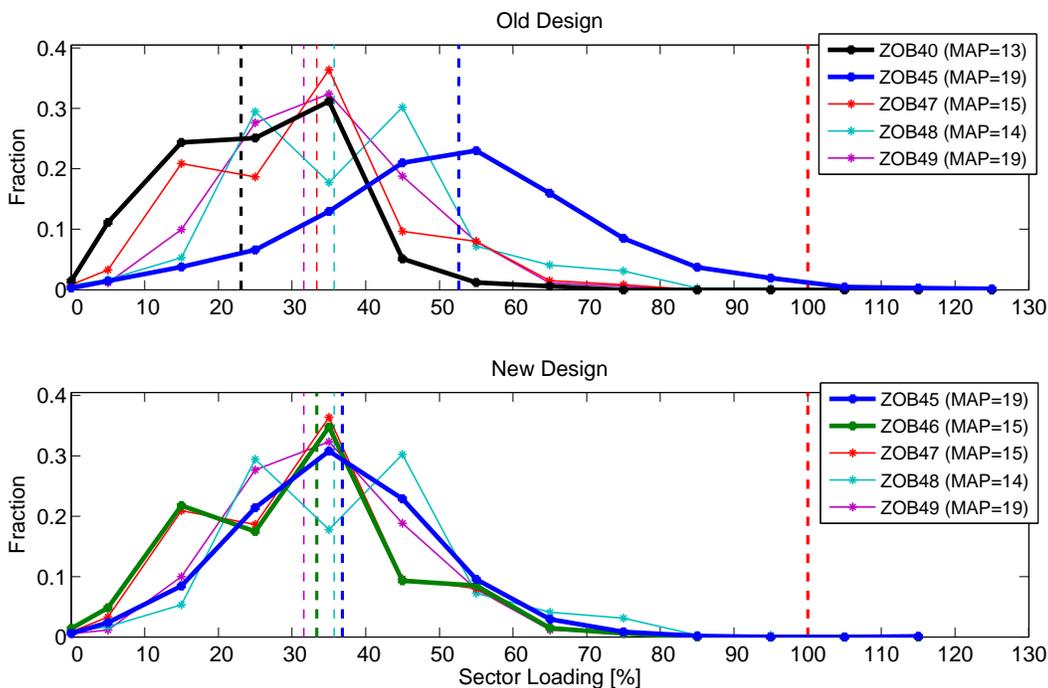


Figure 4. Sector Loading distribution for Area 4.

Fig. 5). Note that the median values of all short-term conflicts for sectors in the area are matched at one in the new design.

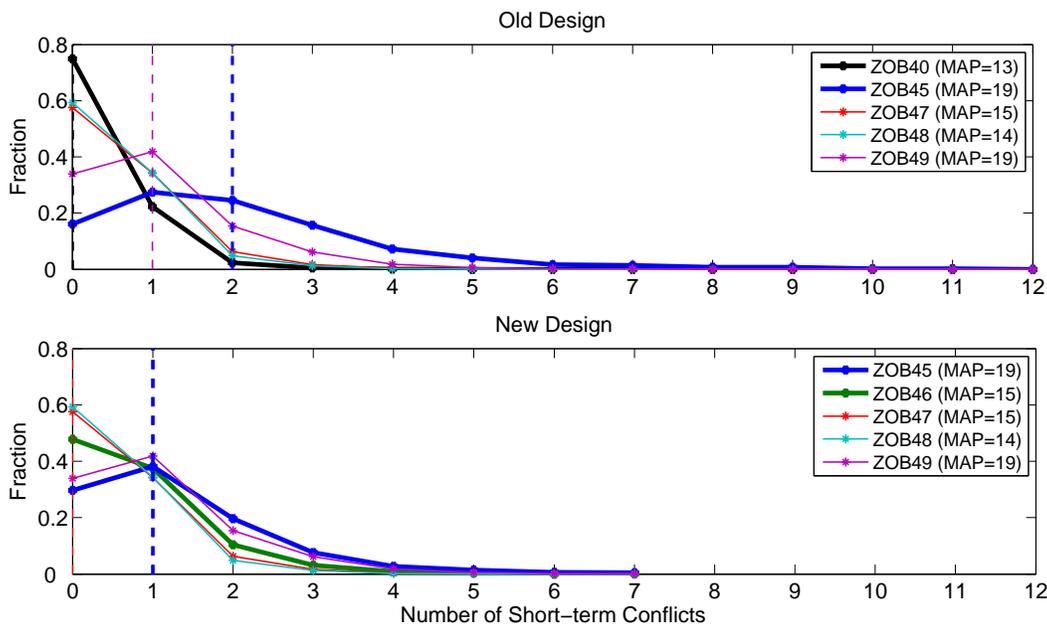


Figure 5. Peak 15-minute counts of short term conflicts in Area 4.

The remaining three factors show minor improvements as well. In Fig. 6, for example, the average number of flights near horizontal boundaries is plotted in a stacked bar fashion for both the old and new designs. Comparing the combined height of the blue and green bars for sectors 45 and 46 in the new design of Fig. 6 to the height of the green bar for the old sector 45 shows that the same volume of airspace now experiences a greater average number of flights near horizontal boundaries. This is partly due to the splitting of sector 45 into two smaller sectors, which produces more horizontal boundaries (one boundary counted twice—once for each new sector). However, on a per-sector basis, the height of the individual bars shows that this factor has been reduced for sector 45, and for sector 46 it is less than the outgoing sector 40. In fact, in all of Area 4 combined, the average number of flights near horizontal sector boundaries has been slightly reduced.

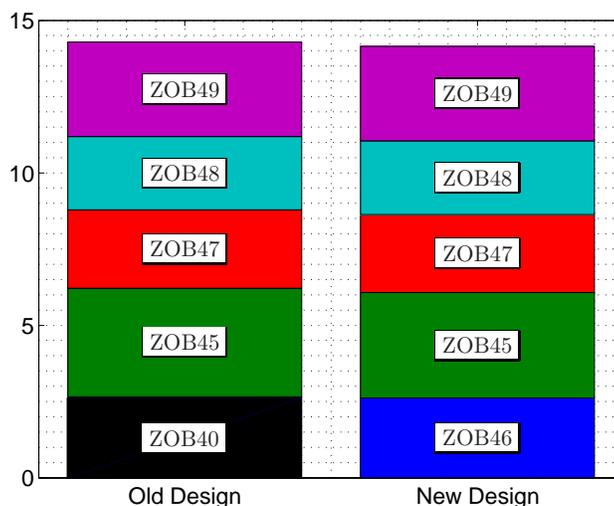


Figure 6. Average number of flights near horizontal sector boundaries for Area 4. Each bar's height is the average of the the approx. 2000 maximum values—one from each 15-minute interval.

B. Area 5 Low

The low sectors (FL230 and below) of Area 5 were changed in two major ways. The new Johnstown TRACON with a ceiling of 8000 feet was carved out below several of the Area 5 Low sectors. Then, the four low sectors from Area 5 and sector 61 from Area 6 were redesigned into three sectors. At the time of this analysis these three new sectors had not been given official designations, nor been commissioned for operations. Herein they will be denoted as sectors 50, 53, and 55. MAP values for the three new sectors are estimated based on input from SMEs familiar with Cleveland Center airspace. Boundaries of the old and new sectors in this region are shown in Fig. 7. Note that the boundaries shown in Fig. 7(b) have been slightly modified since this analysis was performed.

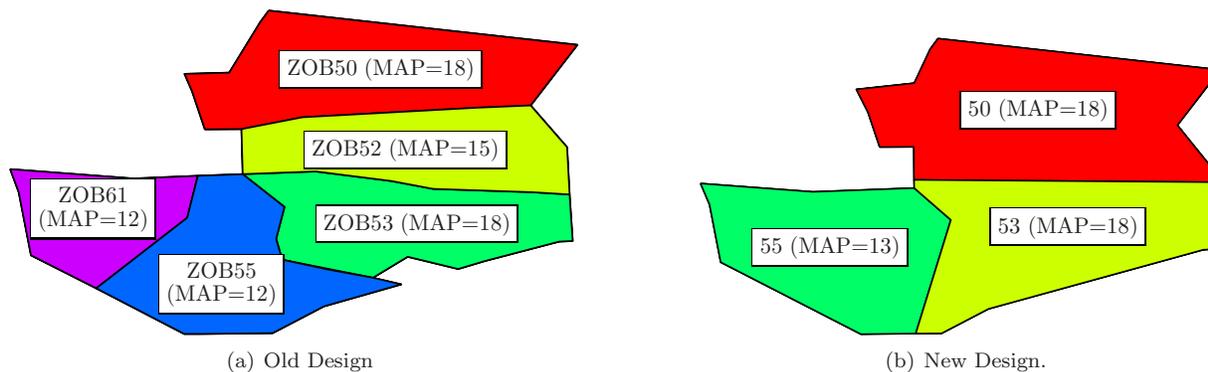


Figure 7. Area 5 Low Sectors FL230 and below. TRACON boundaries are not shown.

The sector loading analysis for the old and new Area 5 Low sector design is shown in Fig. 8. Notice that in the old design, five sectors appear to be under-utilized based on their low median sector loading values. In the new design, the median loading values of the three new sectors are slightly higher, but there are still no over-MAP occurrences during the roughly 2000 15-minute intervals measured over the course of the thirty-one days.

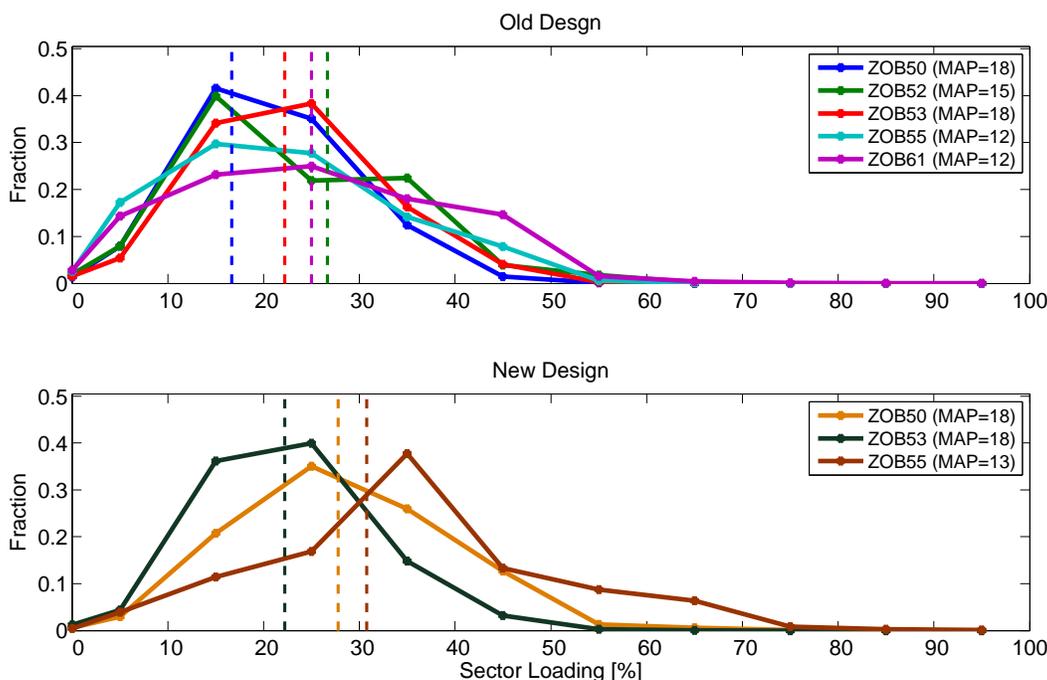


Figure 8. Sector Loading distribution for Area 5 Low Sectors. Note that sector names and MAP values in the new design are estimated based on SME input.

The workload factor analysis for the number of short-term conflicts, transitioning flights, and vertical sector boundary crossings show only minor increases, despite there being two fewer sectors in the new design. This is partly due to the nonlinear relation of this analysis method to airspace size. Recall that only the maximum value of each factor during a 15-minute interval is recorded. Thus, an airspace region partitioned into fewer sectors will not necessarily produce proportionally larger peak factor values. Furthermore, the volume of the three new sectors is smaller than the volume of the older five sectors due to the new Johnstown TRACON located within.

Again, analyzing the number of flights near horizontal sector boundaries shows a contrast between the old and new designs. With fewer sectors covering the same volume of airspace (except for the new Johnstown TRACON), one would expect to see workload slightly increase on a per-sector basis. However, in Fig. 9 where the average number of flights near horizontal boundaries are plotted for the old and new designs, the height of the bars on the right indicate that on a per-sector basis, only sector 50 experiences a significant increase in this factor compared to other sectors. More importantly, with fewer horizontal boundaries in this region, cumulatively this factor has dropped significantly, and the new design shows a reduction of more than three. This translates into a reduction in the amount of handoff- and point-out-related workload. Seen another way, the distributions of the peak 15-minute counts of flights near horizontal boundaries shown in Fig. 10 demonstrate that the new design better balances this factor among the three new sectors.

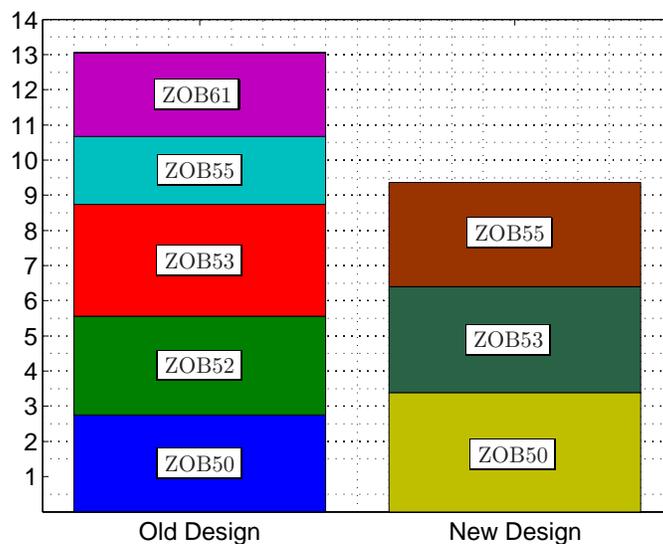


Figure 9. Average number of flights near horizontal sector boundaries for Area 5 Low. Each bar's height is the average of the the approx. 2000 maximum values—one from each 15-minute interval.

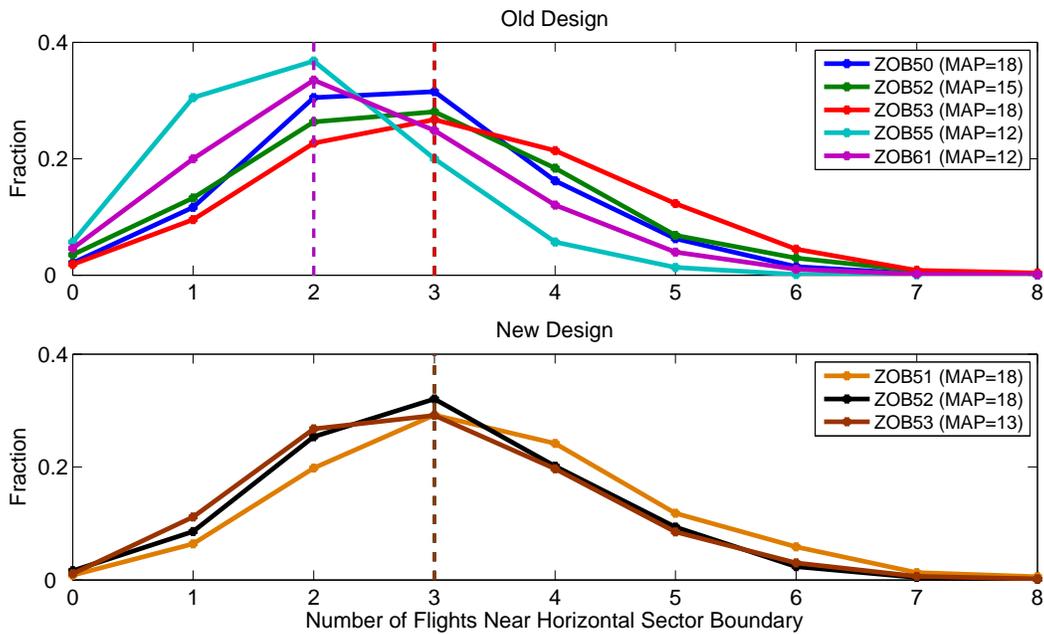


Figure 10. Peak 15-minute counts of flights near horizontal sector boundaries in Area 5 Low.

C. Area 5 High

The original high altitude sectors of Area 5 consisted of sector 57, ranging from FL240 - FL310, directly beneath super-high sector 59 spanning FL320 and above. In the new design the ceiling of sector 57 is raised to FL320, and sector 59 spans FL330 - FL370. A new sector (58) is added covering FL380 and above. The MAP value of sector 57 is held constant at 16, but since the volume of sector 59 is reduced, the MAP value is decreased from 19 to 17. The new sector 58 primarily handles high-altitude en-route flights that are simpler to control. Its MAP value is also set at 17. Figure 11 depicts the old and new Area 5 high sectors.

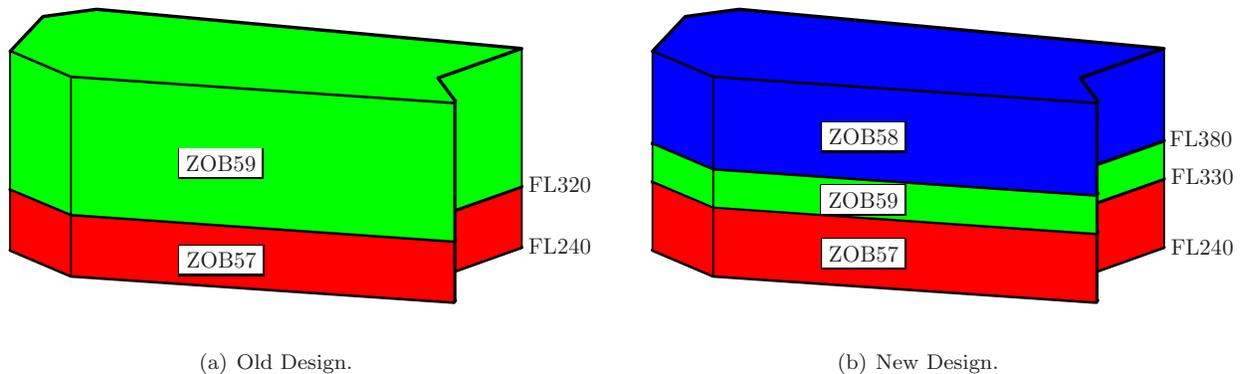


Figure 11. Area 5 High Sectors.

Fig. 12 shows this design change's effect on sector loading. Note that new sector 58, with its high floor of FL380 and relatively high MAP value of 17, is shown to be very under-loaded compared to the other sectors. However, the traffic loading of sectors 57 and 59 is now more closely matched.

Because the design change in this region involves vertically splitting an existing sector (as well as altering floor and ceiling altitudes), it is interesting to observe the effect on vertical sector boundary crossings. In Fig. 13, the average number of peak 15-minute vertical sector boundary crossings is plotted in stacked-bar form. The new sectors show an increase in this workload factor on both a per-sector and region-wide basis.

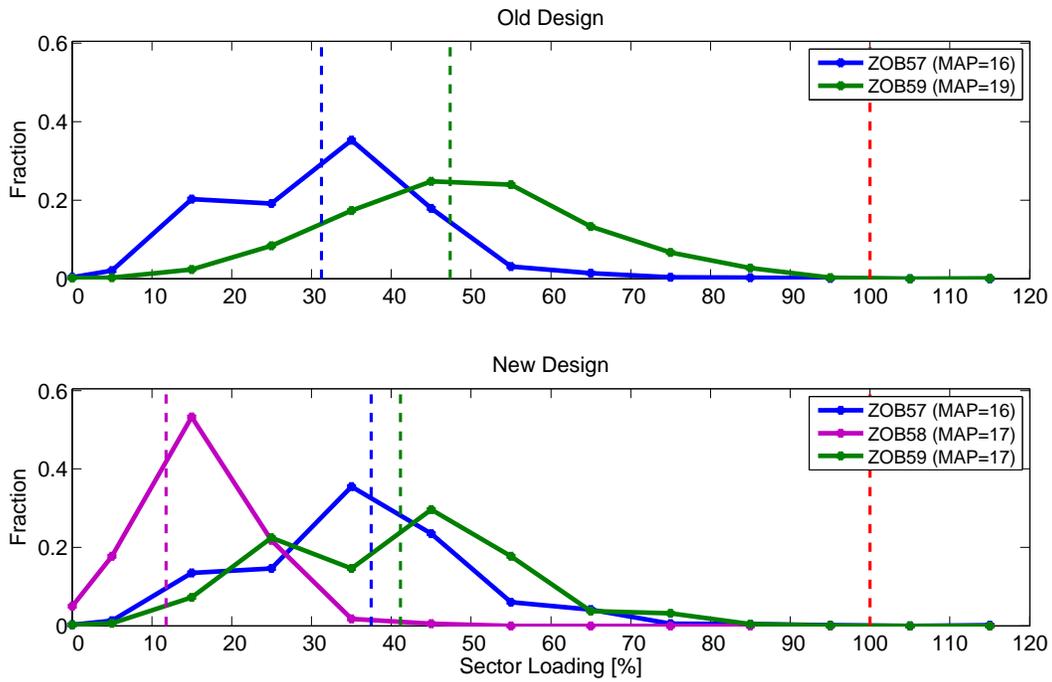


Figure 12. Sector Loading distribution for Area 5 High Sectors.

This is primarily because a vertical boundary has been added inside what used to be one large sector (old sector 59). Obviously, the same traffic will cross more vertical boundaries in the new design. Even the new sector 57 shows a slight increase in this factor due to its ceiling being raised to FL320.

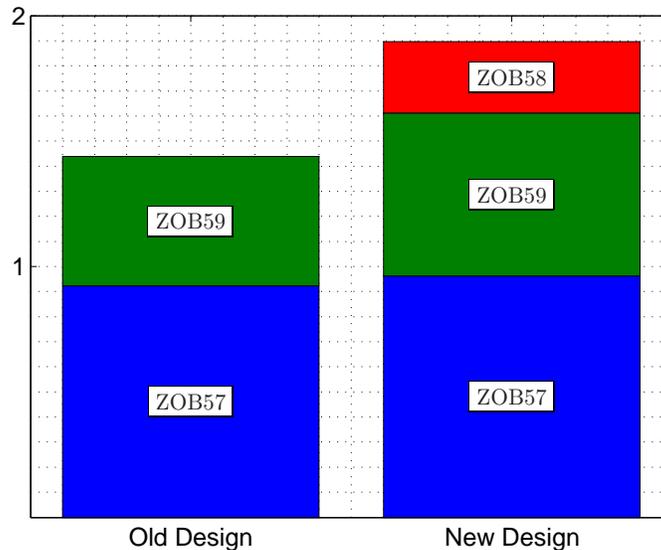


Figure 13. Average number of vertical sector boundary crossings for Area 5 High. Each bar's height is the average of the the approx. 2000 maximum values—one from each 15-minute interval.

D. Area 6

Area 6 consists primarily of high and super-high sectors, with the one low sector 61 becoming part of Area 5 in the new design. The high and super-high sectors are restratified with the purpose of better serving inbound flights to the Washington DC metropolitan area; MAP values remain unchanged.

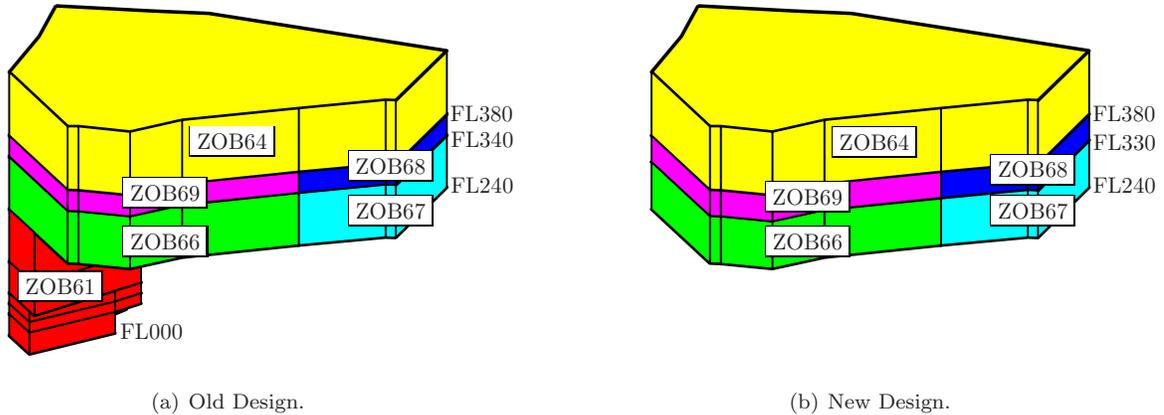


Figure 14. Area 6 Sectors.

The 15-minute peak sector loads for both designs are compared in Fig. 15, and the new design is shown to perform better in terms of balancing workload. Also, the median loading of sectors 66 and 67 is markedly reduced. The remaining workload factors do not show much contrast as this change was motivated primarily by balancing flight volume.

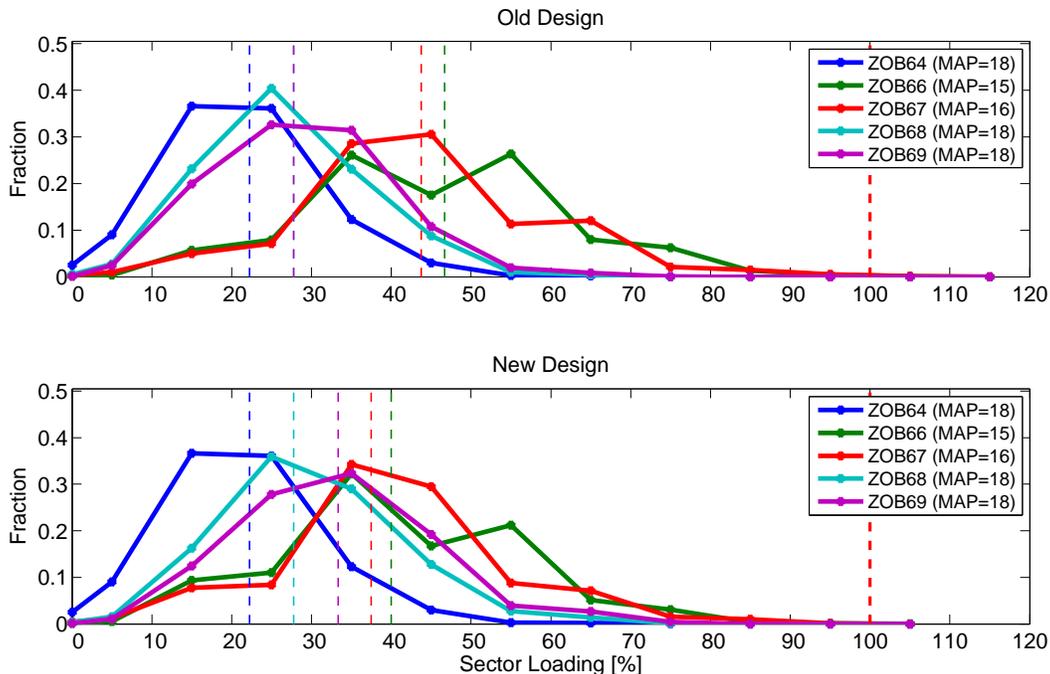


Figure 15. Sector Loading distribution for Area 6 High Sectors.

E. Area 8 Low

In Area 8, low sector 01 is combined with sector 02, and low sector 05 is combined with 06. Also, low sector 40 from Area 4 is transferred into Area 8. The low sectors in Area 8 are shown in Fig. 16.

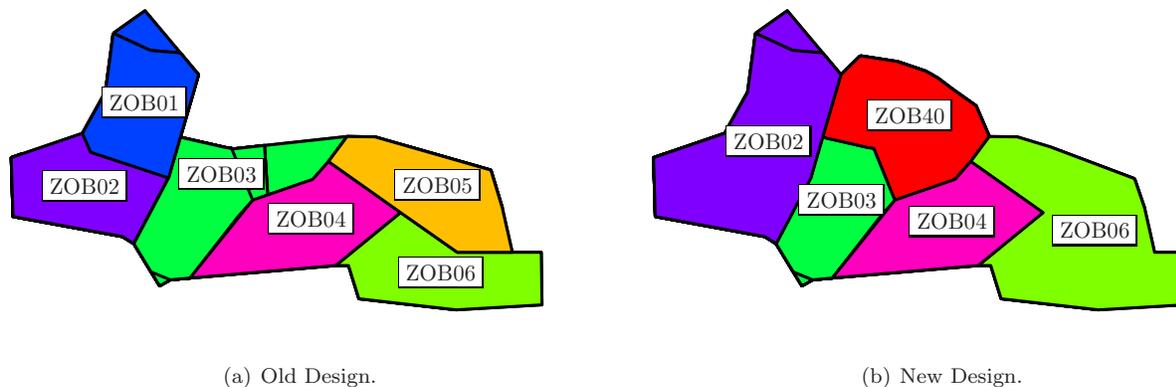


Figure 16. Area 8 Low Sectors FL230 and below.

From Fig. 17 it is apparent that the original Area 8 low sector design involved several small sectors that were under-utilized. In fact, several of the sectors display median loading values of only 15%. In the new design, the sector loading of the newly formed sectors 02 and 06, along with sector 40, is very closely matched with a median of 31%. As a whole, the low sectors are well balanced, yet despite containing fewer sectors, there are no over-MAP conditions.

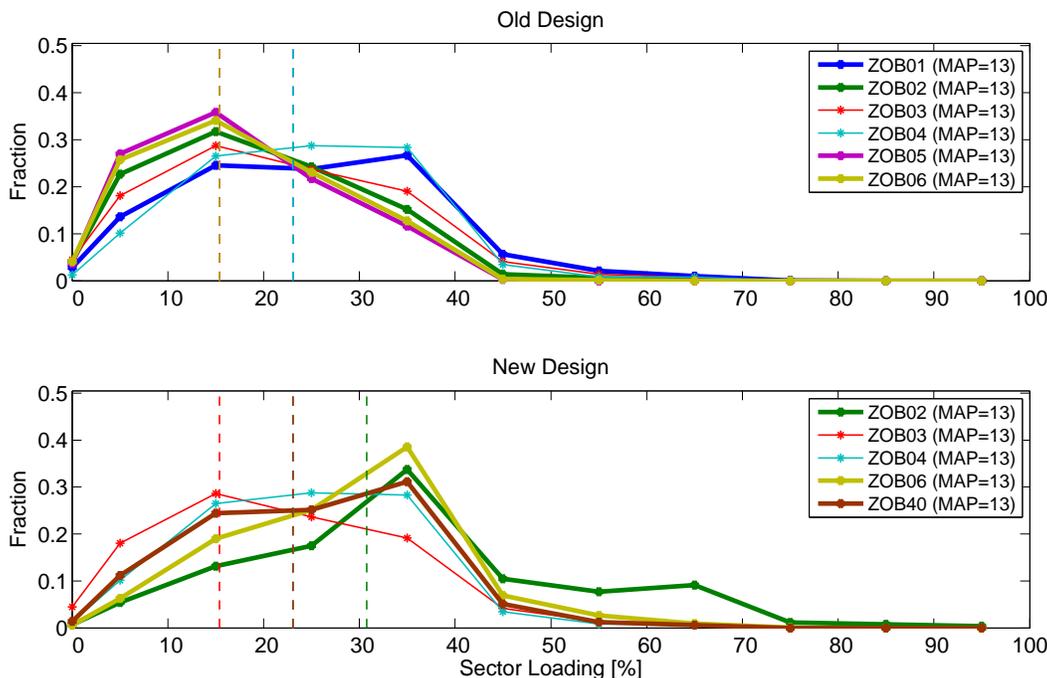


Figure 17. Sector Loading distribution for Area 8 Low Sectors.

As expected, the distributions of the other workload factors are shifted to the right for the new larger sectors 02 and 06. However, none of the factors increase substantially on a per-sector basis, despite the new sectors being roughly double the size of the old ones.

F. Peak Sector Loading Analysis

In an effort to see all the changes made to Cleveland Center airspace from a broader perspective, a metric called *Peak Sector Loading* is plotted together for all the low, high, and super-high sectors in the center. Here, “peak” sector loading is measured as the top 99-percentile value from all the 15-minute sector loading data collected for each sector. The remaining 1% of data are considered to be outliers. As an example, the sector loading data for sector 73 shown in Fig. 18 shows a peak sector loading value of 78.6%. The difference between peak sector loading and 100% is indicative of the sector loading margin relative to the sector capacity (MAP).

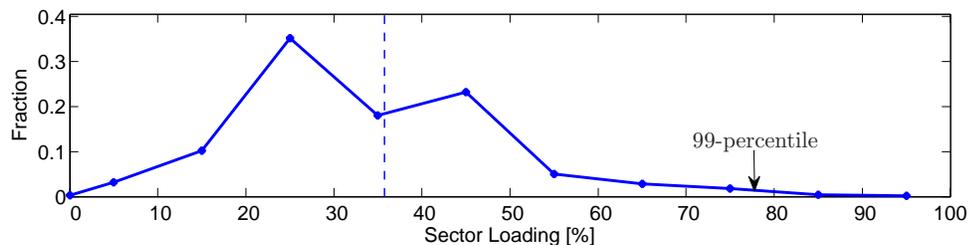


Figure 18. Sector Loading distribution for sector 73 showing the 99-percentile “peak” sector loading value of 78.6%.

Figure 19 shows a comparison of peak sector loading for all the low sectors in Cleveland Center. Here, the changes to Area 5 are quite obvious. Combining the five older sectors (50, 52, 53, 55, 61) into three new ones (50, 53, 55) does not result in critically high peak loading values. Also, within the old design, Area 8 sectors 02, 05, and 06 were among the lowest peak loaded sectors, whereas in the new design, most of Area 8, which now includes sector 40, shows a consistently low peak loading value. Sector 02 is the exception with a peak loading value of 85%. This is consistent with the distributions plot of Fig. 17 that shows sector 02 having the highest median value and a distribution farther to the right than the other Area 8 low sectors. The peak loading also significantly increased in areas 3 and 7 (sectors 31, 33, 70, 73) because the ceiling of these sectors was raised from FL230 to FL270. This was partially done to fill the airspace formerly occupied by high sector 74. This change may result in occasional over-loading of sector 73, which remains the highest loaded low sector with a peak load of 93%.

A similar analysis is done for the high sectors (FL240 - approx. FL320) in Fig. 20. Most of the changes done to the high sectors involve those in the eastern portion of the center, and most resulted in lower peak loading values. The most notable change involves sectors 36 and 37, which show significantly lower peak loading value as a result of their floors being raised from FL240 to FL280. Sector 57 is the only sector showing a minor increase in peak loading because its ceiling was raised from FL310 to FL320. Again, note

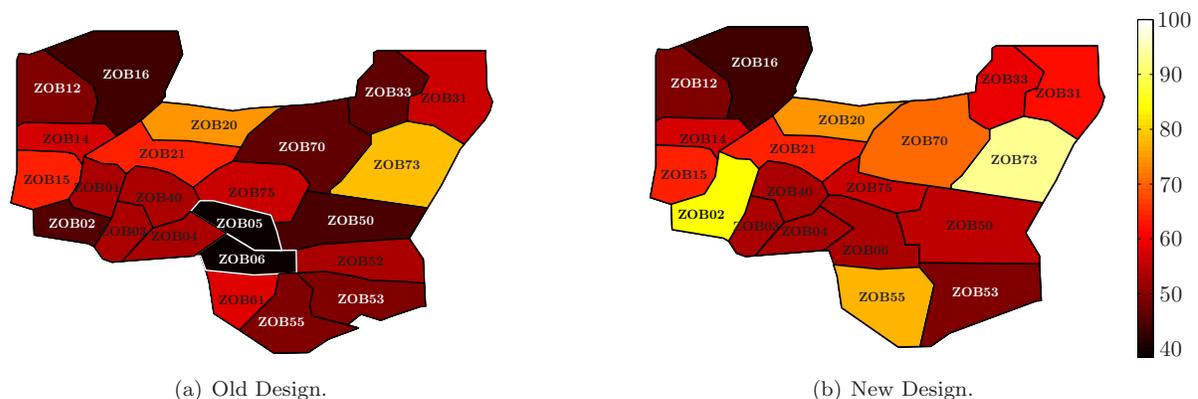


Figure 19. Peak sector loading of all Cleveland Center Low Sectors (FL230 and below).

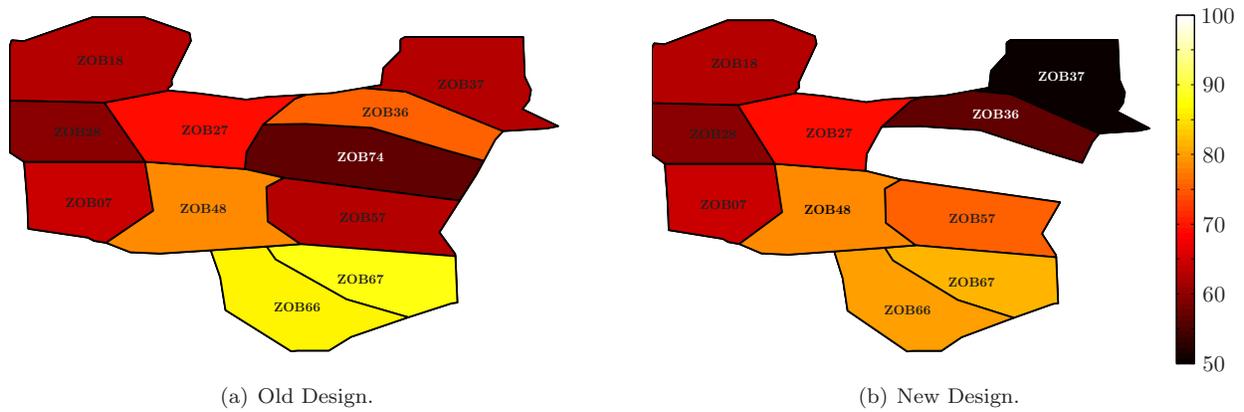


Figure 20. Peak sector loading of all Cleveland Center High Sectors (FL240 - approx. FL320).

that the vacant space in Fig. 20(b), which is the result of sector 74 being decommissioned, has been filled by raising the ceilings of low sectors 70 and 73, and lowering the floor of super-high sector 77.

Lastly, the peak loading results for the old and new super-high sectors (approx. FL320 and above) are shown in Fig. 21. The difference between the old and the new design is stark. The peak loading of the old sector 45 was easily the highest with a value of 100%. After being split into 45 and 46, the peak loads are greatly reduced. Similarly, sector 59, which showed the second highest peak loading of 89% is split in the new design, and the new sector 58 has a peak load of only 33%. Other than sector 77, which exhibits a slightly higher peak loading due to having its floor lowered from FL290 to FL280, the other sectors remain unchanged.

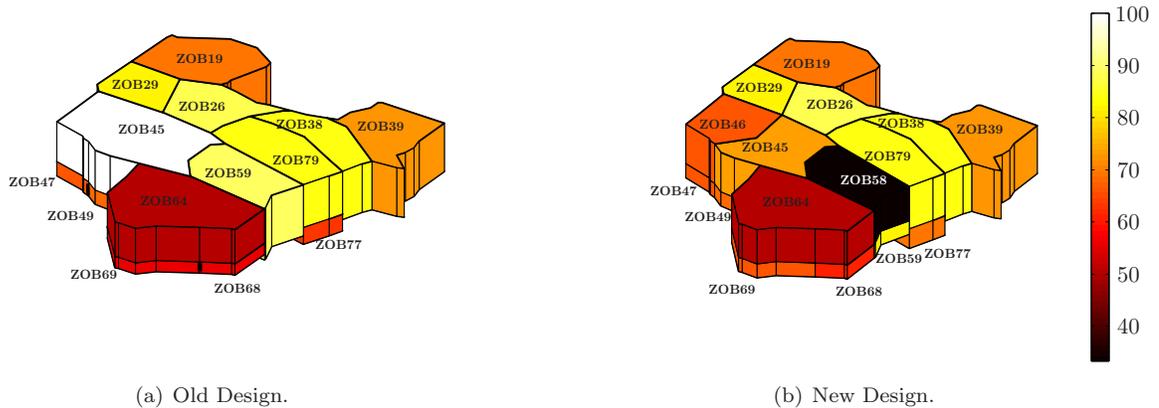


Figure 21. Peak sector loading of all Cleveland Center Super-high Sectors (approx. FL320 and above).

V. Conclusions

An analysis of the Cleveland Air Route Traffic Control Center is detailed in this paper. A sector loading metric is defined and used to compare the new design to the old one. In order to analyze some of the more nuanced contributors to controller workload, selected workload factors are used to highlight the differences between the two designs. Also, a measure of peak sector loading is used to evaluate the performance of the sector design changes on a center-wide low, high, and super-high sector basis.

The majority of the changes address imbalances among sectors that are either under- or over-loaded. Changes like those in areas 5 and 8, where multiple sectors are combined to reduce under-utilization, demonstrate a predictable increase in loading as well as other workload factors. However, in none of these situations does the data suggest that the new sectors would be over-loaded or unmanageable with current-day traffic patterns. Nevertheless, the changes made to sectors 02 and 73 resulted in a significant increase in loading,

which may result in future traffic congestion in those regions. Conversely, changes made to sectors 45 and 59 resulted in a welcomed reduction in traffic volume on a per-sector basis, as well as a better balance of workload within the area of specialization.

Acknowledgments

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