2013 Aviation Technology, Integration, and Operations Conference
August 12-14, 2013, Los Angeles, CA
AIAA 2013-4337

Impact of Cleveland Center Jet Route Changes on Airspace Metrics

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Major jet routes within the Cleveland Air Route Traffic Control Center are being altered. The new routes (known as Q-routes) will match the corresponding new routes in New York Air Route Traffic Control Center, which better serve traffic into and out of the major New York Metroplex airports. Also, a new design for the high and super-high sectors in Cleveland Center has been proposed in order to better accommodate the new route structure. This paper presents an analysis of the new routes and new sectors that is conducted using simulated flight tracks based on historical filed flight plans. The performance of three scenarios is measured: a baseline scenario simulating the existing flight routes in the existing sectors, a scenario simulating the new routes flying through the existing sectors, and a scenario using the new routes flying in the new proposed sectors. A metric for evaluating the performance difference between the scenarios among all sectors and factors is developed. Several controller workload factors are measured in the simulations, but two factors, sector loading and flights near horizontal sector boundaries, show the greatest difference between the scenarios. The difference metric is used to identify the sectors in the existing design that are most affected by the route changes and a subset of them are discussed herein. Then, the performance of the proposed sector design is evaluated against that of the existing sectors and routes, and again, a selection of the sectors showing the greatest difference is presented. Most of the sectors in the proposed sector design are found to better accommodate the new routes than the existing sectors, but a small number of them exhibit undesirable loading and/or boundary crossings that may indicate a modification of those sectors' design.

I. Introduction

In 2011, Cleveland Air Route Control Center (ZOB) redesigned significant portions of its airspace to address traffic imbalances among sectors. 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, and an analysis of these changes was previously performed and documented in Ref. 1.

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In the meantime, starting in December 2007 significant operational changes within the neighboring New York Air Route Control Center (ZNY) were under way. Included in these changes are the re-routing of arrivals and departures to and from airports in the New York and Philadelphia metropolitan areas. This airspace and procedural redesign is motivated in part by the fact that one third of all US flights are directly affected by delays in this region.[2] The changes to routes and procedures are expected to reduce the number of delays locally and nationally by expediting arrivals and departures at airports in those areas. As of May 2012, two of the four stages of redesign have been implemented in ZNY.[2]

Because a significant portion of traffic within Cleveland Center consists of en route flights to and from New York Center, a new set of jet routes has been proposed for this traffic that connect with the new routes in New York Center. These routes (known as Q-routes) are being phased in to replace the existing routes (known as J-routes).

With so much of the traffic in Cleveland Center (particularly in the eastern portion of the center) being rerouted, it is natural to expect that controller workload will be affected in those sectors where the reroutes have occurred. The existing sectors have been designed with the existing route structure in mind, and the new routes may alter traffic volume distribution that increases workload in some sectors while decreasing it in others, resulting in an undesirable imbalance in sector loads within an area of specialization (AoS). Furthermore, if new routes are located closer to sector boundaries, it is natural to assume that controller workload of the sectors that share those boundaries will increase due to an increase in point-outs and handoffs of aircraft on routes that encroach on those boundaries.

With this in mind, a team of Cleveland Center staff and controllers proposed a new candidate design for the high and super-high sectors with most of the changes concentrated in areas where the majority of route changes exist. Thus, this paper compares three simulation scenarios: a baseline scenario consisting of the existing routes and existing sectors, a scenario consisting of the new routes with the existing sectors, and a scenario with the new routes and the new sectors. The first two scenarios are compared to determine the extent and location of the impact the new route structure has on the sector performance. Then, the third scenario is compared to the first in order to evaluate the overall effect of the route and proposed sector redesigns.

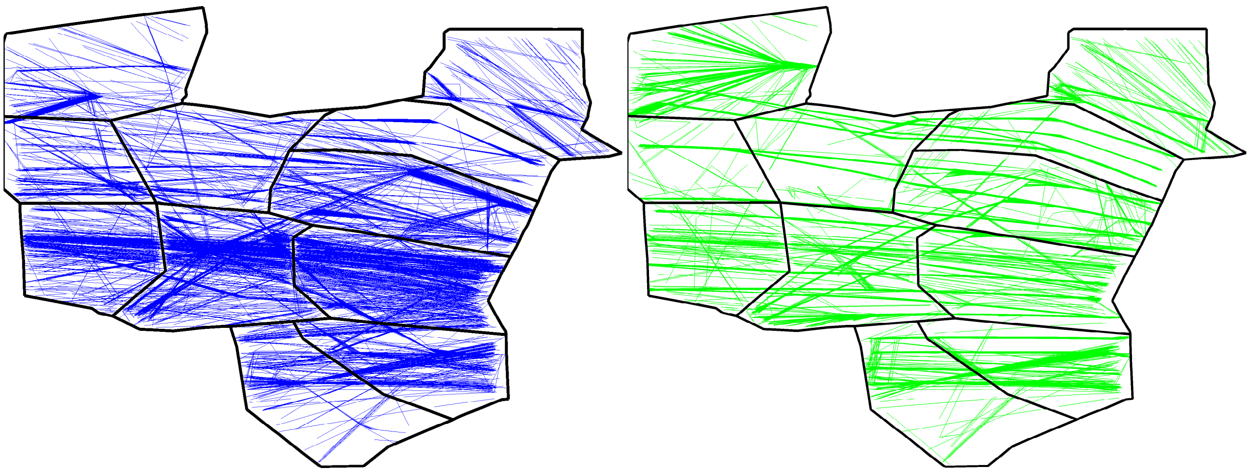
This paper is organized as follows: Section II highlights the major route changes proposed for Cleveland Center. The new sector design, which is proposed as a response to the new routes, is also presented. Section III details the method used for the airspace analysis. This includes a description of the traffic data used, as well as the metrics used to evaluate the performance of the three scenarios. Section IV begins with a comparison of the second scenario (new routes with existing sectors) to the baseline scenario, then proceeds to an analysis of how the new routes perform with the new sectors. Section V presents concluding remarks on the analysis and results.

II. Cleveland Center Route and Sector Changes

A. Route Changes

As stated, several of the routes through Cleveland Center were redesigned to connect with the new routes in New York Center, which have been changed to improve efficiency, and reduce delay of the nation's most congested airspace. The new routes primarily affect arrivals and departures in and out of the major airports of the New York Metroplex (JFK, EWR, LGA, PHL, TEB), with some departures from Toronto (YYZ) affected as well. Examples of simulated flight data under the existing and new flight routes are shown in Fig. 1 where only flights into and out of these airports are shown from several 16-hour segments of selected days. The volume of the traffic has not changed, but note how the flights in the new route design are more distinctly and precisely segregated into lanes according to their origin and destination airports rather than being concentrated in the center of the region.

The existing super-high sectors are shown in Fig. 1, and from this snapshot of traffic it is clear how the distribution of traffic is drastically changed within the sectors. Not only has the volume of flights within individual sectors been altered, the location of major flows has also changed with several east-west routes in close proximity to horizontal sector boundaries. It is clear from a subjective perspective that these route changes pose potentially negative effects on existing sector workload.

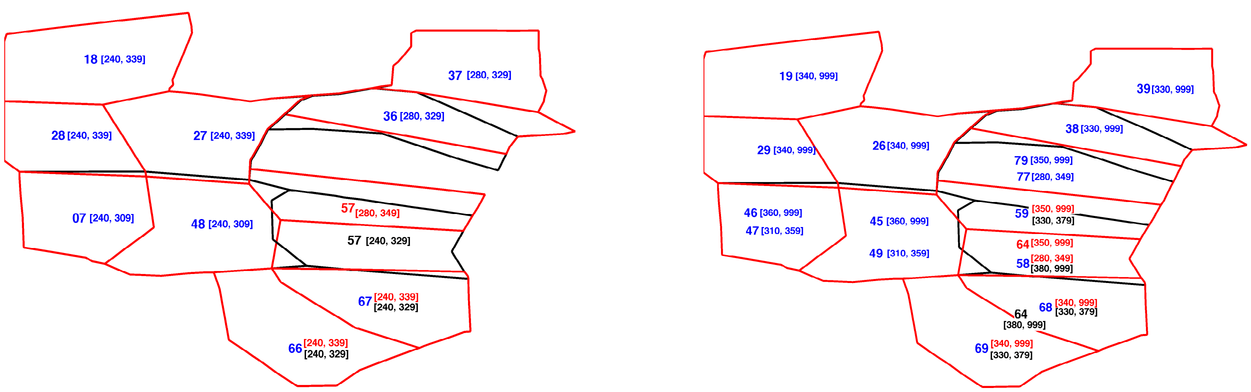


(a) Existing Routes. (b) New Routes.

Figure 1: Route changes for en route New York Metroplex flights. Existing super-high sectors shown.

B. Sector Changes

In order to address the problems of controlling the new route structure within the old sector design, a team at Cleveland Center proposed a new design for the high and super-high sectors that might better accommodate the new routes. Fig. 2 shows the new sector design in red overlaid on the existing sector design in black. Sectors are classified by their existing status as high or super-high sectors (ultra-high sectors are included with super-highs), but this distinction is not always consistent according to altitude, and is used herein primarily to better organize and visualize the analysis. Low sectors are not included in this analysis since the rerouting involves en route aircraft at flight level (FL) 240 and above. However, this currently-proposed sector design change results in some gaps and mismatches with the existing low sectors. At the time of this analysis a new low sector design had not been completed.



(a) High Sectors. (b) Super-high Sectors.

Figure 2: Existing (black) and proposed (red) sector designs. Note floor and ceiling changes for some sectors identified by black and red colored font.

Note that most of the changes are in the eastern portion of the center where the majority of route changes occur. Note, also, the extensive redesign of sectors 58, 59, and 64. Sector 64, which currently sits above sectors 68 and 69, is proposed to be relocated above sector 59, while sector 58's ceiling has been lowered to accommodate the change. It is emphasized that this sector design has only been proposed, and at the time of this analysis, has not been finalized. The next section discusses the approach used to evaluate the effect the new routes has on the existing sector design and the performance of this proposed design with the new routes in place.

III. Approach

The method used to evaluate Cleveland Center's design changes involves using the performance of the existing airspace under the existing route structure as a baseline (referred herein as Scenario A). First, the performance of the new route structure under the existing sector design (Scenario B) is compared to Scenario A to identify those sectors with the greatest impact due to the new routes. Then, the performance of the new routes under the new versions of those sectors (Scenario C) is evaluated. Finally, a comparison between Scenarios A and C is made to identify those sectors showing the greatest overall impact of the new route structure and the new sector design.

For all three scenarios, the Future ATM Concepts Evaluation Tool (FACET)[3] is used to record the number of aircraft in each sector (also referred to as *sector count*), as well as several other workload factors for each sector. Since the new routes have yet to be flown, simulated flight tracks are used in the three scenarios. Simulations use historical filed flight plans (as recorded prior to departure), but en route trajectory specifics such as top of descent/ascent are based on prescribed database parameters. En route flight plan updates and controller traffic management are absent, and any existing letters of agreement for local traffic procedures are not enforced. While such simulations lack the fidelity that historical data tracks would provide, this evaluation involves a comparison between the three scenarios, and the data presented herein is not meant to be an accurate absolute measure of real world operations. For Scenarios B and C, which simulate the new routes, an algorithm was introduced in the FACET code that reroutes flights meeting specific origin/destination criteria along the new Q-route waypoints within Cleveland Center.

The flight traffic data is selected from 30 days between June and October of 2012. For each day, only traffic between 6 and 10 pm EDT is used, which is when most of the traffic occurs. The selected days are all among the highest traffic volume days (as recorded by Cleveland Center) and are judged to be relatively free of major weather impacts throughout Cleveland Center and nearby airspace, such as that near Chicago, and the major airports along the northern east coast of the US. Weather-related factors are not included in this analysis.

A. Sector Loading

The raw traffic data produced by a FACET simulation consists of several workload factors recorded every minute over a 16-hour period for the selected 30 days, resulting in nearly 29,000 data points per workload factor for every sector. The first factor used in this analysis is called *sector loading*. This factor is derived from the sector count factor and the assumed capacity of each sector for which the published (if available) or estimated Monitor Alert Parameter (MAP) is used.[4] The MAP values of the proposed new sectors are assumed herein to remain unchanged, since, at the time of this analysis, the new routes and sectors had yet to be implemented. Sector loading is found by dividing its sector count by its MAP value. Thus, a value of 1 (or 100%) indicates that the sector is at full capacity. The maximum value of the sector count values during every fixed 15-minute interval is determined, reducing 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 30 selected days.

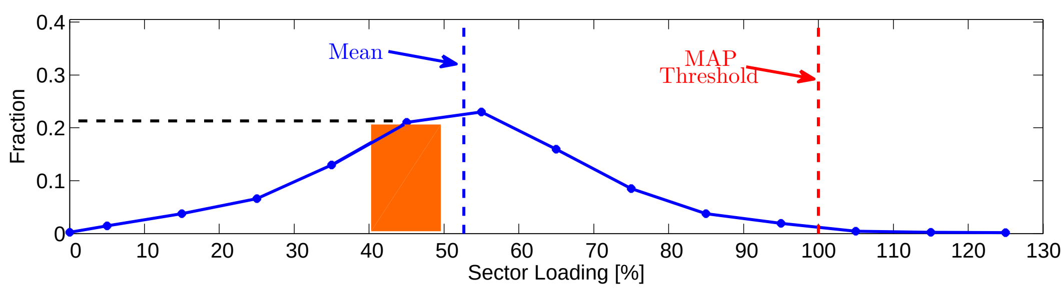


Figure 3: Example sector loading distribution.

A typical sector loading distribution plot is shown in Fig. 3. Note that the mean value of this sector is shown as is the MAP threshold line at 100%. To illustrate how this plot can be read, it can be seen, for example, that in roughly 20% of the 2000 data points, this sector has a 15-minute max sector loading of between 40 - 50% as indicated by the orange bar . Also, for some small but not insignificant part of the time, the sector is over-loaded because it experiences sector counts exceeding its MAP value.

By comparing the sector loading distributions between the three scenarios, quantitative insight can be gained into how the new route structure and proposed sector design affects Cleveland's airspace. For example, sector load distributions that have values beyond 100% loading and/or mean lines to the right of about 45% indicate the sector may be over-loaded. Likewise, load distributions with mean lines to the left of about 25% suggest the sector might be under-loaded. Also, when sector loading distributions are plotted together from multiple sectors within a region or an AoS, similar sector loading distributions are preferred because they indicate that workload is well balanced among those sectors.

B. Additional Workload Factors

As mentioned, FACET also records additional flight factors at every 60-second interval for every sector. Some of the factors can be used directly as sector workload factors, while others can be combined to calculate new ones. These factors are:

1. Predicted conflicts
2. Transitioning flights
   (a) Total number of flights climbing faster than 300 ft/min.
   (b) Total number of flights descending faster than 300 ft/min.
3. Flights near horizontal sector boundaries
4. Vertical sector boundary crossings

1. Predicted Conflicts

Predicted conflicts are estimated by simulating every flight forward in time along its filed flight plan 3D trajectory in 15-second intervals for 15 minutes into the future. A predicted conflict is counted for the sector if any pair of these flight projections originating from the sector results in the aircraft flying within 8 nmi horizontally and 1000 feet vertically of each other.

2. Transitioning Flights

At every minute in the simulation, FACET records the number of flights climbing faster than 300 ft/min, t_c, and the number of flights descending faster than 300 ft/min t_d. Rather than evaluate these data separately, two workload factors were calculated from them: the total of climbing and descending aircraft at every minute $t_{cd} = t_c + t_d$, and a measure of the ratio of simultaneously climbing and descending sets of flights $t_{simultrns}$, which is calculated as follows:

$$t_{simultrns} = \begin{cases} 0, & t_c = t_d = 0 \\ \frac{\min(t_c, t_d)}{\max(t_c, t_d)} \cdot t_{cd}, & \text{otherwise.} \end{cases}$$

This workload factor is upper-bounded by t_{cd}. The motivation of this workload factor can be illustrated by example. Given a scenario where a sector has six aircraft climbing and/or descending faster than 300 ft/min ($t_{cd} = 6$), it is reasonable to assume that if all six were descending aircraft ($t_{simultrns} = 0$), this would require less workload than if three were climbing and three were descending ($t_{simultrns} = 6$).

3. Flights Near Horizontal Sector Boundaries

Figure 4 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 was used as a simple proxy for handoffs 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.

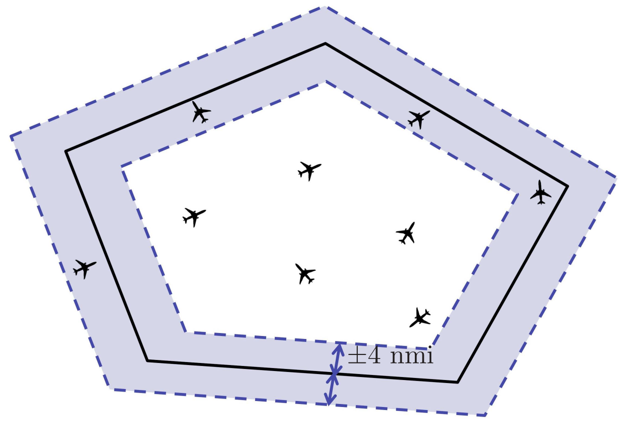


Figure 4: Flights near horizontal sector boundaries.

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.

The above factors are evaluated in the same way as the sector loading metric discussed above. Distributions of max 15-minute values are found and compared between the three scenarios. While over fifty factors have been suggested in the literature (see Ref. 5 for example), sector counts/loading, short term conflicts, transitioning flights, and handoffs/point-outs were identified by subject matter experts (SMEs) as being among the most critical. The last two factors, flights near horizontal sector boundaries, and vertical sector boundary crossings, are used as a proxy approximation for handoffs/point-outs. As will be discussed below, only two of these factors, sector loading and flights near horizontal sector boundaries, were shown to be significantly affected by the Cleveland Center route changes.

C. Scenario Workload Factor Difference

From the simulations, each of the six workload factors discussed above can be compared and contrasted between the three scenarios in several ways. The difference between the means and medians of the factors, for example, is a reasonable method. However, the shape of the factor distributions may change greatly with little effect on median and mean, so differences between those values will miss such changes. Also, the range of the recorded factors can vary greatly between sectors, scenarios and the factors themselves. Therefore, it it desired to derive a common method of measuring the difference between the workload factor distributions from one scenario to another.

Noting that the sum of the individual distribution values (area under the curve) of the distribution plots (see Fig. 3) must equal one, it is proposed that a good method for measuring the change in a workload factor from one scenario to another is to compute the sum of the absolute value of the difference of the distribution entries along the range of the factor's values. The difference in sector loading between Scenarios A and B, for instance, is computed as:

$$SL_{A-B} = \sum_{i}^{n} |sl_i^A - sl_i^B|. \tag{1}$$

Here, i is the index of distribution values along the range of the workload factor (up to n values), and sl_i^A is the fraction of occurrences of sector loading values of the i^{th} entry of the distribution plot for Scenario A. For example, referring to Fig. 3, $n = 14$ because it has a total of 14 distribution data points, and the orange bar (the sixth data point) shows that $sl_6^A = 0.22$. Since $\sum_i^n f_i = 1$ for any workload factor f, this difference metric is in the range of $[0, 2]$.

In the following section, this metric is used to identify the factors, and then the sectors, for which the new routes would have the greatest effect on the existing sectors. It is used again later in the analysis to identify those sectors with the greatest performance change with the new route and sector design.

IV. Results

This analysis is separated into two parts. The first part identifies the workload factors and the sectors most affected by the new routes by comparing Scenario B to Scenario A. Once identified, the performance of the new design with the new routes (Scenario C) is investigated. The second part of the analysis involves identifying those sectors most affected overall by both the new design and new routes by comparing Scenario C to Scenario A.

A. Existing Sectors Affected by New Routes

Here, the performance of the new routes flying through the existing sectors (Scenario B) is compared to the baseline of existing routes flying in existing sectors (Scenario A). The appropriate workload factors will indicate the sectors in greatest need of redesign to better accommodate the new routes. The difference metric developed above is used to identify (1) those *workload factors* most affected by the route changes, and (2) those *sectors* most affected in terms of those workload factors. Once identified, a deeper analysis is presented of how those sectors were affected (positively or negatively) by the new routes, and then how their new design accommodates the new routes (Scenario C).

Of all the workload factors discussed above, and subjectively considering the route changes depicted in Fig. 1, it is reasonable to assume that the sector loading (*SL* for short) workload factor might exhibit the greatest difference between Scenarios A and B. Note that the total traffic volume through the entire center will remain unchanged since the same set of historical flights are simulated in all three scenarios. However, the spatial and temporal distribution of those flights will differ between Scenarios A and B. It is clear from Fig. 1 that fewer flights are concentrated in the middle of Cleveland Center, with a greater number of flights being spread northward and southward, and segregated into distinct lanes. Furthermore, the appearance of new traffic lanes in the new route design suggests that there could be an increase in the number of flights near horizontal sector boundaries (*HB* for short). Thus, from a qualitative perspective, one would expect that *SL* and *HB* would show the greatest contrast between Scenarios A and B.

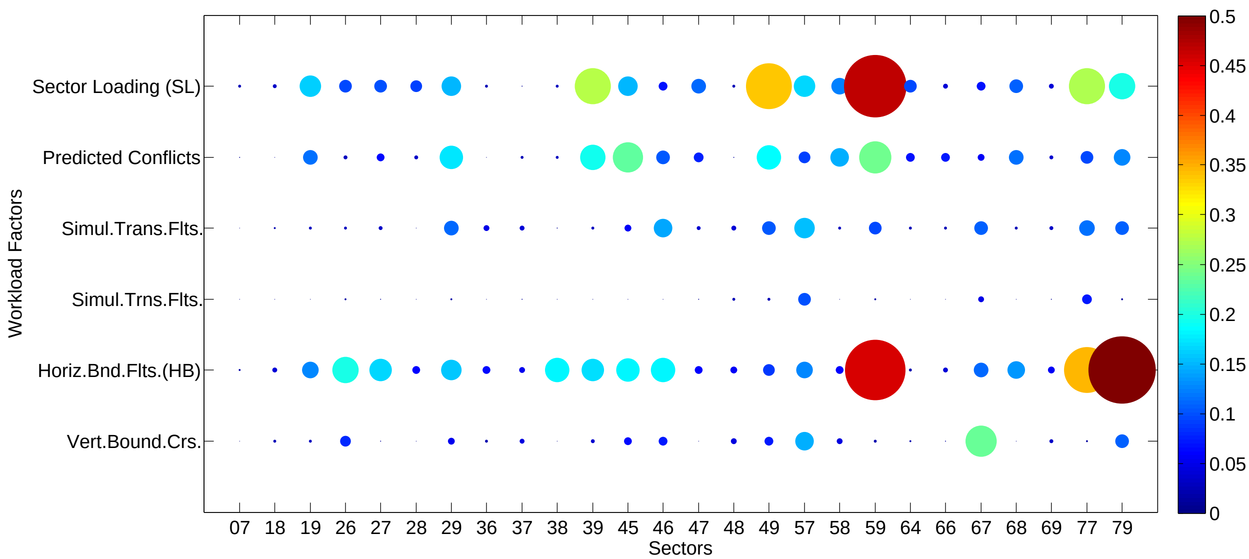


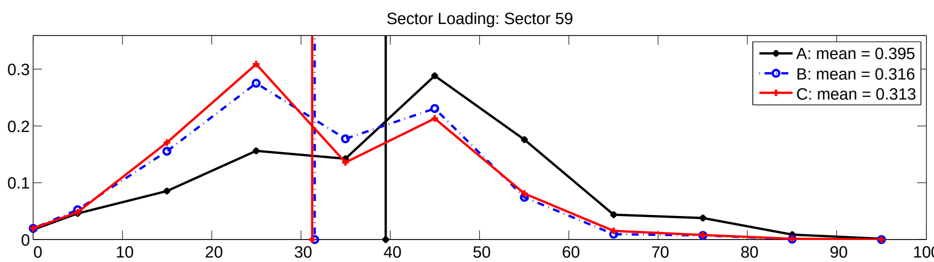
Figure 5: Distribution difference calculated for all sectors and workload factors between Scenarios A and B.

The distribution difference formula of (1) is applied to all six workload factors and all high and super-high sectors. Fig. 5 shows the magnitudes of the results (indicated by circle size and color), and confirms the hypothesis that sector loading and flights near horizontal sector boundaries are the two workload factors affected the most by the route changes.

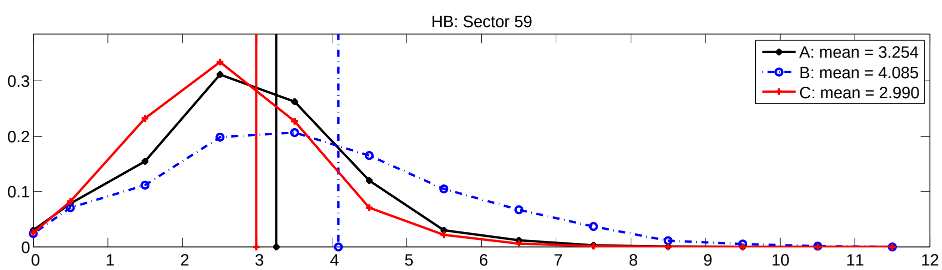
A comprehensive analysis on all the sectors and all workload factors was performed, however Fig. 5 shows that several super-high sectors stand out as being significantly affected by the new route design in terms of the SL and HB. The analysis for a selection of these sectors is presented in the following sections, and though all workload factors were analyzed in this work, since the SL and HB factors showed the greatest distinction between scenarios, the discussion will focus on them.

1. *Sector 59*

Fig. 5 shows that Sector 59 is greatly affected by the new route design in terms of SL and HB. A look at the 15-minute peak SL and HB workload distributions in Fig. 6 shows how drastically traffic changed in this sector. Comparing the baseline Scenario A curves (shown in black) to the Scenario B curves (shown in dashed blue) it is clear that the new routes substantially reduce traffic loads in this sector, while substantially increasing the number of flights near horizontal sector boundaries. This is obvious when the flight tracks of New York Metroplex arrivals and departure are compared in Fig. 7. Note that while there is less traffic in Fig. 7b, there is a route on the northern boundary that remains within ±4-nmi of the boundary for the majority of the sector's length. This is not an ideal arrangement, so it is reasonable to expect that this boundary should be moved away from this route and made to be parallel to the routes in that region.

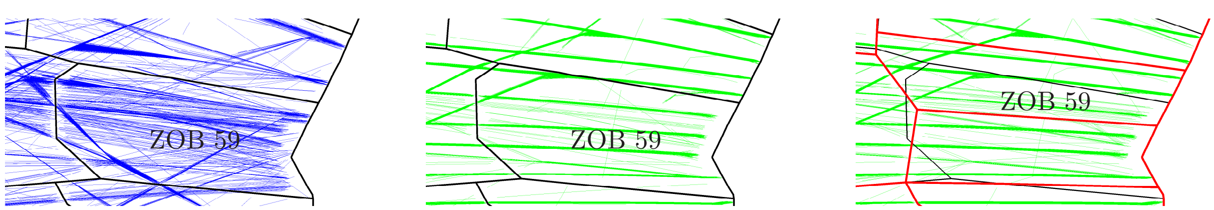


(a) 15-minute peak sector loading distributions for Sector 59.



(b) 15-minute peak flights near horizontal sector boundaries distributions for Sector 59.

Figure 6: Workload distributions for Scenarios A, B, and C for Sector 59.



(a) Scenario A: Existing Sector 59 with existing routes. FL = 330-379.

(b) Scenario B: Existing Sector 59 with new routes. FL = 330-379.

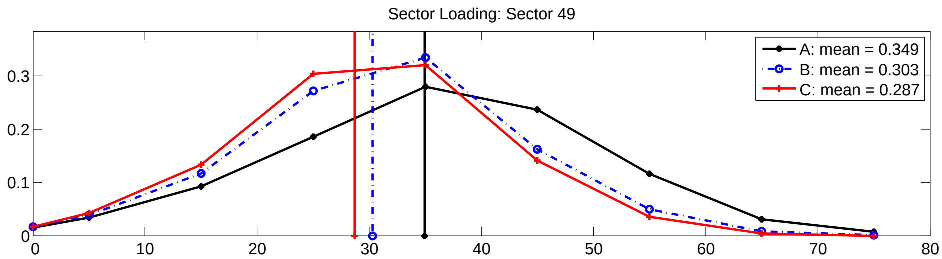
(c) Scenario C: Proposed Sector 59 with new routes. FL = 350-999.

Figure 7: Existing (black) and proposed (red) Sector 59 with existing (blue) and new (green) routes.

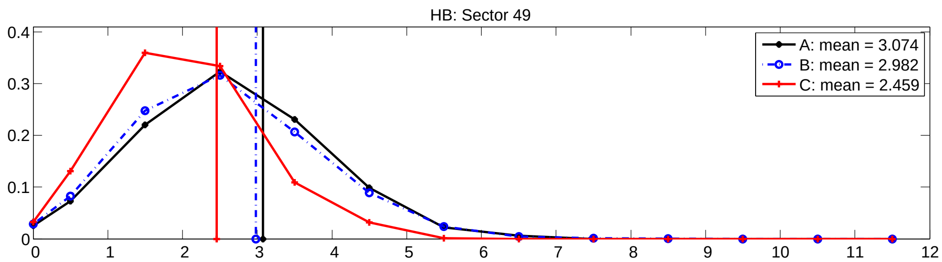
Fig. 7c shows the proposed design for Sector 59. It has been moved to the north, and its floor and ceiling altitudes have been changed to FL 350 and above. Note that the northern and southern boundaries are also parallel to the surrounding flows, to keep a consistent distance between routes and boundaries. Fig. 6 shows that the new design with the new routes (depicted in solid red) results in a mean SL and HB that is lower than even in Scenario A. Finally, it is worth noting that Sector 59 also benefited from the greatest reduction in predicted conflicts. It is interesting to note that Sector 59 is one of most altered sectors compared to its original design.

2. Sector 49

Sector 49 displayed the second greatest difference in sector loading with the new routes. Fig. 8 shows that this sector benefited from the new routes in terms of reducing its SL as well as HB, though the latter factor was probably reduced primarily due to a reduction in overall sector volume. As with Sector 59, the new routes pose an issue on the northern boundary with an east-west route skirting that edge. This is addressed in the new design by moving the boundary to the south and aligning it with the major flows. See Figs. 9b and 9c. The result is a drastic drop in HB as well as in SL, as shown by the red distribution lines in Fig. 8.

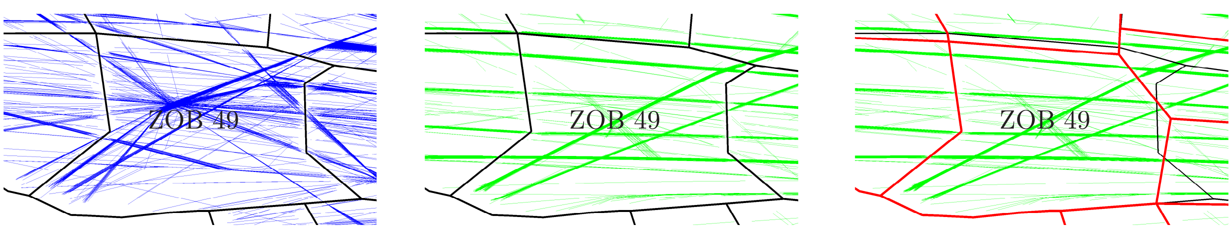


(a) 15-minute peak sector loading distributions for Sector 49.



(b) 15-minute peak flights near horizontal sector boundaries distributions for Sector 49.

Figure 8: Workload distributions for Scenarios A, B, and C for Sector 49.



(a) Scenario A: Existing Sector 49 with existing routes. FL = 310-359.

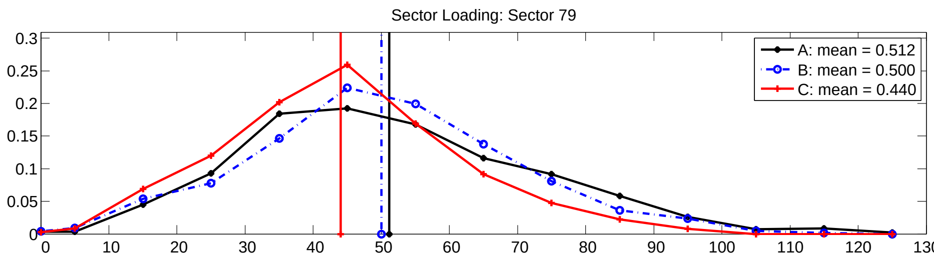
(b) Scenario B: Existing Sector 49 with new routes. FL = 310-359.

(c) Scenario C: Proposed Sector 49 with new routes. FL = 310-359.

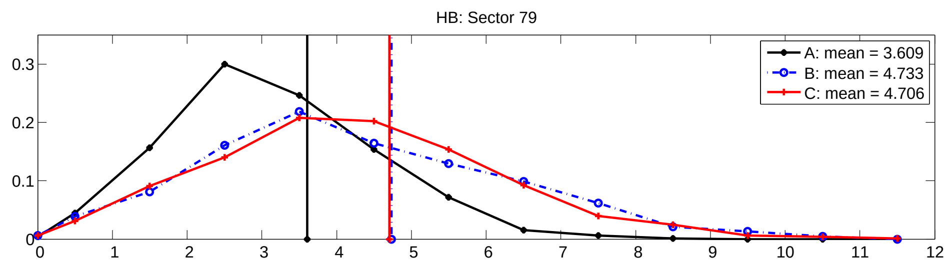
Figure 9: Existing (black) and proposed (red) Sector 49 with existing (blue) and new (green) routes.

3. Sector 79

In terms of the HB workload factor, Sector 79 experiences the greatest change with the new routes. This is clearly shown in Fig. 10b, where the distribution (and mean) are shifted significantly to the right. The reason for the higher occurrence of flights near horizontal sector boundaries can be seen in Fig. 11b where the southern boundary is crossed at a very shallow angle by the new PHL arrival route. This issue is addressed in the new sector design shown in Fig. 11c, however; this design introduces a new problem with the northern boundary, which is crossed twice by a new route of Chicago-bound flights. Thus, HB remains as high as prior to the sector redesign as shown in Fig. 10b. One benefit of the new design is a reduction in sector loading - especially in over-MAP loads which can be observed on the tail of the SL distribution of Fig. 10a. It should be mentioned that Sector 77 (third highest in HB_{A-B} in Fig. 5), which is the high sector sitting directly below 79 with the same footprint, has nearly identical performance results between all three scenarios.



(a) 15-minute peak sector loading distributions for Sector 79.



(b) 15-minute peak flights near horizontal sector boundaries distributions for Sector 79.

Figure 10: Workload distributions for Scenarios A, B, and C for Sector 79.

(a) Scenario A: Existing Sector 79 with existing routes. FL = 350-999.

(b) Scenario B: Existing Sector 79 with new routes. FL = 350-999.

(c) Scenario C: Proposed Sector 79 with new routes. FL = 350-999.

Figure 11: Existing (black) and proposed (red) Sector 79 with existing (blue) and new (green) routes.

B. Sectors Affected by New Routes and New Design

In this part of the analysis, the sectors affected the most overall by the new routes and the new design are identified. Again, the difference metrics for the SL and HB factors are used, but this time they are calculated between the existing routes and sectors (Scenario A) and the new routes with proposed sectors (Scenario C). Several sectors once again stand out as having significant changes in performance, and some of the sectors that were not identified in the previous subsection of having been greatly affected by the new routes are shown here among the most affected sectors overall.

The top two sectors as shown in Fig. 12 with the greatest difference in sector loading are sectors 57 and 59. Sector 59 was analyzed in the previous section, and sectors 57, 58, and 59 share the same footprint (differing only by altitude) in both the existing and the proposed designs. Therefore, it is not surprising that both the SL and HB factors trend similarly downward in Sector 57 from Scenario A to Scenario C as Sector 59 does.

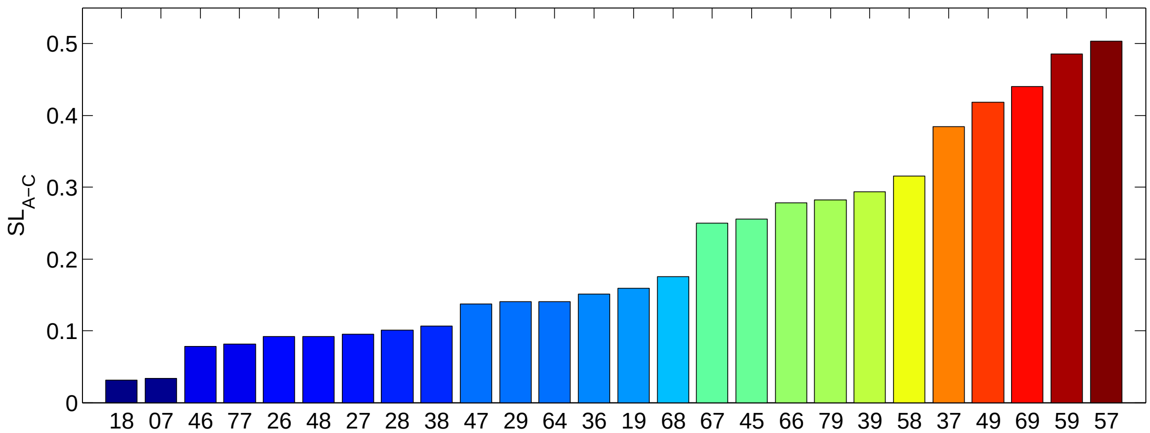


Figure 12: Sector loading distribution difference SL_{A-C} for Scenarios A and C.

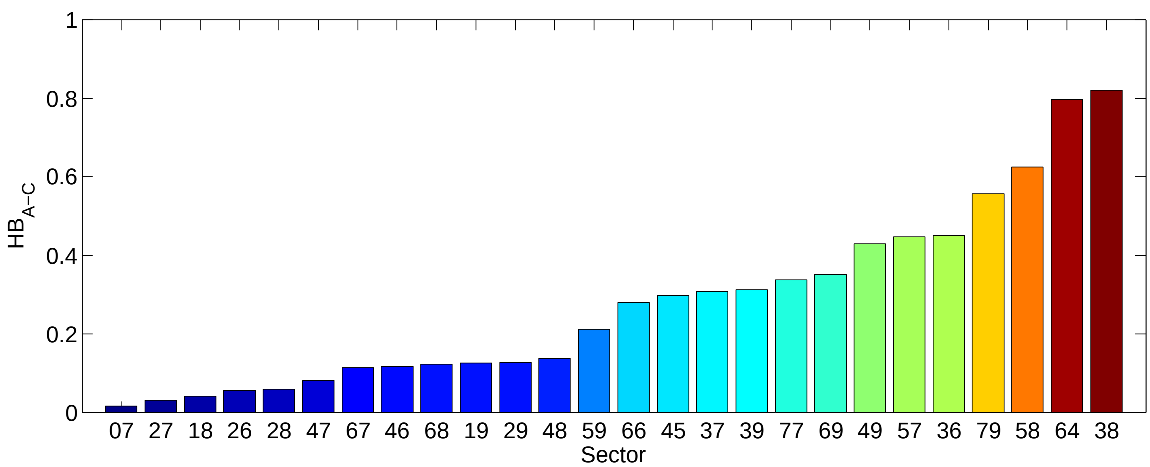
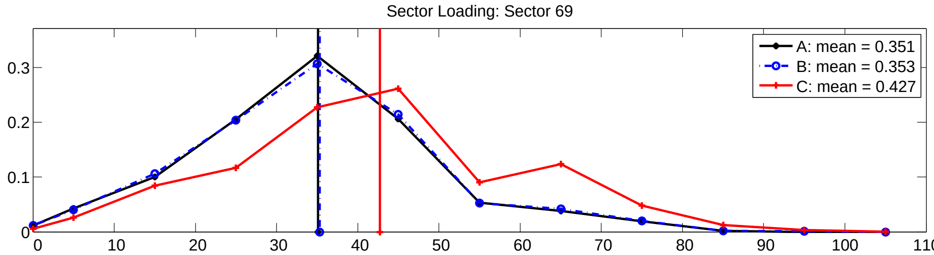


Figure 13: Number of flights near horizontal sector boundaries distribution difference HB_{A-C} for Scenarios A and C.

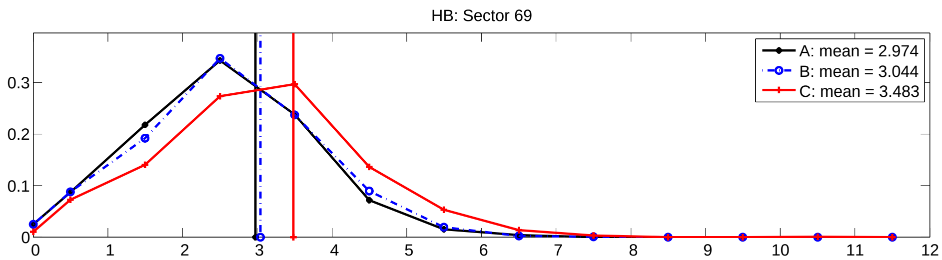
1. Sector 69

Sector 69 shows up third from the top in Fig. 12, and it is the only sector in the top tier of this plot that exhibits an increase in sector loading mean, as shown in Fig. 14a. With barely any change from Scenario A to Scenario B in both these factors, the increase observed in Scenario C comes from the increase in altitude range of the sector. Formerly spanning the FL 330-379 strata, the proposed new design spans FL 340 and above, filling half the volume of what used to be Sector 64 (moved to the north in the proposed design).

An increase in sector loading is not always a bad thing if the sector was formerly underutilized. Previous work with SMEs indicated that an underutilized sector can lead to inattention.[6] However, the SL distribution of Scenario C exhibits a significantly thick tail in the 55-85% range, suggesting that this proposed sector design may be lead to excessive volume and number of over-MAP conditions.

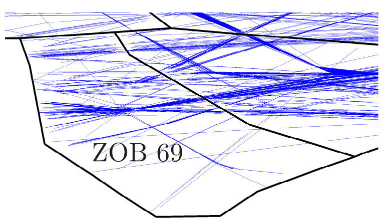


(a) 15-minute peak sector loading distributions for Sector 69.

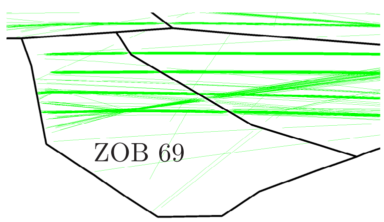


(b) 15-minute peak flights near horizontal sector boundaries distributions for Sector 69.

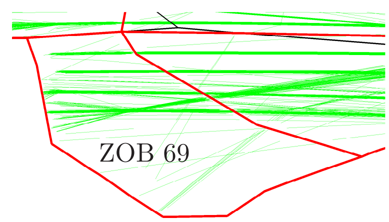
Figure 14: Workload distributions for Scenarios A, B, and C for Sector 69.



(a) Scenario A: Existing Sector 69 with existing routes. FL = 330-379.



(b) Scenario B: Existing Sector 69 with new routes. FL = 330-379.



(c) Scenario C: Proposed Sector 69 with new routes. FL = 340-999.

Figure 15: Existing (black) and proposed (red) Sector 69 with existing (blue) and new (green) routes.

2. Sector 38

From the HB difference plot shown in Fig. 13, Sector 38 is shown to have the greatest change between Scenarios A and C. The change in sector loading is minor. Looking at the HB distribution comparison in Fig. 16 reveals a major increase in this metric, and Fig. 17c reveals why. Sector 38 shares its southern boundary with Sectors 77 and 79, and this boundary (as discussed in the Sector 79 section above) is crossed twice by a major flow. In fact, the mean of this metric is the highest of all the sectors in this study, suggesting that this boundary be redesigned.

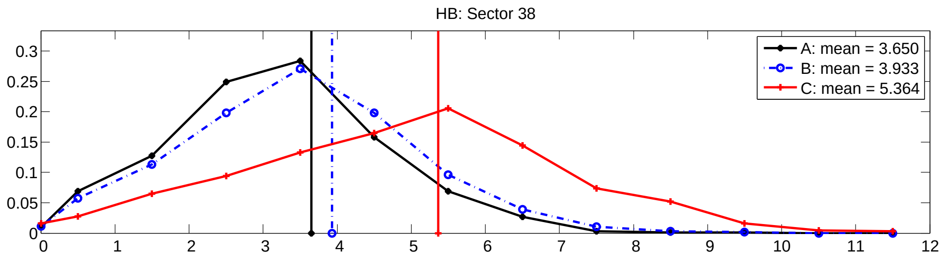
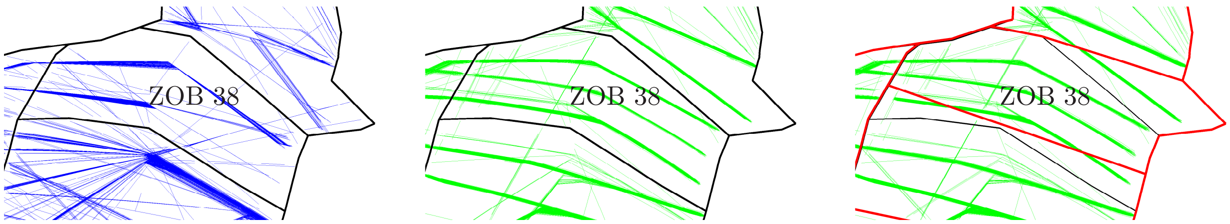


Figure 16: 15-minute peak flights near horizontal sector boundaries distributions for Sector 38, Scenarios A, B, and C.



(a) Scenario A: Existing Sector 38 with existing routes. FL = 330-379.

(b) Scenario B: Existing Sector 38 with new routes. FL = 330-379.

(c) Scenario C: Proposed Sector 38 with new routes. FL = 340-999.

Figure 17: Existing (black) and proposed (red) Sector 38 with existing (blue) and new (green) routes.

3. *Sector 64*

This section is concluded with a look at Sector 64, which, like Sector 38, also shows a significant change in HB distribution from Scenario A to C that results in an increase in mean HB. See Fig. 18. The proposed design significantly changes the sector, moving it north so that it sits vertically above Sector 58. However, even though the change is significant, the mean and distribution is still low when compared to most of the other sectors. Looking at the major flows in Fig. 19c doesn not reveal any obvious potential issues for this design.

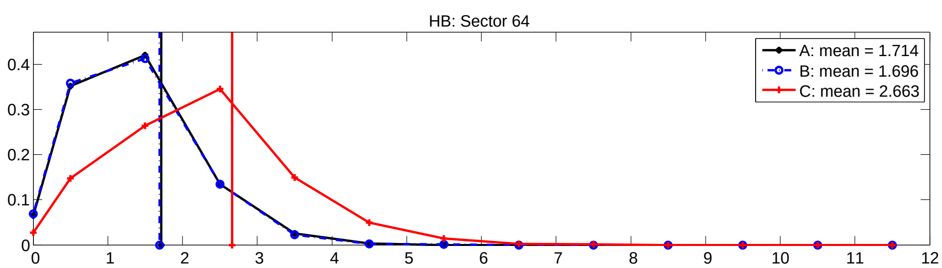
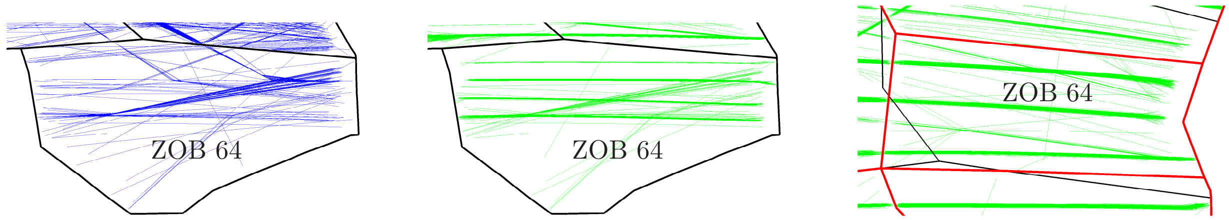


Figure 18: 15-minute peak flights near horizontal sector boundaries distributions for Sector 64, Scenarios A, B, and C.



(a) Scenario A: Existing Sector 64 with existing routes. FL = 330-379.

(b) Scenario B: Existing Sector 64 with new routes. FL = 330-379.

(c) Scenario C: Proposed Sector 64 with new routes. FL = 340-999.

Figure 19: Existing (black) and proposed (red) Sector 64 with existing (blue) and new (green) routes.

V. Conclusions

An analysis of proposed route and sector changes in Cleveland Air Route Traffic Control Center was detailed in this paper. The analysis was carried out by studying the simulated sector performance of six workload factors using three scenarios: the existing sector design with existing routes (baseline), the existing sectors with the new routes, and the proposed sector design with the new routes. A difference metric was derived to measure how much each workload factor distribution changed between the scenarios for each sector. First, this metric was used to determine that when the new routes were flown through the existing sectors, among the six workload factors, the distributions for sector loading (SL) and the number of flights near horizontal sector boundaries (HB) showed the most significant difference. Next, the metric was used to identify those sectors most significantly affected in terms of SL and HB, and a detailed analysis of several of those sectors was presented.

Among those existing sectors that showed the greatest impact by the new routes, several were impacted in an arguably negative way, but most of those issues were resolved in the newly proposed sector designs (e.g. Sector 59). However, when a comparison between the baseline scenario and the new routes in the new sectors was made, some candidate sector designs stood out as potentially problematic with increased SL (e.g. Sector 69), or an increase in HB due to routes that cross boundaries multiple times (e.g. Sector 38). Admittedly, there are several operation details that this analysis may have neglected that might explain these design choices. Nevertheless, this finding may motivate a modification of the proposed design, which could then be evaluated using the methodology presented in this paper.

Acknowledgments

The authors would like to thank the Cleveland Center airspace design team consisting of Connie Atlagovich, Eric Gaines, Brian Hanlon, Doug Odell, Craig Pass, Mike Ruples, and Ron Wood for providing us with the data required for this analysis and for answering our questions about airspace design.

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