AN EFFICIENT METHOD FOR AIRSPACE ANALYSIS AND PARTITIONING BASED ON EQUALIZED TRAFFIC MASS

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Abstract

We present a potential new partitioning mechanism for NAS-scale airspace that utilizes a high-resolution hexagonal grid. We use the Traffic Mass metric: total aircraft position report ("ETMS TZ hit") count in each grid cell or airspace sector/center. Its relationship to Workload metrics is discussed. We describe a fast algorithm that processes large amounts of traffic data and creates potential airspace center boundaries starting from a selected number of seed locations. The airspace partitioning is based on the Equalized Traffic Mass principle: total traffic counts for each center must be about equal, with busy centers being smaller in size than centers with sparser traffic. The same principle can be applied to sector boundary design inside a center. By selecting appropriate seed locations (e.g. around major airports or along major flows), we can control how the algorithm grows the Centers. We discus possible applications and extensions of the algorithm, including TZ hit rate as a metric, "delta-traffic-mass" comparisons, effects severe weather patterns and temporal changes in traffic flows on the "elasticity" of the airspace boundaries generated by the algorithm. Finally, we outline future work, including the use of fast-time simulation tools in conjunction with grid-based air traffic analysis.

Introduction

This paper presents initial results of our research into potential new techniques for airspace repartitioning with the aim of equalizing traffic load (and, indirectly, amount of workload), in multiple airspace centers or sectors. First, we review prior research in the areas of traffic density and traffic load metrics analysis and discuss the potential for further research.

Not all of the methods and metrics used for analysis of existing airspace structure can be used for clean-slate airspace design, especially on macro-scale. In the latter case, as we look at possible alternatives for NAS airspace repartitioning, we start with just Centers as major blocks of airspace. Thus, initially we are not concerned with individual Sectors, so coordination across Sector boundaries is not a factor at this stage. Also, workload related metrics such as traffic density, aircraft proximities, etc become "less granular".

Airspace analysis and partitioning (or re-partitioning) methods based on superimposing traffic flows over a fine grid have been used by a number of researchers. Traditionally, Traffic Density was chosen as a metric, although a range of workload related metrics and workload assessment techniques have also been proposed. While workload analysis is important, we have decided to start with Traffic Density as a simpler metric. But we prefer using the term Traffic Mass, defined as the total aircraft position report ("hit") count in a grid cell or in an airspace sector/center.

As an approach to studying the relationship between traffic mass and workload, and to have a better justification for using the Traffic Mass metric, we had several experiments conducted using TAAM, a sophisticated fast-time air traffic simulator; results are discussed in this paper.

It is intuitively obvious that studying airspace partitioning cannot be based on traffic density. Neither the US nor European airspace *density* (defined as traffic mass divided by area), will ever be uniform. Airspace around major metropolitan areas, such as New York or London, will always be very busy, while airspace in remote areas, such as North Dakota, will be less densely populated with airplanes.

The principle that we are exploring for airspace partitioning is that of Equalized Traffic *Mass*. That is, total traffic counts in each Center, over a selected period, should be equal, so that busier Centers will be smaller and less-busy Centers will be larger in size. (The time period could be an entire day or a smaller period, e.g. 5 busiest hours in the NAS in the afternoon).

We use the FAA's ASDI/ETMS data as it offers rich analysis environment with flight plans, their amendments, 1-minute or more frequent radar position reports (the so-called "TZ hits) etc available for approximately 70,000 flights daily.

To explore alternatives for potential consolidation of all or part of NAS airspace, we first remove existing Center or sector boundaries and use a high-resolution grid overlay as a starting point.

In terms of grid type, we have opted for a less-conventional hexagonal grid as it offers some advantages over rectangular grids. We describe a fast algorithm that processes large amounts of traffic data and then creates airspace center boundaries starting from a selected number of seed locations.

Since it would be difficult to conduct a completely automatic boundary generation, we chose a simpler, but effective, seeding method. By selecting appropriate seed locations (around major airports or along major flows, for instance), we can control our optimized partitioning algorithm.

In addition to lateral boundaries, vertical stratification is considered. For Center airspace, we ignore all position reports below FL180. Above that, we divide the airspace into two layers (e.g. FL180-FL340 and FL340-FL600) which may each contain an unequal number of new centers.

Temporal changes in traffic flows during the day affect traffic mass distribution in the airspace and with it, the airspace boundaries. We study these changes by running the algorithm with consecutive one-hour traffic samples extracted from a full day's data. Similarly, effect of severe weather patterns on the "elasticity" of the newly created airspace boundaries can be studied: in the US, storm fronts may result in major traffic flow shifts during the day.

It is important to point out that at this stage, our goal is to propose some new *methods* for potential airspace redesign rather than any specific design layouts or the number of Centers.

Background

Numerous air traffic and airspace partitioning analyses have been conducted in the US, Europe and elsewhere using archived traffic data.

An interesting approach to NAS traffic mass analysis is offered by MITRE CAASD IDAT [1]. This tool analyzes the intersections of flight tracks in the NAS. The argument is that the density of intersects, rather than just flight tracks or radar position "hits", is a good reflection of NAS traffic flow structure and, to an extent, of controller workload in each sector. As such, it could serve as a useful complementary metric in addition to traffic mass *per se.*

Research conducted by Delahaye et al [2] uses graph partitioning as a method to optimize airspace layouts, where the emphasis is on the route structure of the airspace. Since coordination at sector boundaries is a major contributing factor to controller workload, the objective of the graph partition optimization method is to minimize (or rather, harmonize) traffic flow across sector boundaries. This is achieved by applying an evolutionary algorithm with constraints and finding an optimal allocation of routes (route segments) to airspace sectors.

In terms of airspace partitioning, the approach explored by Trandac, Baptiste and Duong [3] also uses a graph clustering algorithm. In order to take advantage of the well-developed clustering techniques, the airspace is represented by a network of routes rather than by volume. Clearly, there is a strong correlation between the route structure and the traffic complexity in a sector, especially in the European airspace where effects of severe weather en route are less significant.

The work by Donohue and Yousefi [4, 5] proposes a number of new approaches in NAS traffic mass and complexity analysis. First, a hexagonal grid covering NAS airspace is proposed. In clustering applications, hexagonal partitioning is arguably better than rectangular or triangular because it can be expanded smoothly in diagonal directions, not just vertically or horizontally. It is the only partitioning scheme where an individual cell has common edges with neighbors in vertical, horizontal and diagonal directions. In this study, hexagonal cells were created as ATC sectors in TAAM; its workload model was used to estimate traffic complexity in each cell. Also, a clustering algorithm based on linear programming is developed for exploring new ATC sector boundaries that provide even distribution of TAAM workload across multiple sectors. This work provides a good foundation for our research.

In [6], Callaham et al analyze traffic flows impacted by weather, although the primary metric is the arrival delay, not traffic mass. The data gathering method is to count the number of "TZ hits" (radar position updates) in each cell of a rectangular grid and to also calculate the intersections of the NCWF polygons (5-min updates of significant weather outlines NAS-wide) so as to assess the impact of severe weather on NAS performance. The concept introduced is Weather Impacted Traffic Index (WITI), i.e. the notion that on a bad weather day, NAS may have performed poorly in absolute terms, but given the circumstances, NAS performance might not have been all that bad.

Prior research, as well as our own experiments using TAAM simulation, indicate that traffic mass is well correlated with complexity / dynamic density / workload type indicators. As an example of correlation between traffic mass and dynamic density, NASA Ames researchers, Sridhar et al [7] have investigated traffic in selected sectors of the FtWorth Center (ZFW). The resulting graphs representing traffic counts and dynamic density indicators show a strong correlation between the two metrics and a close-to-linear relationship.

As another illustration of this trend, Figure 1 shows hourly Traffic Count vs. Workload chart for three ATC sectors in a busy US TRACON, computed from a TAAM simulation. TAAM simulated impact of traffic density, coordination actions, altitude clearances, conflict detection and resolution. These and other factors had different weights and the "workload" was calculated as a weighted, normalized sum of these factors / events in each sector. While the "workload" metric is just a reflection of controller workload as modeled by TAAM, the chart below is nevertheless a good indicator of the two metrics' relationship. From this and similar analyses we can conclude that, as a *first iteration*, traffic mass can indeed be used as an airspace partitioning metric.

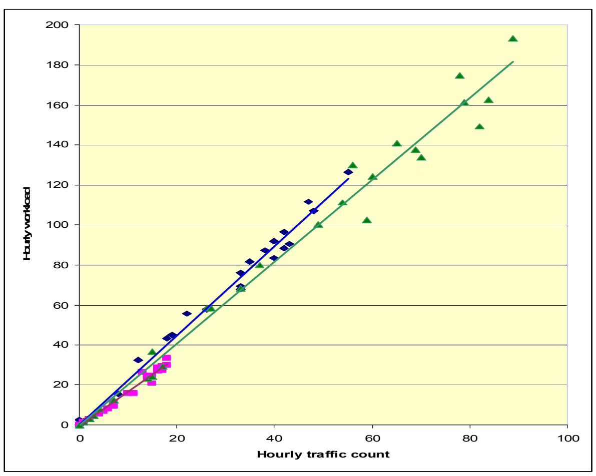

Figure 1: Traffic Mass-vs-Workload Chart

The Grid

A TZ hit is identified by its coordinates (Latitude/Longitude) and its altitude. Finding the correct vertical layer for each TZ hit is simple, but finding the correct hexagonal cell is a different matter. On a rectangular grid, this task would be trivial: a simple arithmetic division would yield the indices of the cell into which a TZ hit (a red cross in Fig. 2) falls. On a hexagonal grid, this is not possible.

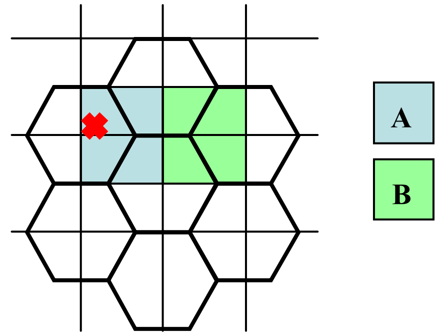

Figure 2: Rectangular and hexagonal grid

Since we will be processing millions of TZ hits on a hexagonal mesh consisting of thousands of cells for each day of NAS traffic, the algorithm assigning hexagonal cells to TZ hits must be very fast indeed.

We have therefore developed a new algorithm that ties the hexagonal grid to a rectangular grid (in fact, creates the former from the latter), finds the corresponding rectangular cell for each TZ hit and identifies the corresponding hexagonal cell.

The algorithm can be illustrated as follows.

1) A rectangular grid is first created.

2) A hexagonal grid is created from the rectangular grid. Columns 0, 2, 4, … of hexagonal cells are created such that the centers of these cells are located at the South-West corners of the rectangular grid cells. In columns 1, 3, 5, … the hexagonal cells are adjacent to the neighboring even columns.

3) For each TZ hit, the rectangular cell is found first from a simple arithmetic relationship between the TZ hit position and the rectangular cell index.

4) With this type of grid pairing, there are only two possible relationships between rectangular and hexagonal cells, A and B, as shown in Figure 2 above. The hexagonal cell indices can be derived directly from the rectangular cell index because that is how the hexagonal grid was created.

5) It is now easy to find the correct hexagonal cell for the TZ hit (three different possibilities for type A or type B relationship). In this process, our algorithm subdivides these type A or B cells into smaller rectangular sub-cells to maximize computational performance. Then, for sub-cells on the left and

right, the task is again reduced to rectangular sub-cell checks; and it is only for the two sub-cells in the middle that a slightly more complex check (whether the TZ hit is above or below the diagonal hex cell edge) needs to be performed.

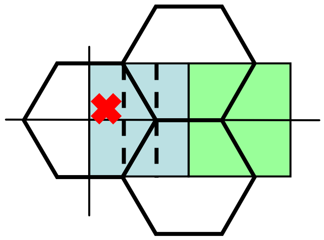

Figure 3: Sub-cells for TZ hit location

The algorithm has proved to be quite fast. Our tests show that, for instance, finding the correct hexagonal cell for each of about 1,700,000 TZ hits (NAS traffic for five busiest hours) on a hexagonal grid of 30,000 cells, takes about five seconds.

For grid units, we chose *degrees* (as opposed to nautical miles) for easier calculation. Our grid cells will be of slightly *uneven* size, in that the cells further to the North will be somewhat narrower than the cells closer to the Equator. Further, the cells will be almost, but not completely, symmetrical: they can be slightly narrower or wider. But none of this has any impact on the airspace subdivision algorithm or results: the only parameter that really matters is the number of TZ hits in each cell.

The geographical rectangular region studied included all of the current US airspace centers (with oceanic airspace): longitude from 62 to 130 degrees West and latitude from 18 to 50 degrees North. We used a grid consisting of 200 by 150 cells.

Collecting Traffic Mass Metrics

To test our algorithm, we have developed a computer program that ingests TZ hits for an entire day of for N busiest hours NAS-wide (N could be, say, 5 hours, from 1900 to 2359Z). An altitude interval can be specified as well, e.g. all Class A airspace or a smaller layer such as FL180-340.

Total TZ hit counts are stored for each hexagonal cell. The result is displayed on the screen in color. The use of colors corresponding to the traffic mass in each cell is somewhat subjective but can be adjusted for best visual effect. The increase of traffic mass count in a cell is represented by colors from dark green to brighter green, then yellow, red and finally, magenta.

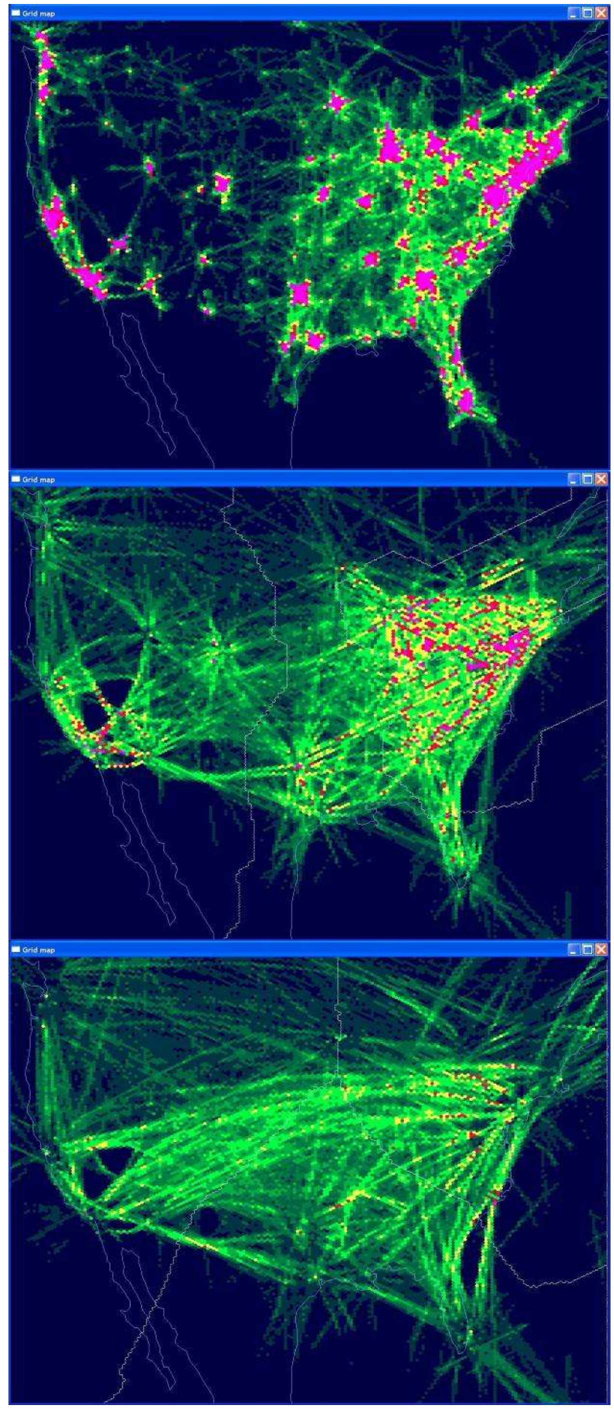

Figure 4a-4c: US NAS traffic in three altitude layers (0-FL180; FL180-FL340 and FL340-FL600)

The three pictures above illustrate the traffic mass in three layers: 0-FL180, FL180-FL340 and FL340-FL600 are shown. In higher-altitude pictures, one can clearly see the North-Eastern Triangle (ORD-BOS-MIA), transcontinental tracks, California and Nevada with restricted areas free of traffic, oceanic tracks, traffic across the Gulf of Mexico, and over-water tracks along the Eastern seaboard.

It is interesting to note how traffic mass distribution patterns change in these three altitude intervals. At lower altitudes, traffic is clustered around major airports. At medium to higher altitudes, both the presence of major airports with their approach paths and the en-route traffic (especially shorter-range flights) can be seen. At high altitudes, longer-range and transcontinental flight tracks are most visible.

Center Boundary Formation Method and Algorithm

Our algorithm is somewhat similar to seed growth algorithms used in modeling the growth of crystals, forests, population of bacteria etc; see, for example, the paper by Govindarajan et al [8].

First, we select a fixed number of seed locations (for example, 5 or 8 or 15) from which the potential future Centers will be grown. The selection of seed locations is not automatic and is fairly subjective. But this simple approach allows us to control the growth and location of the new Centers and to take into account major traffic flows, location of hubs etc.

A practical start is to select several major airports in different parts of the country as the initial seed locations. Obviously, the locations ought to be spread across the area; otherwise it may be difficult to generate Center boundaries that make sense.

The Center Growth Algorithm:

a) "Embryonic" Centers are formed first – each consists of a single hexagonal cell enclosing each of the selected seed locations.

b) The Center with the lowest TZ hit count is determined. That center is allowed to grow one cell layer by finding all cells neighboring its current outer layer (initially, six hexagonal cells around the seed location). All TZ hits in the cells just acquired through this one-layer expansion are added to the Center's total TZ hit count.

c) The Center with the lowest TZ hit count is again identified. It may still be the Center that grew a new cell layer during the previous step, or it may be another Center. This new lowest-TZ-count Center is now allowed to grow another layer.

d) If the lowest-TZ-count Center "bumps" into a neighboring Center (i.e. the cell it wants to acquire already belongs to some other Center), it simply grabs cells from that Center.

e) The procedure is repeated over a sufficient number of iterations which depends on the size of the grid cells. Our experiments show that approx. 800 iterations work well for the grid with our chosen size, 200x150 cells for US NAS.

The next three Figures below illustrate the Center growth process for eight initial seed locations. The vertical boundaries for this example were set as FL180 to FL341.

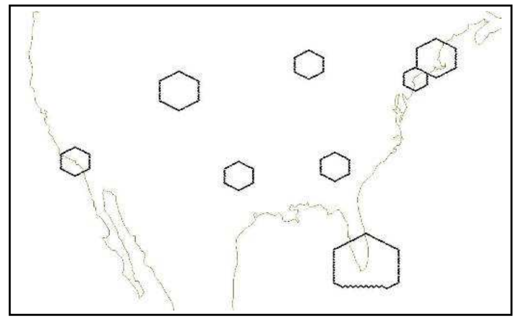

Figure 5: Center growth after 50 iterations

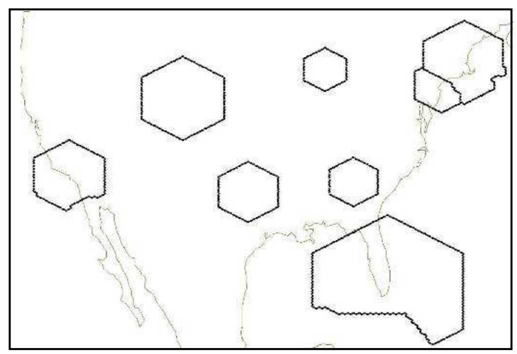

Figure 6: Center growth after 100 iterations

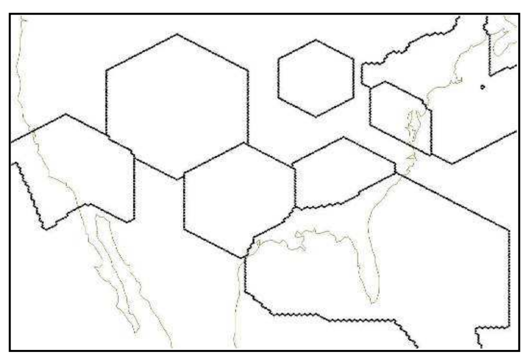

Figure 7: Center growth after 200 iterations

Note that Center growth is uneven: Centers with higher traffic mass grow slower and sparser-traffic Centers grow in size faster.

f) Because the algorithm may create some unequal traffic mass counts in the newly formed Centers, a brief equalizing procedure is performed. Our experiments show that just one or two iterations are sufficient. In each cycle, each Center attempts to expand by grabbing cells from the neighboring Centers with higher TZ counts.

The final result is shown below. Internal boundaries between Centers are shown as thicker lines. The largest-size Center in this case is the one that includes the South-East, Florida and the adjacent part of the Atlantic Ocean. The smallest-size Center is located in the Mid-Atlantic.

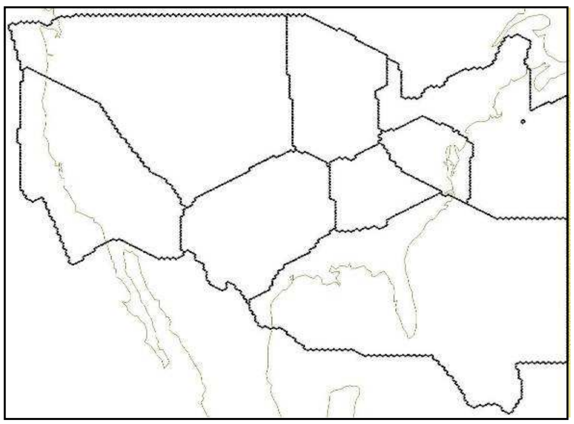

Figure 8: Final boundaries for eight Centers

Total traffic mass counts in each Center are practically equal: variations typically don't exceed 1%, as the data for the 8-Center partitioning shown above demonstrates:

Figure 9: TZ hit count data for the 8 Centers

The result of another calculation, this time for

Center A:	Cells: 14538;	TZ hits: 64484;	Avg dens: 4.0
Center B:	Cells: 9298;	TZ hits: 64520;	Avg dens: 6.0
Center C:	Cells: 10547;	TZ hits: 63975;	Avg dens: 6.0
Center D:	Cells: 11616;	TZ hits: 64589;	Avg dens: 5.0
Center E:	Cells: 8234;	TZ hits: 64524;	Avg dens: 7.0
Center F:	Cells: 8006;	TZ hits: 64643;	Avg dens: 8.0
Center G:	Cells: 15162;	TZ hits: 64845;	Avg dens: 4.0
Center H:	Cells: 8112;	TZ hits: 64807;	Avg dens: 7.0

six Centers, is shown next, but now in color. The altitude interval used for this partitioning was FL180-FL340.

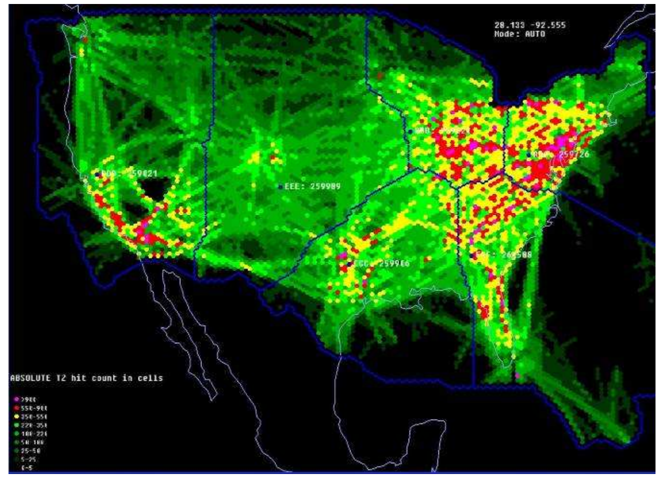

Figure 10: Six Centers in color

Limiting Cell Growth with User-Defined Boundary Polygon(s)

We can define one or more boundary polygons and make the algorithm ignore all cells outside those polygons. An obvious example, used in our experiments, was to load the current US ARTCC boundaries so that the new Centers do not grow outside the US controlled airspace.

The same idea can be used for dividing Centers into Sectors. Having created new Centers, we can select one of them and re-input it as the boundary polygon. Then, we can create a number of seed locations inside this Center and run the algorithm to create Sectors which will have approximately equal traffic mass counts. As a test case, a hypothetical Center in the picture below is divided into 3 Sectors of different size but equal traffic mass (sector boundaries shown in white color):

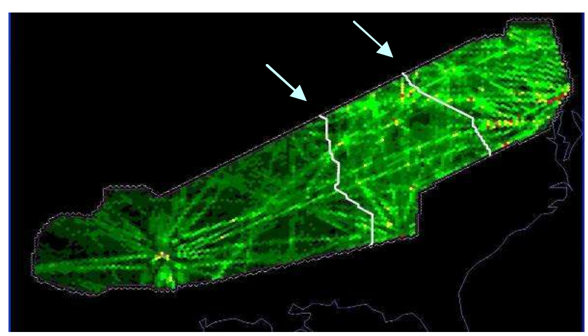

Figure 11: Center subdivision into Sectors

Airspace Boundary Elasticity vis-à-vis Severe Weather Impacts & Temporal Shifts

Airspace partitioning derived from "good-weather" day's traffic needs to be examined with respect to traffic flow changes induced by severe weather en route. For example, if a new Center contains a major flow near its boundary and if during typical weather front passages, the flow shifts across the Center boundary, we may want to adjust the boundary so that the flow stays within the same Center. Even during the day, changes in traffic flow patterns may warrant an analysis of airspace boundary "elasticity".

As an example, boundaries generated for one Center in five hourly increments, from 1900 to 2359Z, are shown in Figure 12 (grid cell colors are those for the first hour). Variability of the boundaries is clearly visible; it is moderate where traffic density is higher and is greater where traffic density is low.

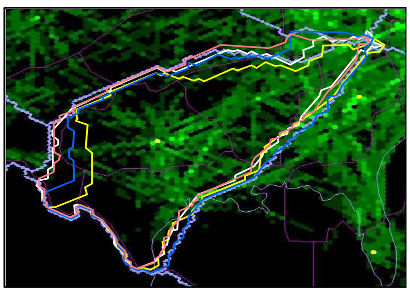

Figure 12: Temporal boundary variability

The next Figure shows the variability of Center boundaries for seven different weather days: from good weather across the NAS, to "medium", to high weather impact (convective activity in the North-East and South). We use the same initial seed locations as for the Centers shown in Figure 10 but hide cell coloring for clarity.

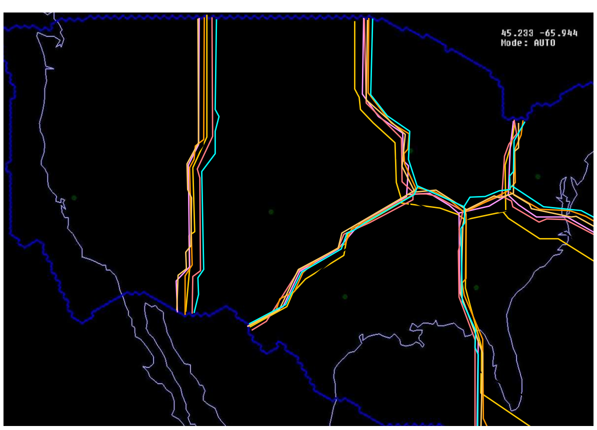

Figure 13: Center boundary variability due to severe weather impacts

Software Performance

Just as the algorithm finding the appropriate cell for a TZ hit on a hexagonal grid, the center growth algorithm is fast, which obviously is an advantage when processing large amounts of data.

As a typical benchmark, the "C" program that we have developed takes about 17 (seventeen) seconds to ingest 5 million TZ records, populate the 20,000-cell hexagonal grid, and generate Centers from a known number of seed locations.

Analyzing "Delta-Traffic-Mass"

An extension of our "C" program compares data from two different files. These could represent two equal periods from different traffic days or two different hourly intervals from the same day's traffic. The color scheme we selected uses shades of gold for positive "delta-TZ-counts" ("Period 1 minus Period 2" for each cell) and shades of blue for negative differences. For example, consider the Traffic Mass differences between a good-weather day (3/13/04) and a bad-weather (6/17/04) day (Figure 14). Precipitation summaries for the two days are shown in upper and lower right corners. More gold color means denser traffic on June 17; more blue means denser traffic on March 13. Weather impacts, as well as seasonal schedule changes, can be clearly seen.

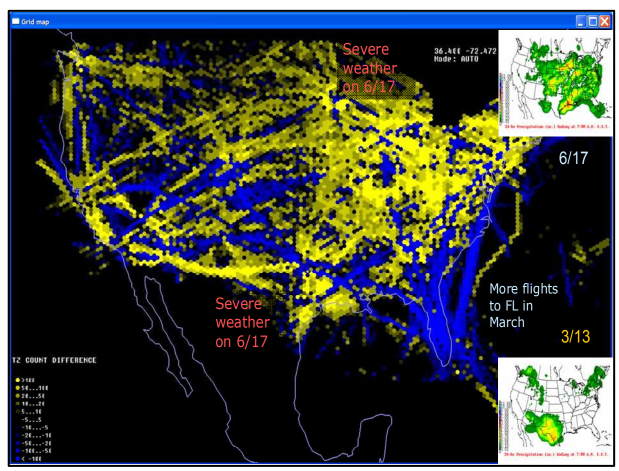

Figure 14: Delta-Traffic-Mass vs. Weather Effects

Such analyses can be useful for a number of reasons. First, effects of severe weather en route can be visualized by comparing ASDI data from a "good-weather day" and a day affected by e.g. major frontal systems. By counting the sum of absolute values of cells (which contain differences in TZ counts), we can, to an extent, quantify the effects of rerouting:

greater shifts in traffic patterns will likely result in greater differences in hexagonal cell counts.

Second, we can perform the “as-filed vs. as-flown” traffic comparisons.

A number of 4D flight profile calculators have been developed that generate these profiles from ASDI FZ records (flight plans as filed). Using these, we could “fly” the aircraft – basically, interpolate – to create artificial TZ records at 1-minute intervals. Another method would be to run a fast-time simulation model such as TAAM. The latest TAAM version can generate ASDI-formatted output from a complete NAS-scale simulation run.

We would then use TZ hits from 4D flight-plan profiles or from simulation (i.e. aircraft flying their flight-planned tracks) and compare them with archived TZ hits for the same day (these TZ hits now showing actual tracks). This will produce the as-filed vs. as-flown data for our “delta-traffic-mass” analysis. Again, the total of absolute values of TZ count differences for all hexagonal cells will show how closely the actual tracks matched the flight-planned tracks.

Maximum TZ Hit Rate as a Metric

An alternative to the Traffic Mass metric could be the Maximum TZ Hit Rate. We record the amount of TZ hits in each cell in specified time intervals (e.g. 15, 30, 60 minutes) and find the maximum TZ hits per interval for each cell over the entire day. This metric is perhaps a better reflection of workload because it includes a temporal element.

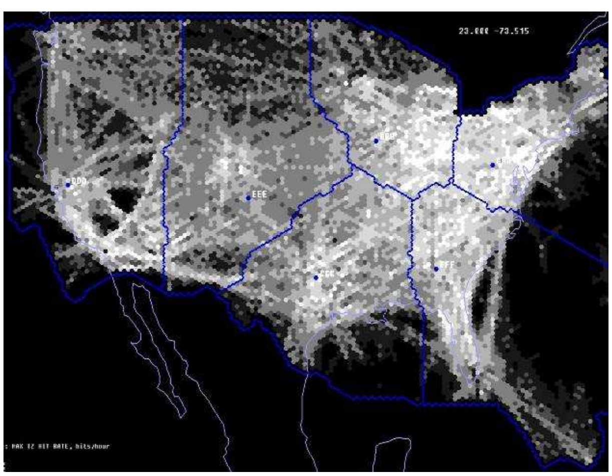

Figure 14: Maximum TZ Hit Rate Visualization over 30-minute intervals, FL180-340

Figure 14 above shows airspace partitioning into 6 Centers using this new TZ Hit Rate metric. The grey scale colors have been chosen to distinguish this visualization from the one based on the Traffic Mass.

Comparing the boundaries in Figure 14 to those in Figure 10 (i.e. compare airspace partitioning based on TZ hit rate vs. traffic mass) we can see that the two results are similar but not identical. A closer look at a smaller area (see Figure 15) reveals the overall similarity but also noticeable local differences. The resulting new Center boundaries are different, too, which should be expected. Note also the differences between total TZ hit count and its peak hit rate in areas such as the northern section.

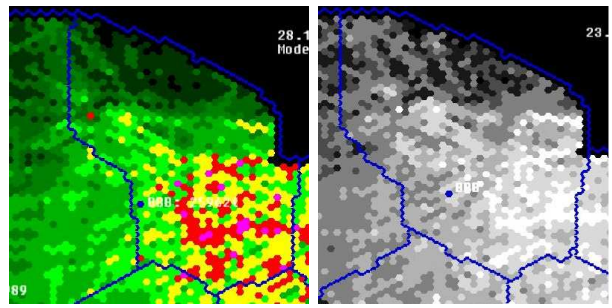

Figure 15: Traffic Mass (left) vs. Maximum TZ Hit Rate (right) – a closer comparison

Number of Airspace Partitioning Variants for a Given Number of Seeds

There can be a very large, number of possible partitioning variants for each fixed number of initial Center seeds. Clearly, there are many other factors, apart from traffic mass or other traffic complexity metrics, that would need to be considered. The airspace partitioning software would need to be made interactive to allow the designers to explore the various layout alternatives. Our further research will turn to some of these additional requirements.

Airspace Redesign and Simulation

Taking the approach described above a step further, one could envisage using the traffic mass count and airspace partitioning algorithm in conjunction with fast-time simulations – the aim in this case would be airspace redesign based on *future*, not just historical, traffic patterns.

Various airspace designs and flow patterns generated by TAAM or other fast-time simulation model can be analyzed; the model would need to produce output in ASDI or similar format. Traffic mass and “delta-traffic-mass” metrics can be computed, visualized, and related to the airspace partitioning or airspace redesign tasks at hand.

Traffic Complexity Analysis

Currently we count only the number of TZ hits in hexagonal cells. However, since ASDI/ETMS TZ records contain the timestamp, flight ID, altitude and speed data, the method described in this paper could be enhanced to utilize that data.

For example, by pre-sorting the traffic data file on (a) flight number and (b) timestamp, we would be able to ingest consecutive series of TZ records belonging to individual flights. This will allow us to extract additional information such as:

- Whether the aircraft were climbing or descending;
- Aircraft proximities and potential conflicts;
- Tracks in the vicinity of neighboring Centers or vertical transition areas (e.g. FL180 – TRACON to Center transition).

Using this information, we could begin to account for workload related factors: climbing/descending traffic, crossing tracks, vicinity of transition areas all mean higher workload than e.g. straight-and-level traffic on parallel routes. TZ hits belonging to these higher-workload tracks could be assigned a higher weight.

Additionally, we could take airspace saturation into account: if, for instance, the traffic mass or the maximum TZ hit rate in a hexagonal cell reaches a certain level, the cell would get a higher-than-1.0 weight coefficient. A non-linear model of the dependency of workload on traffic in congested airspace can be considered.

While all these methods cannot replace a more complete workload assessment application, we believe it will be possible to generate a reasonably good approximation of workload impact for any given traffic data set, and do so efficiently. Additional processing described above is likely to have only moderate effect on the speed of the traffic mass count and airspace partitioning algorithm. And if an entire NAS day of traffic can be processed in several minutes, this would be sufficiently fast for conducting extensive – and interactive – traffic analyses using multiple days, time periods etc.

Conclusions

In this paper, we have introduced the Traffic Mass metric and have presented a new, fast algorithm for processing massive amounts of traffic data, computing the metrics and displaying the results in color using a hexagonal rather than rectangular grid.

We have also developed an airspace partitioning algorithm based on the Equalized Traffic Mass (which seems a more appropriate name than the Traffic Density). The Seed Growth-type algorithm generates potential new boundaries for airspace Centers or Sectors while providing practically equal traffic mass distribution in each partition.

The computational performance of the software implementing these algorithms is very high, which can be helpful for interactive design involving the analysis of large numbers of traffic data samples.

As might be expected, the airspace partitioning algorithm produces some boundary elasticity vis-à-vis temporal changes and weather-related impacts. In the latter case, boundary shifts are proportional to the weather effects.

Comparing air traffic data from different days, or from different time period of the same day, can provide additional insight into air traffic dynamics. Our comparison method for traffic mass in hexagonal cells may be suitable for quantifying the effects of aircraft rerouting when severe weather en route was present. In this case, 4D flight profile calculators or fast-time simulation tools could produce the "as-planned" tracks for aircraft while ASDI/ETMS data provides the "as-actually-flown" tracks.

Maximum TZ hit rates in hexagonal cells can be computed for specified time intervals as an alternative metric to the traffic mass count. This may reflect traffic dynamics better.

A likely extension of the methods presented here will be to extract additional value from flight tracks in hexagonal cells: altitude change trends, conflicts, proximity to transition altitudes, and possibly non-linear weighting depending on traffic mass in a cell. From this, airspace complexity (and in fact, dynamic density) related metric can be constructed as a weighted sum of the above factors.

Finally, methods and software presented in this paper may also be useful for airspace redesign necessitated by future changes in traffic volumes, flows, and procedures. Fast-time simulation can generate the new tracks from which we can extract traffic-mass and airspace complexity metrics and compare them to baseline data.

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Keywords

Airspace partitioning; Traffic mass; Hexagonal grid; Temporal effects; Comparative analysis; Airspace complexity; NAS; Fast-time simulation.

Author's Biography

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