

An Investigation of the Operational Acceptability of Algorithm-generated Sector Combinations

Pramod Gupta*

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

Michael Bloem[†] and Parimal Kopardekar[‡]

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

In this paper, algorithm-generated airspace sector combinations are analyzed to determine if they are operationally acceptable. Discussions with practitioners identified three desirable characteristics for operational sector combinations. The first is that at each time during a weekly cycle, approximately the same number of sectors are operational. The second is that sector combinations be familiar, and the third is that sector combinations do not change frequently. Methods for visualizing and quantifying these characteristics are proposed. The methods are used to analyze historical sector combinations from the national airspace system and sector combinations generated by a sector-combining algorithm. The results were analyzed by researchers and practitioners. This analysis indicates that changes to the sector-combining algorithm may be required to ensure combinations that are acceptable for current operations. However, the identified characteristics may be less important in a mid-term timeframe (~2018), which is when a sector combining algorithm is being targeted for deployment.

I. Introduction

In current operations, supervisors in Air Route Traffic Control Centers (ARTCCs or centers) dynamically combine sectors when they are under-utilized (operating below their capacity). This is done primarily so that there are not more controller teams monitoring airspace than are necessary. There are many factors that impact supervisor decisions about when to combine and split sectors, such as air traffic levels, staff availability and capabilities, equipment availability, current and predicted weather, airport configurations, and air traffic demand management initiatives. Currently, these decisions are made based on supervisor experience and judgement. Some previous research has focused on predicting sector combinations and splits based on past supervisor decisions.¹ In Ref. 2, an algorithm to systematically suggest combinations of under-utilized airspace sectors has been proposed. Results suggest that this algorithm may utilize air traffic control resources more efficiently than they are currently utilized. However, feedback from practitioners regarding the sector combination algorithm in Ref. 2 suggests that the proposed sector combinations may not be operationally acceptable due to controller situational awareness and staff planning factors that are not explicitly considered in the algorithm.³

In this research, the algorithm-suggested sector combinations are compared to historical sector combinations to determine if the algorithm produces operationally acceptable sector combinations. Three desirable characteristics of operational sector combinations specified by practitioners in Ref. 3 are investigated. Quantitative comparisons are designed to study each characteristic in the operational and algorithm-generated sector combinations. Further practitioner feedback on the results of these comparisons is reported.

*Research Scientist, Systems Modeling and Optimization Branch, MS 210-10, NASA Ames Research Center, Moffett Field, CA 94035.

[†]Research Aerospace Engineer, Systems Modeling and Optimization Branch, MS 210-10, NASA Ames Research Center, Moffett Field, CA 94035.

[‡]Principle Investigator, NextGen-Airspace Project, MS 210-8, NASA Ames Research Center, Moffett Field, CA 94035 and Senior AIAA Member

The paper is organized as follows. High level discussion of the algorithm is given in II. The important characteristics of combined sectors identified through discussions with practitioners described in Ref. 3 are reviewed and discussed in detail in Section III. In Section IV, the technical approach is described. Simulations and analysis of the algorithm are described in Section V. This section is followed by feedback from practitioners and then concluding remarks and future research in Sections VI and VII, respectively.

II. Algorithm for Combining Sectors

In this section a brief introduction to the sector-combining algorithm is given. Details of the algorithm can be found in Ref. 3. There are two data inputs to the algorithm. The first is predicted sector utilizations. The utilization of sectors is expressed as the maximum instantaneous aircraft count over all relevant 15-minute time intervals. The second input is the information about the capacity, area of specialization, and neighbors of each uncombined sector. In this work the Monitor Alert Parameter (MAP) value is used as the capacity. For combined sectors, the smallest MAP value among all the sectors in the combination is used as the capacity of the combined sector. Each sector is assigned to an area of specialization, a group of sectors that can be combined. Sectors from different areas of specialization cannot be combined in current operations and the algorithm is set up to not allow such combinations.

There are two parameter inputs to the algorithm. The first is the minimum capacity gap (g). It specifies the smallest allowable amount by which capacity can exceed the predicted demand in a sector combination. Any hypothetical combination in which the gap between capacity and predicted demand is smaller than g is not implemented by the algorithm. The second parameter is a vector of times at which new sector combinations will be computed. In this paper g is set to three aircraft and the sectors are reconfigured at frequencies ranging from every hour to every 15 minutes.

A block diagram depicting the algorithm for combining sectors is shown in Fig. 1.

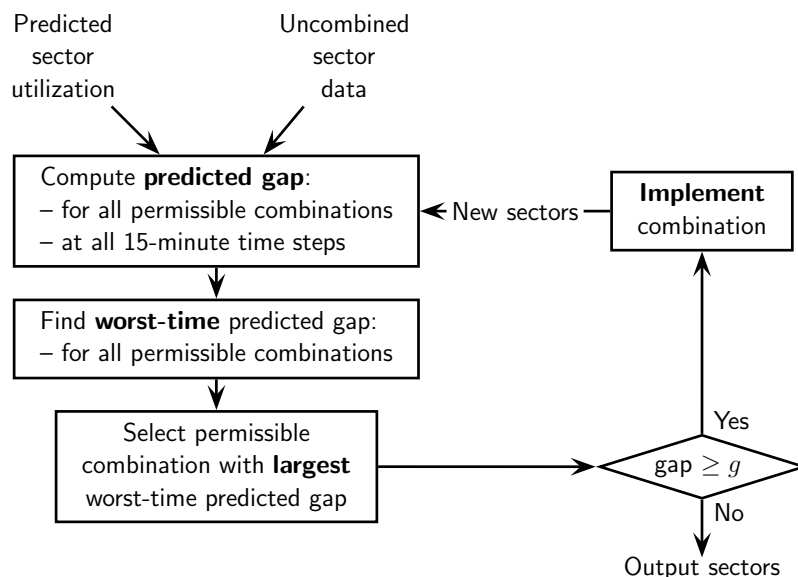


Figure 1. Block diagram depicting the operation of the algorithm for combining sectors proposed in Ref. 2.

III. Characteristics of Operationally Acceptable Sector Combinations

Feedback from air traffic control staff suggest that there are three aspects of sector combinations that are beneficial and even essential to the implementation of an approach for combining sectors.³

1. *Repeatable Number of Operational Sectors*: Repeatability in the number of sectors that are operational over time is useful for staff planning purposes. For this characteristic, the actual sector combinations that are implemented are not particularly important. What is important is knowing that at a particular

period of time, it is likely that a particular number of sectors are required. For example, a pattern might exist such that between 2 pm and 6 pm on Mondays in the winter season, 4 low sectors and 3 high sectors usually need to be open in a particular area of specialization. If such patterns exist, they would be helpful when deciding how many staff people to schedule at a particular time. These patterns would likely change when airlines change from one seasonal schedule to another.

2. *Familiar Sector Combinations*: If a controller is presented with an unfamiliar combination of sectors, then his/her situational awareness will be lower than with a familiar sector combination. For this characteristic, the time at which the particular sector combination is implemented is not important. What matters is that the controller(s) working with the combined sector are familiar with the airspace volume.
3. *Continuity in Sector Combinations*: Thirdly and finally, it is helpful if there is continuity when changing from one set of sector combinations to the next. Continuity in sector combinations is one where many combinations do not change frequently. If many sector combinations change from one configuration to the next, it will be hard for controllers to maintain situational awareness, even if they are familiar with each of the sector combinations that are implemented.

IV. Technical Approach

There are three steps to the technical approach that is used to determine whether the sector combinations suggested by the sector-combining algorithm from Ref. 2 are acceptable. The first step is to propose metrics and plots that measure and show each of the three characteristics mentioned previously. The second step is to compute these metrics and plots for algorithm sector combinations and for historical sector combinations. The third step is to compare the metrics and plots for the two cases to determine if the sector combining algorithm is producing operationally acceptable sector combinations.

The metrics and plots described in the first step of the approach have been defined. The metric or plot for each of the three characteristics is described in the following paragraphs.

1. *Repeatable Number of Operational Sectors*: To determine if the number of sector configurations is repeatable enough for staff planning, the combining sectors algorithm is run for various days with similar traffic patterns. Then, the spread in the number of sectors that are operational at each time on similar days can be computed. Ideally, there will be a small spread in the number of sectors that are operational at each time.
2. *Familiar Sector Combinations*: To determine if the same sector combinations are being implemented repeatedly, the algorithm is first run on actual traffic data. Next, the number of times that each particular sector combination occurred is counted. To assist with controller familiarity, each sector combination should occur many times per day.
3. *Continuity in Sector Combinations*: Finally, to study the continuity in sector combinations, the algorithm is first run with actual traffic data. At each time where sectors are reconfigured, the number of combined sectors that change and the number of combined sectors that stay the same will be counted. Fewer sectors change at each reconfiguration means there is continuity in the sector combinations.

V. Results

Cleveland Center was selected for this analysis because practitioners from Cleveland were available to provide feedback on the results. Simulation results for eight consecutive Thursdays from February to April of 2007 are presented. Practitioners at Cleveland Center suggested these days because they all fall within the traditional winter schedule season for airlines, so traffic patterns should be similar on these days. The data are Aircraft Situational Display to Industry (ASDI) data. The sectors chosen for simulation are those high and low sectors containing airspace at or above 10,000 feet. Other parameters were set to the same default values as in Ref. 3.

Figure 2 shows box and whisker plots of the number of operational sectors over time for various sector combining methods. Plot (a) is computed from the historical sector combinations implemented on these days. Plots (b)-(d) contain the number of operational sectors over time when combined by the algorithm

every 15, 30, or 60 minutes, respectively. The historical sector combinations are repeatable in the sense that there is very little spread in the number of sectors that are open at any given time step. The algorithm-suggested sector combinations, on the other hand, lead to fewer sectors but a higher variation in the number of sectors open at each time. This relatively low repeatability is possibly due to some variation in traffic across the days, but also likely due to the lack of explicit consideration of repeatability or staff availability by the algorithm.

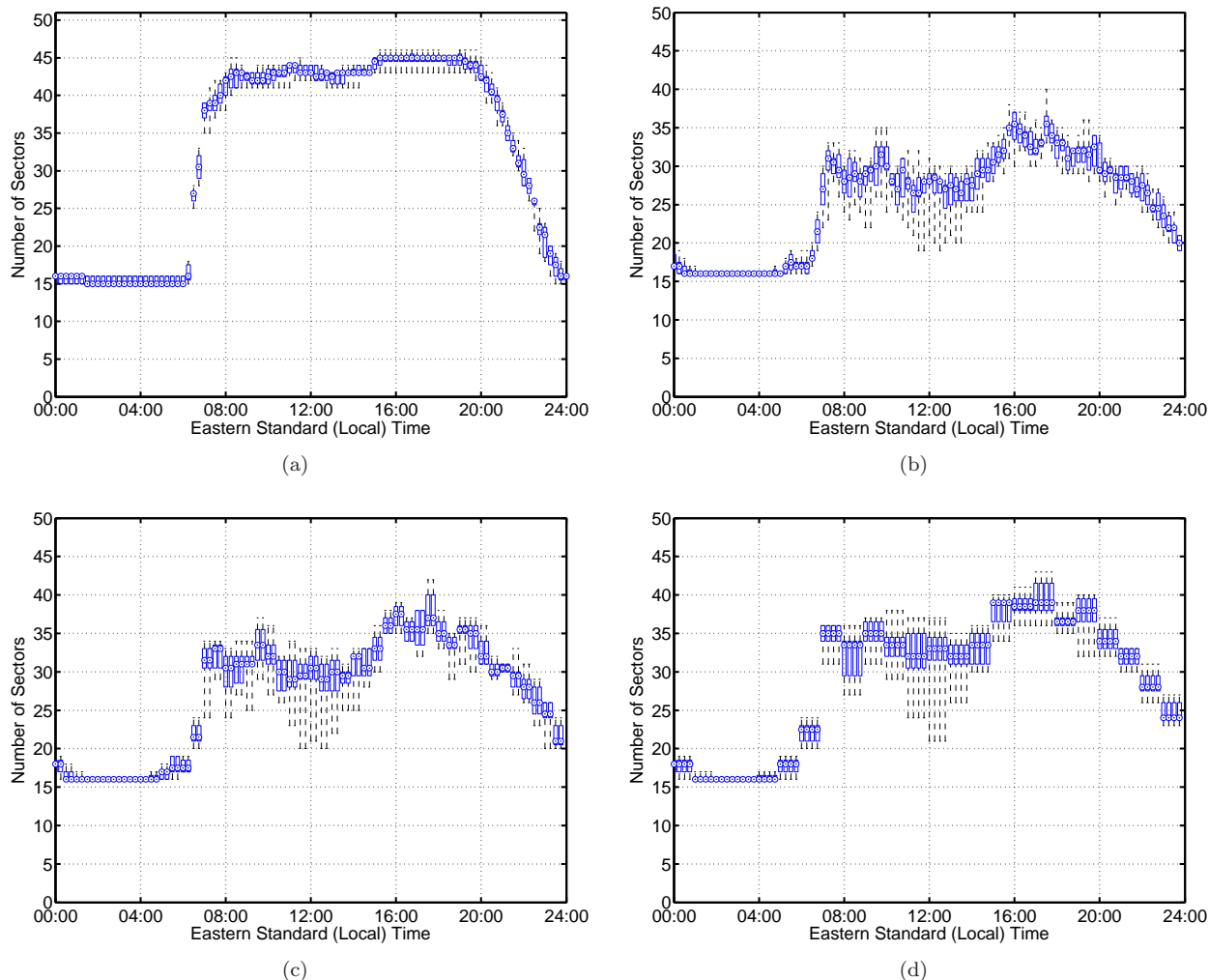
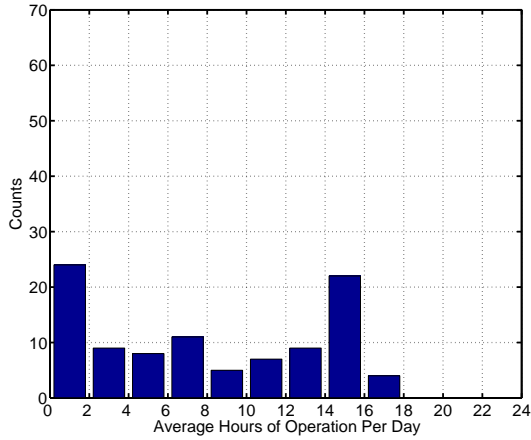


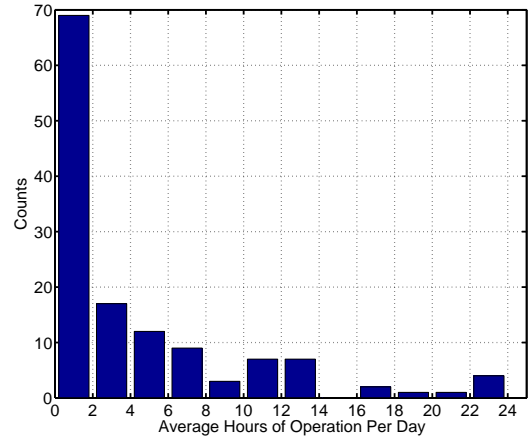
Figure 2. Box and whisker plots showing the spread in the number of operational sectors (a) in current operations and when sectors are combined according to a sector combining algorithm that reconfigures sectors every (b) 15 minutes, (c) half hour, and (d) one hour. The upper whisker is the 100th percentile, the top of the box is the 75th percentile, the dark dot is the median, the bottom of the box is the 25th percentile, and the bottom whisker is the 0th percentile.

Figure 3 is a histogram that shows the average number of hours of operation per day for each sector combination. Plot (a) shows the statistics for historical sector combinations while plots (b)-(d) show statistics for the algorithm when it reconfigures sectors every 15, 30, and 60 minutes, respectively. For controller familiarity with sector combinations, it is preferred that each sector combination occurs frequently. The algorithm suggests 132, 129, and 130 unique sector combinations when combining sectors every 15, 30, and 60 minutes, respectively. However, actual operations only use 99 unique sectorizations. While the algorithm does find more sector combinations that can be in place for 18 or more hours each day, it also suggests many sector combinations that are only in place for 0-2 hours per day on average. Controllers will not be as familiar with these sectors, which may be problematic. The algorithm likely behaves in this way because it combines sectors with the objective of reducing sector hours and without considering combination familiarity.

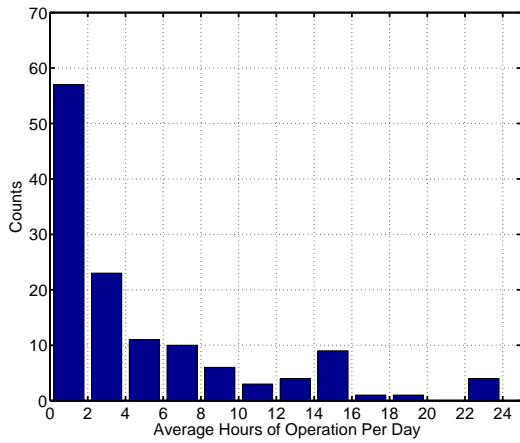
Figure 4 shows the number of combined sectors that change and the number of combined sectors that



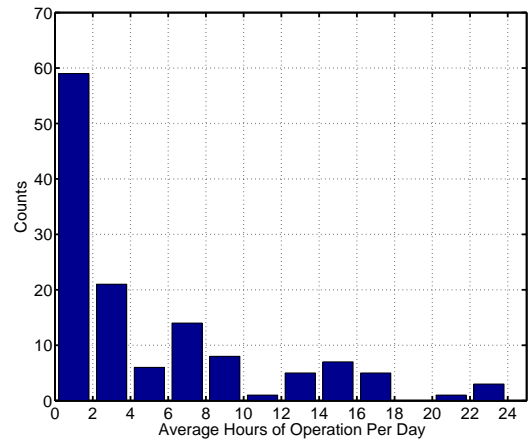
(a)



(b)



(c)



(d)

Figure 3. Histogram showing the average number of hours of operation for each sector combination (a) in current operations and when sectors are combined according to a sector combining algorithm that reconfigures sectors every (b) 15 minutes, (c) half hour, and (d) one hour.

remain the same at each reconfiguration time. Plot (a) shows the statistics for historical sector combination changes and plots (b)-(d) show the same for the algorithm-generated sector combinations when they are generated every 15, 30, and 60 minutes, respectively. The historical sector combination data in plot (a) indicates that except for when many sectors are opened at the beginning of the day, very few sector combinations change at any given time even though there are many times where some combinations change. The algorithm-generated sector combinations do not share these characteristics. At every opportunity the algorithm is given, it finds many sector combinations that should change. Again, this behavior is not surprising because the algorithm does not consider the previous sector combinations when designing the next sector combinations.

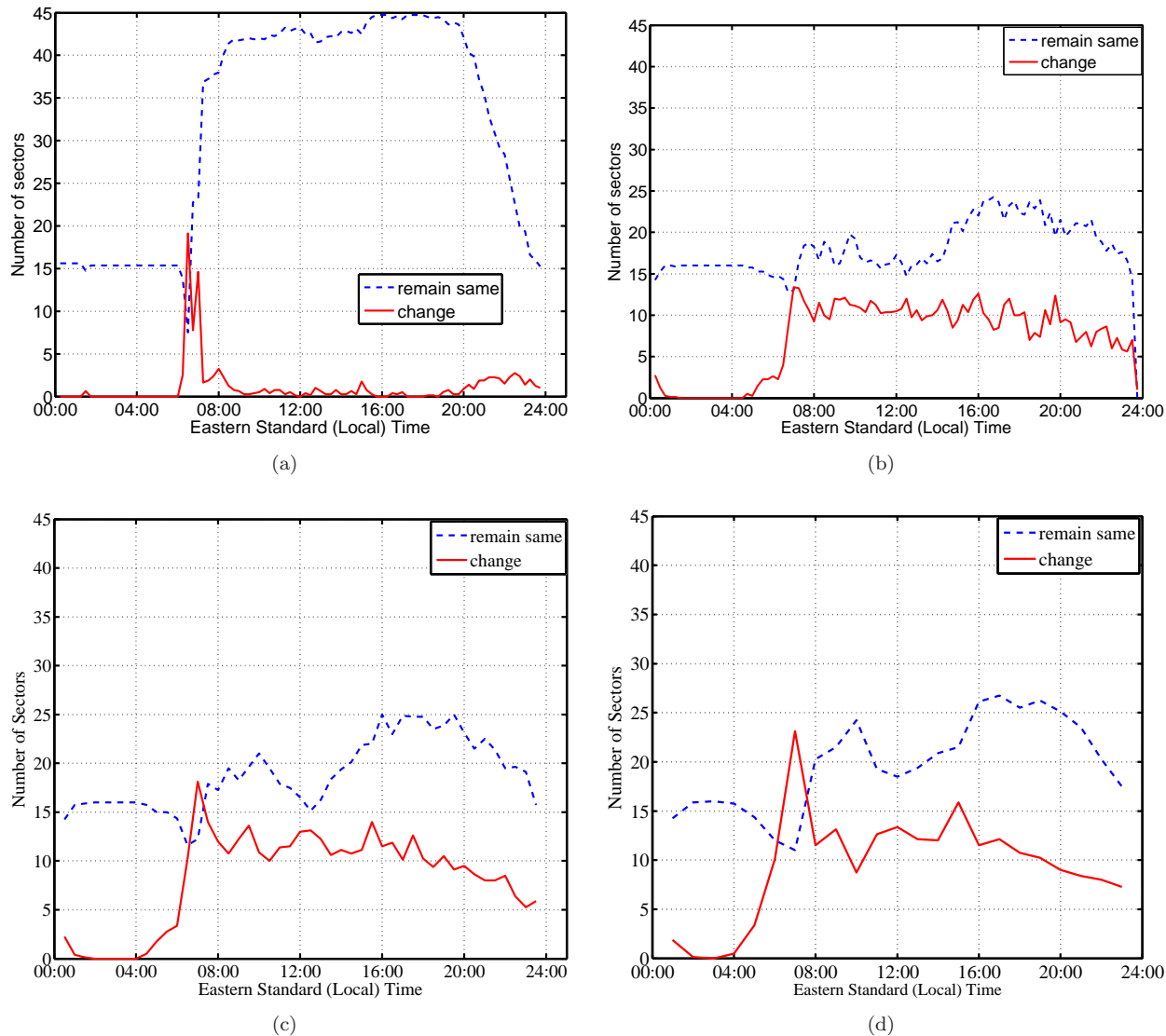


Figure 4. Number of combined sectors that change and stay the same at each configuration time (a) in current operations and when sectors are combined according to a sector combining algorithm that reconfigures sectors every (b) 15 minutes, (c) half hour, and (d) one hour.

VI. Feedback from Practitioners

Practitioner’s feedback has been received on the operational acceptability of the sector combinations proposed by the combining sectors algorithm. The relative lack of predictability in the number of sectors open at each time was not a concern (see Figure 2). The extreme repeatability in the historical data is largely

a result of area supervisors managing to the number of available controllers rather than managing to the volume of traffic. In periods where traffic volumes are high and controllers are scarce, there would be more variability in the number of open sectors, as supervisors would use sector combinations to more efficiently use their staff. The experts indicate that it is possible to handle the variability seen in these results, even if such variability was not seen in the historical data set.

Practitioners were concerned about controller familiarity with sector combinations generated by the algorithm (Figure 3). Some of the algorithmically generated sector combinations are not used for enough hours of operation to allow controllers to become familiar with them.

The lack of continuity in the sector combinations proposed by the sector-combining algorithm was a concern to the practitioners (Figure 4). This degree of constant change in the sectors would lead to confusion and the staff efficiency savings may not be worth the trouble of the constant reconfigurations. Further analysis is needed to understand the nature and cause of the unstable reconfigurations.

Overall, the practitioner feedback indicates that future algorithmic should ensure the continuity in sector combinations and generate sector combinations that foster controller familiarity with the combined sectors. However, these constraints may change if this algorithm were used in the mid-term.

VII. Conclusions and Future Work

An analysis has been performed to determine if the sector combinations from a sector-combining algorithm are operationally acceptable. Three main characteristics of operationally acceptable sector combinations were defined based on practitioner feedback, and quantitative methods for studying these characteristics were proposed. These methods were used to compare algorithm-generated sector combinations with operational sector combinations. Feedback from practitioners indicates that the algorithm may have to be augmented to ensure that there is continuity in sector combinations and sector combinations are familiar to controllers. Implementing these algorithm changes should be possible because the algorithm is a heuristic to which additional constraints or objective function changes can easily be added.

Future research will focus on developing a sector-combining algorithm for mid-term (~2018) high altitude airspace, the context in which the algorithm may be deployed. In this timeframe, some of the desirable characteristics studied here may be irrelevant. For example, automation and training could remove the need for familiarity with sector combinations. Mid-term automation (data link, automated conflict detection with proposed resolutions, ADS-B, etc.) will alter controller workloads, and an appropriate measure of controller workload in the mid-term must be found for use by the algorithm.

Acknowledgements

Al Mahilo (Supervisory Traffic Management Coordinator, Cleveland ARTCC), Bill Hikade (Operations Supervisor, Area 5, Cleveland ARTCC), and Mark Evans provided helpful feedback, questions, and suggestions regarding this work. The authors would like to thank Wim den Braven and John Schade (ATAC) for providing operational sector combination data. Thanks also to Dr. Michael Drew for his invaluable input.

References

- ¹Gianazza, D., Allignol, C., and Saporito, N., "An efficient airspace configuration forecast," *Proc. of USA/Europe Air Traffic Management Research & Development Seminar*, Napa, CA, July 2009.
- ²Bloem, M. and Kopardekar, P., "Combining Airspace Sectors for the Efficient Use of Air Traffic Control Resources," *Proc. of AIAA Guidance, Navigation, and Control Conference and Exhibit*, Honolulu, HI, August 2008.
- ³Bloem, M., Gupta, P., and Kopardekar, P., "Algorithms for Combining Airspace Sectors," *Air Traffic Control Quarterly*, 2009.