# Dynamic Resectorization in Air Traffic Control: A Human Factors Perspective

Earl S. Stein, Ph.D., ATO-P
Pamela S. Della Rocco, Ph.D., ATO-P
Randy L. Sollenberger, Ph.D., ATO-P

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**16. Abstract**

The National Airspace System is a highly structured environment. Structure provides benefits including predictability for the decision-maker, the air traffic controller. When something is unusual, controllers can identify the event as out of the ordinary given their inherent and trained capacity for pattern recognition. The expertise in pattern recognition does not develop quickly. In the current system, it takes En route controllers an average of about three years to certify as Certified Professional Controllers (CPCs, formerly Full Performance Level). In general, CPCs must learn and check out on at least six different sectors to certify. There are situations, however, when the usual structure is reduced and the typical patterns do not work. This can happen with weather events and systems outages as examples. Dynamic resectorization offers a tool in these situations to increase the options and promote flexibility. In our current system, traffic managers can resectorize in a very systematic, structured way to balance the load and increase the level of structure for controllers. The system of the future may include several types of resectorization supported by automation tools. Limited dynamic resectorization is similar to what is done now but may see more widespread use. Unlimited dynamic resectorization represents a leap into the future with underlying technology that does not exist today. Both approaches raise human factors questions, which should be approached systematically in a proactive manner. The more flexible the system becomes the more dynamic the options will be. Operators will need solid anchors if they are going to be able to efficiently and expeditiously maintain safe separation between aircraft.

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## Executive Summary

Dynamic Resectorization (DR) is a concept designed to increase flexibility in the National Airspace System (NAS), and increase capacity while reducing delays. The concept involves dynamically moving airspace boundaries to accommodate traffic flow constraints such as weather, equipment outages, or active Special Use Airspace. There have been a number of proposals found in the Federal Aviation Administration's (FAA's) planning documents, including the Flight Plan 2004-2008, the Target System Description, and documents from the Joint Planning and Development office. In addition, Eurocontrol proposed adaptive airspace management techniques like DR as an alternative to ground delays or reroutes (Eurocontrol, 1998). NAS controllers do some limited DR in today's system. However, there remain a number of questions about how NAS might implement the concept of unlimited DR and whether unlimited flexibility would be ideal.

Current resectorization regularly occurs when sectors are combined or decombined depending based on traffic demand within all Air Route Traffic Control Center areas. There are also numerous examples of controllers delegating airspace to another facility for specific uses. As a follow on to the Massachusetts Institute of Technology DR conceptual reports, the MITRE Corporation's Center for Advanced Aviation System Development developed a casebook describing situations in which DR was already being used in FAA facilities within the limits of the Host computer (MITRE, 2000). They identified clear procedures that were established for the transfer of predefined airspace. These included new maps provided to the receiving facility and, when appropriate, even produced flight progress strips for the receiving facility prior to the transfer. Although this indicated considerably flexibility under some conditions, much of the day-to-day activity in the NAS depends on organization and repeatability.

Fundamentally the NAS is a highly structured environment. Structure provides benefits including predictability to the decision-maker, in this case, the air traffic controller. When something is unusual, it is easily spotted as out of the ordinary, because of the brain's capacity for pattern recognition and identification of pattern changes. Expertise in pattern recognition does not develop quickly. In the current system, it takes En route controllers an average of about 3 years to certify as Certified Professional Controllers (CPCs, formerly Full Performance Level). In general, en route controllers must learn and check out on at least six different sectors to become CPCs.

There are situations, however, when the expected structure is lost and typical patterns cannot be achieved. These situations include but are not limited to the impact of weather systems and equipment outages. DR offers a tool in these situations to mitigate the loss of the decision makers' usual options. In our current system, those DR options themselves have been highly structured, adding the benefits of that structure back to the controller's strategy options.

# 1. Introduction

Dynamic Resectorization (DR) is a concept designed to increase flexibility in the National Airspace System (NAS), and thereby increase capacity while reducing delays. The concept involves dynamically moving airspace boundaries to accommodate traffic flow constraints such as weather, equipment outages, or active Special Use Airspace (SUA). Proposals can be found in a number of Federal Aviation Administration (FAA) planning documents, including the Flight Plan 2004-2008 (2004b), the Target System Description (FAA, 2003), and from the Joint Planning and Development Office. In addition, Eurocontrol proposed adaptive airspace management techniques like DR to replace ground delays or reroutes (Eurocontrol, 1998). Some limited DR is practiced in the NAS today. However, there remain a number of questions about how the NAS might implement the concept of unlimited DR and whether unlimited flexibility would be ideal. Answers to these questions have human factors implications for air traffic controllers. This report reviews existing literature on DR with a view to identifying the human factors issues that need to be considered as we move toward realizing the concept. This report also examines several alternatives to an unlimited implementation of DR.

## 1.1 Background

Air Traffic is projected to continue increasing in the foreseeable future (National Academy of Sciences, 2003). In the summer of 2000, delays were substantial enough that the FAA Administrator held meetings with aviation industry representatives and developed a plan to reorganize airspace to relieve nine “choke points” in the system. As of July 15, 2004, FAA Air Traffic Organization’s performance statistics revealed that two capacity indicators, on-time gate arrivals and operational availability, were below expected performance, indicating continuing capacity problems.

The FAA’s Flight Plan 2004-2008 notes that the challenges for aviation call for nothing less than transforming the system (FAA 2004b, p. 8). DR is a concept designed to provide a tactical tool, which theoretically may improve the situation. DR represents a radical change from today’s operations.

The concept is found in a number of the future plans for the NAS. In the Radio Technical Corporation of America (RTCA) Operations Concept, planners presented DR as flexible airspace to match the dynamics of demand. In the late 1990s, the FAA Air Traffic Airspace Management Program (ATA-1) lead a DR Workgroup with representatives from headquarters, Massachusetts Institute of Technology (MIT), Lincoln Laboratory, MITRE Center for Advanced Aviation System Development (CAASD), and the FAA William J. Hughes Technical Center (WJHTC) Human Factors Group (Wilhelmsen et al., 1999a).

The authors of the MIT report noted the following:

> Limited DR permits airspace management and reconfiguration based on a limited set of predefined airspace modules. Unrestricted DR allows unrestricted airspace reconfiguration. The limited DR concept is inherent in the current Host En route automation system. Enhancement of the Host's limited DR capability may be possible in the near term. Unrestricted DR requires a new automation system and is therefore not a

> near-term product-improvement option. Limited DR is a functional subset of unrestricted DR. (Wilhelmsen et al., 1999a, p. ii)

While unrestricted DR seemed a distant possibility, the authors focused on the present and near future in which they could conceive of Limited DR (LDR). The key word here was "limited" implying that considerable structure was likely to continue as long as technology took its current form and controllers continue to function in similar roles as they do today.

The current NAS is the baseline for all future modifications and improvements. A full understanding of DR requires an in depth knowledge of the system as it exists today.

### 1.1.1 The Current Airspace System

Current airspace is generally composed of rigid, predefined structures, or volumes. One operational volume is called a sector. One controller or a team of controllers is responsible for the safe and efficient flow of traffic through that sector. The airspace staff within the Air Route Traffic Control Center (ARTCC) defines sector sizes and boundaries. Sectors are based upon historical patterns of traffic and geography to ensure appropriate distribution of workload.

The air traffic system developed with route structures based on navigational aides as pilots navigated from one to another. Fixes were identified along the routes where controllers documented an aircraft's position by recording time over the fix. A fix could be a navigational aid, named or unnamed intersections of airways, or other location. The system prepared flight progress strips for each of these fix posting areas to keep track of each aircraft's progress. With automation of the NAS in the Host computer in the early 1960s, these fix posting areas (FPA) became the building blocks of the airspace adaptation database. Together, all of the FPAs in the airspace adaptation uniquely define the entire airspace within an ARTCC.

Sectors comprise one or more FPAs and are predefined in the adaptation database. Staffing levels to accommodate traffic flows commonly require combining or decombining sectors. This process is accomplished in the Host with a resector command (CS) in real time. In addition, the CS command allows reassignment of specific FPAs to another sector. Thus, the Host offers a limited resectorization capability. However, it is defined and limited by the FPA geometries and building blocks (Wilhelmsen et al., 1999a). Wilhelmsen and his colleagues pointed out that a substantial number of sectors (e.g., 60% of all ZKC sectors) are comprised of only one FPA and many sectors are very large. So, while the current system provides some DR flexibility, the flexibility is restricted by the automation's structural requirements (i.e., FPAs) and the logistics of changing the adaptation database. There have been a number of research studies concerning the concepts underlying resectorization.

### 1.1.2 The Concept of Dynamic Resectorization - Studies

#### 1.1.2.1 Contract Studies

Goldberg and Eberlin (1997) used fast-time modeling simulations to investigate the concept of DR. Using Salt Lake City ARTCC airspace, they adjusted sector boundaries to accommodate representative traffic flows from actual traffic patterns. They concluded that using adaptive boundaries allowed for more user-preferred routing, which resulted in fewer delays and better aircraft fuel efficiency.

Pawlak, Bowles, Goel, and Brinton (1997) completed a study under the joint National Aeronautics and Space Administration (NASA) and FAA Advanced Air Transportation Technologies (AATT) Program. They conducted a human-in-the-loop (HITL) simulation to evaluate sector complexity with more flexible, user-preferred flight paths (Pawlak, Bowles, Goel, & Brinton, 1997). Controllers were responsible for two adjacent high-altitude sectors from Cleveland ARTCC airspace. The researchers explored continuously changing boundaries versus a change to optimize airspace configuration at 15-minute intervals, as well as limited and unlimited resectorization. The authors found that they were able to duplicate modeling results for aircraft traffic density.

However, they warned that controllers rely on existing sector/air route dependencies for maintaining traffic awareness and safety. Pawlak, Bowles, Groel and Brinton (1997) began developing a tool to assist with more flexible flight routing entitled "Dynamic Resectorization and Route Coordination (DIRECT) System." This system could in theory facilitate increased information sharing among Traffic Management Units (TMUs) and Airline Operations Centers (AOCs). It would be designed to include prediction of airspace complexity and impact on controllers.

In an evaluation of the DIRECT System, Pawlak, Bowles, Groel and Brinton (1997) reported the following results:

- Procedures for changing sector boundaries should be formalized to ensure that transitions proceed smoothly.

- Certain automated enhancements can be used to minimize the amount of controller-controller coordination needed to accommodate a sector change.

- The frequency with which sector boundaries can change will be constrained by the complexity of traffic situations as well as the complexity associated with making each boundary change.

- Unless significant ATM system changes are made the magnitude of boundary changes will probably be restricted by current radio frequency limitations and controller specialization in certain areas of airspace.

- New sector configurations may need to be limited to a pre-defined set so that controllers can receive appropriate training for each configuration.

- Although more difficult to implement, added flexibility to accommodate weather systems or unusual traffic patterns may also prove beneficial.

The developers of the DIRECT, concluded that there are advantages with more flexibility in resectorization. However, the same authors sounded a note of caution. They concluded that despite potential flexibility, resectorization has limitations. It reduces the structure inherent in the current system, which allows it to work as well as it does.

#### 1.1.2.2 Massachusetts Institute of Technology (MIT) Lincoln Laboratory Reports

In 1999, the En route Integrated Product Team (IPT) requested an examination of a concept of DR and associated issues from the MIT Lincoln Laboratory (Wilhelmsen et al., 1999a). This effort resulted in four reports.

The authors noted that their idea arose out of a significant need expressed by personnel from oceanic and offshore Air Traffic Control (ATC) facilities (in a previous project) to have more flexibility in managing their airspace. The goals of the MIT DR program were to establish a common definition of the DR concept and to understand operational implications of implementing DR (Wilhelmsen et al., 1999a, p. 4)

The MIT authors defined DR as “a tactical airspace management capability that permits ATC sector boundaries to be adjusted in response to changing traffic flow patterns” (Wilhelmsen et al., 1999b, p. 1). The DR concept is that of a flexible and well controlled process of on-line sector boundary adjustment. They also distinguished between limited (capabilities within reach of near to midterm) and unrestricted DR (capability possible in a longer term timeframe). *Limited DR* provided for reconfiguration of airspace based upon a limited number of predefined airspace boundaries. Airspace planners would define these areas in advance of traffic demand changes. This concept provides flexibility when traffic patterns vary but display recurrent properties (e.g., specific time of day increased traffic demand). Because the boundaries are predefined, the resectorization is predictable. *Unrestricted DR* would, in concept, allow unconstrained boundary reconfiguration, which would handle recurrent, as well as unpredictable traffic flow demands. The MIT definition, however, did not mean an automatic, continuous, real-time boundary movement. The authors postulated that optimally reassigning airspace could result in improved workload balance, reducing coordination workload, and preventing sector saturation.

The MIT reports reviewed current NAS computers and sectorization, current practices of limited DR, human factors, and technical issues associated with the operational implications of implementing DR. Their operational concept “denotes an unrestricted but well controlled on-line process of sector boundary adjustment. It does not imply continuous sector boundary movement in real time in response to changes in traffic flow--that is, DR is not automatic and it is not continuous.” They envisioned a process that ensured positive control during resectorization. Specifically, their operational concept proposed a process in which the following occur: the developing traffic situation is predicted and monitored continuously; sector plans are developed and validated to balance sector demand and not exceed capacity; activation time is determined and prebriefed; and finally, the new sector plan is activated.

Wilhelmsen et al. (1999b) identified issues associated with the DR concept. These included both human factors and technical. Among the human factors issues, they identified the following: sectorization planning, situation awareness (SA), sector capacity, demand and workload, and training and certification. Technical issues involved predicting traffic and weather, automation and airspace constructs, communication, and surveillance.

#### 1.1.2.3 Human-in-the-loop (HITL) Simulation

As a follow on to the MIT work in 2000, the WJHTC NAS Human Factors Branch conducted a HITL simulation to examine the human factors of DR (Hadley & Sollenberger, 2002; Hadley, Sollenberger, D'Arcy, & Bassett, 2000). The researchers simulated adjacent sectors in different ARTCCs using generic airspace to investigate two candidate applications of DR for severe weather and traffic. The study compared fixed boundary sectors to preplanned boundary adjustment. Twelve current, nonsupervisory, full performance level ATC Specialists from several different FAA facilities participated in the study. The researchers examined system effectiveness, controller workload, and subjective measures.

The researchers' approach to DR was to predefine specific airspace that could be dynamically allocated from one ARTCC to the other based upon the traffic situational demands (high traffic or severe weather). Subject Matter Experts provided airspace design and procedures, and briefed the participants on areas of responsibility during DR. In the weather scenario, weather patterns dictated a region of airspace to allocate from one sector to the other so that the controller receiving the new area could accommodate deviations around the weather. The researchers hypothesized that this would decrease the handoff, point out, and communication workload for the controller. In the high traffic scenario, projected traffic loads in the north sector prompted a boundary adjustment to allow the south sector controller to assume responsibility for traffic on a jet route through the north sector and thereby balance controller workload.

The researchers provided controllers with a 2-minute notification prior to the boundary adjustment. They had to complete all handoffs and communication transfers during these 2 minutes. At the end of the 2 minutes, the resectorized maps appeared on the radar display.

Resectorization significantly decreased the number and duration of landline communications between the sectors compared to baseline. On postrun NASA TLX measures of workload, both resectorized conditions resulted in significantly lower ratings than baseline. On the real-time Air Traffic Workload Input Technique (ATWIT; Stein, 1985) ratings of workload, the weather resectorization resulted in significantly lower workload ratings. Controller subjective self-ratings of their own performance were higher for the resectorized scenarios for both weather and traffic density. Subjective situational awareness ratings were significantly better for the weather scenarios after resectorization.

The researchers observed that this was just an initial evaluation of DR in dynamic, HITL simulation under two ideal conditions. They cautioned that a number of additional questions that needed answers when resectorization should occur, how long it takes the controller to adapt, how often airspace can or should be resectorized, and can it be incremental. The authors pointed out that resectorizing too early may waste resources. Waiting too long may adversely affect the controllers' ability to maintain safety and efficiency. Finally, the researchers raised the question of the situation specific character of the benefits and the need to identify where it might not be appropriate.

1.1.3 Current DR Practices at FAA Facilities

Current resectorization regularly occurs when sectors are combined or decombined depending on traffic demand within all ARTCCs. There are, however, other numerous examples of airspace being delegated to the control of another facility for specific uses. The MITRE Corporation's CAASD developed a Casebook describing situations in which DR was already being used in FAA facilities within the limits of the Host computer (MITRE, 2000) as a follow on to the MIT conceptual reports on DR. These situations employ a number of structured, preplanned activities. Facilities establish the airspace boundaries and procedures, a priori, and incorporate them into the facilities' policies and training. The receiving facility gets new maps and when appropriate even flight progress strips. CAASD's casebook focused on six specific examples of DR implementations including equipment outage, weather, SUA, airport configuration change, traffic volume, and oceanic track change. The examples involved transferring control of predefined volumes of airspace to another facility. The examples are summarized here.

Equipment outages can result in reduced service to particular areas. CAASD's casebook (MITRE, 2000) presented an example of an area in Miami ARTCC (ZMA) airspace with radar coverage by one long-range radar. When the radar is out of service due to scheduled or unscheduled maintenance, aircraft in parts of the airspace are not visible under ZMA radar coverage. In this condition without resectorization, controllers must apply nonradar separation procedures, which require greater spacing between aircraft and cause delays. The Jacksonville ARTCC (ZJX) radar provides radar coverage for the affected ZMA airspace. To avoid the nonradar control condition and ensure radar service, both ARTCCs defined a volume of airspace to accommodate northbound and southbound traffic flows for which they could conduct a limited DR. Designated the HOBEE area, this rectangular airspace covers altitudes between Flight Level 240 (FL240) and 600. When the ZMA radar is out, control of the HOBEE airspace is delegated to Jacksonville ARTCC. ZJX controllers provide radar separation to the aircraft transitioning HOBEE and hand off to the next ZMA sector. The ZMA controller accepts the handoff when he/she sees the aircraft has been acquired by another radar covering that Miami airspace. This arrangement provides seamless radar separation rules for flights instead of reverting to nonradar rules or rerouting around the area.

In the current Host automation, ZJX only needed to develop new maps in their airspace adaptation database to show HOBEE. When HOBEE is delegated to ZJX, they just display the maps and traffic at the appropriate controller position. CAASD documents that both ARTCC TMUs coordinate the delegation based upon procedures precisely specified in a Letter of Agreement (LOA). When the radar is taken off-line in a scheduled outage, the TMUs coordinate with the affected areas and determine a time for the change over. If the radar outage is unscheduled, controllers may coordinate with each other before the official switch occurs. ZJX already has flight progress strips for the aircraft transiting HOBEE. Automated features like automatic handoff work across facilities and will flash the target to the next ZMA controller.

Thus, through predefined airspace, plans and procedures, and training, airspace can be dynamically resectored using current automation to accommodate traffic demands. In this arrangement, however, everything is clearly structured, planned, and trained. ZJX controllers are certified like any other airspace to work the HOBEE airspace prior to being assigned to work traffic. CAASD notes that the guidelines for static airspace design are easily adapted to those dynamic procedures. Also there is obviously more to airspace planning and management than traffic demand alone.

Weather provides one of the most compelling cases for unlimited DR capabilities. Weather, alone, accounts for 70% of the delays in the NAS (Ahlstrom & Della Rocco, 2003). Air traffic controllers must regularly reroute traffic flows around weather to avoid storms or turbulence. From day to day, flights request routing to minimize or maximize effects from winds. Unlike the previous case of radar outage, the unusable airspace changes and is less predictable.

The CAASD Casebook presented an example again from Florida airspace. Florida is notorious for the summer thunderstorms that build in the afternoon. Jacksonville and Miami Centers have defined airspace, MALET, on their boundaries, which can be reassigned from ZMA to ZJX to accommodate Orlando arrivals and departures. As storms pass north of the airport, controllers move the departure flow toward the east, which may encroach on an arrival stream from the northeast. Without DR, moving the arrival stream to the east to make room for the departures requires rerouting the arrivals through ZMA airspace. For reroutes, controllers must coordinate the new routes with other controllers, as well as enter the new route into the Host computer, creating a large workload if traffic volume is high. The MALET airspace sits east of Orlando airport and on the north side of ZMA airspace. When ZMA allocates the MALET to ZJX, controllers can route traffic through it using vectors instead of the formal reroute and coordination. As was the case with a radar outage, the airspace could be predefined in this case because the pattern of storms was recurrent and predictable enough. Traffic management then entered MALET in the Host airspace adaptations and maps at both facilities. A negotiated LOA defined the procedures for delegation of the airspace. Specifically, ZJX requests MALET when storms are present. The ZMA TMU sets an appropriate time for the transfer of control based upon their traffic situations. CAASD authors noted that ZJX and ZMA controllers may informally coordinate prior to the formal transfer. Along with weather issues, SUA generates additional opportunities for resectorization.

SUA is a predefined airspace with restrictions on its use. Examples are Military Operations Area (MOA), Restricted and Warning Areas (FAA, 2004a). A MOA is airspace established to indicate areas where the military is conducting activities, such as air combat, aerobatic, or low altitude tactics, and to separate nonhazardous military activities from IFR traffic or identify where activities are occurring for VFR traffic. Restricted areas limit the use of the airspace and usually are established to protect traffic from the existence of unusual, often invisible, hazards to aircraft such as artillery firing, aerial gunnery, or guided missiles. Warning areas are predefined airspace over domestic or international waters identifying an area where there are activities that could be hazardous to nonparticipating aircraft. Many of these are jointly used until they go active. When these SUAs become active, traffic that would otherwise transit the airspace must be moved. CAASD presented the example of a situation created by a Kennedy Space Center launch. For certain types of rocket launches, the airspace over the Atlantic Ocean east of the launch site is closed. A large number of warning areas allocated to the Department of Defense (DOD) along the Atlantic coast complicate this because the normal over- water routes are east and above the DOD warning areas. Controllers reroute air traffic back over land north of the warning areas causing an increase in workload for northern ZJX controllers as the ZJX sectors become congested. To alleviate this situation, ZJX, ZMA and DOD negotiated ZJX access to a corridor of airspace through a warning area and including a small piece of ZMA airspace.

Airport configuration changes present another example in which controllers can effectively use resectorization to improve efficiency.  The CAASD authors described the example of wind shifts that cause reconfiguration of an airport and change traffic flows in overlying airspace.  Sector boundaries may be extended off the departure end of the runway to allow for reduced coordination for climbing aircraft.  CAASD presented the example of shifts in airport configurations at Atlanta and Charlotte airports.  Reconfiguration of these airports affects the traffic flow of departures into the Atlanta ARTCC (ZTL) airspace.  Depending upon the operation, east or west, aircraft departing an airport to the opposite direction of their filed route would need to turn back.  The system can hold aircraft at lower altitudes in Terminal Radar Approach Control (TRACON) airspace until the turn was completed to minimize the controller coordination required.  The lower altitudes interrupted the aircraft's climb and increased fuel consumption.  ZTL designed the airspace to accommodate departures relative to the configuration of airport operations by resectorizing.  Charlotte had a north-south operation and similar issues.  Because Charlotte's airspace is next to Atlanta's, the resectorization included consideration of both airports' configurations.  ZTL designed four new sets of maps for each combination of Atlanta and Charlotte operations.  The new airspace involved changes in boundaries that included airspace from different areas of specialization.  The maps clearly indicated the controller's airspace, the neighboring airspace, and other key information so that no confusion resulted for the controllers.  Switching to the new configuration involves coordination among all affected sectors and facilities prior to switching.

The fifth example of application of DR CAASD presented in the Casebook was due to fluctuations in traffic volume.  Sectors are regularly combined or decombined to accommodate changes in traffic volume.  CAASD described a much more complex example than the usual from Minneapolis ARTCC (ZMP).  In the example ZMP experiences a number of unique scheduled and unscheduled events.  The Oshkosh Fly-in is a scheduled event in which traffic escalates one time per year.  Midwestern thunderstorms can disrupt normal traffic flow into Chicago and Detroit.  CAASD authors noted that entire Chicago inbound and outbound streams that would normally be managed by Cleveland ARTCC could be routed through ZMP airspace. In addition, hunting and fishing seasons bring heavy traffic.  ZMP has very large sectors that may require multiple frequencies.  In addition, they did not have enough workstations to accommodate all the split sectors they needed.  As in other cases, the airspace adaptation designed the FPAs to allow resectorizing.  However, due to the workstation limit, a FPA may be assigned to a specifically designated area workstation, instead of the adjacent workstation. These two items lead to unique issues in this resectorization strategy, in which the supervisor must ensure that flight progress strips and frequency assignments are routed to the appropriate workstation.  CAASD noted that a controller might need to manually route the strips to the right printer.

Finally, CAASD presented the example of Oceanic Track Changes, which result in dynamically changing airspace configurations.  The winds aloft determine the most effective routes for oceanic traffic daily.  When the winds shift, the optimal routes may also shift and result in changes in the oceanic tracks to take advantage of the winds.  Most traffic in Oakland ARTCC's (ZOA) oceanic airspace travels east to west across the Pacific Ocean.  ZOA reconfigured their oceanic sectors to match the east-west tracks, such that each track was controlled by only one or two sectors.  This minimized the number of handoffs and workload for each controller and pilots. As the winds aloft shift, they adjust the sector boundaries to accommodate shifting tracks.

CAASD notes this may occur a couple of times per day. ZOA found a work around in the computer to allow the total number of FPAs required to be flexible. At the time of the report, the same oceanic geographic map was used all the time in the ZOA oceanic area, so no new maps were required. The supervisor drew temporary airspace lines on the map so controllers could visualize the airspace as new tracks were developed.

All of these examples of limited DR are in use in today's airspace. In closing their report, the CAASD authors identified some topics addressing concerns noted by facilities when they provided the examples above. After listing a number of candidate situations, the authors suggested that when the "effects of an identified factor are consistent each time the situation occurs, with predictable impacts that standard airspace configurations do not address, the LDR techniques presented in the six cases may be helpful"(MITRE CAASD, 2000, p. 4-2). The CAASD authors pointed to existing airspace management guidelines, which include periodic refresher training, periodic evaluations to see if additional situations qualify, and periodic evaluation of the strategy. They noted that LDR is unlike a one-time airspace change, because LDR requires procedures for applying the strategy, which should cover the criteria for activation and the roles and responsibilities of the participating controllers.

Most researchers who have worked with resectorization concepts and have included controllers in their process see both possibilities and limitations with DR. From the beginning of formal ATC, controllers themselves have been both the strongest asset (we have not been able to replace them with machines despite predictions to the contrary over 20 years ago), and they also represent the limitations that human beings bring to system operations.

### 1.1.4 Human Factors Issues

The NAS is a highly structured environment. Structure provides benefits including predictability for the decision-maker, in this case, the air traffic controller. When something is unusual, it is easily spotted as out of the ordinary because of the brain's capacity for pattern recognition and pattern anomalies. Expertise in ATC pattern recognition does not develop quickly. In the current system, it takes En route controllers an average of about 3 years to certify as Certified Professional Controllers (CPCs, formerly Full Performance Level). In general, En route controllers, for example, must learn and check out on at least six different sectors to become CPCs.

As noted in the CAASD examples, there are situations when the structure is lost and typical patterns cannot be achieved as with weather systems and equipment outages. DR offers a tool in these situations to mitigate the loss of some of the decision makers' usual options. In our current system, DR options are highly structured, adding the benefits of that structure back to the controller's strategy options. This section discusses the human factors issues associated with the controller and DR.

#### 1.1.4.1 Mental Models of the Airspace

A mental model can be defined as the mental structure within which an individual understands how a system works with respect to its internal components and processes (Kieras & Bovair, 1984). In many respects, the mental model drives both prediction of system future states and problem solving (Gott, Lajoie, & Lesgold, 1991). Controllers must rely on their mental model of the airspace and the air traffic patterns through the airspace to successfully and safely control traffic (Redding, Ryder, Seamster, Purcell, & Cannon, 1991). Controllers refer to their mental model as the "Picture." Recent efforts to remove structure from the system have been proposed in Free Flight efforts and have raised safety concerns (Nunes, 2003). Controllers fear loss of their picture and sufficient situational awareness to maintain separation.

Researchers have reported several studies of controllers' conceptual structures. Mogford, Murphy, Roske-Hofstrand, Yastrop, and Guttman (1994) used two scaling techniques to investigate the controller's internal representation of the relationships among ATC system elements. The researchers developed a list of 17 concepts from an ATC task analysis (Ammerman et al., 1987) and asked 11 controllers to provide ratings of relatedness between all possible pairs. They divided the 11 controllers into "high timers" (25-35 years experience) and "low timers" (5-10 years experience). Five individuals with no ATC experience also provided ratings. Researchers used multidimensional scaling (MDS) to infer the underlying dimensions among the concepts and Pathfinder network analysis to explore the importance of local relationships between concepts. The MDS derived two dimensions, planning and context. The Pathfinder network analysis generates network diagrams among the concepts. Analyses demonstrate associations, centrality of concepts and cycles in which a concept is a beginning and end. The researchers found for example that high time controllers organized other concepts around weather. They found clear differences between the controller groups and the control group. In addition, they found subtle differences between the two controller groups. Experience leads controllers to more effectively structure their environment to temper the taskload and make events more predictable. Sector structure has an impact on organization and how controllers think. Other studies as well have also focused on controller cognitive processes.

Fields, Wright, Marti and Palmonari (1998) examined ATC using a distributed cognition analysis. This analysis regards cognition as a property of a system of individuals, such that the unit of analysis, in this case, is the group of controllers working on the approach sector, the pilots under their control, and the artifacts that are part of their work. They describe ATC as "undertaking a computation to maintain separation between aircraft in a region of airspace, and at the same time attempting to improve the routing of aircraft through airspace" (p. 2). To do this, the authors suggest that the system has three parts. First, a controller is "looking for near intersections of four-dimensional (4D) trajectories (three spatial dimensions (3D) and time), or rather looking for times where two 4D trajectories are not separated in 3D space" (p. 2). Second, a controller takes some action when a future conflict is detected within a number of possibilities (changing altitude, speed, or route or one or both aircraft). The controller continues to update the projection of the situation into the future to incorporate changes and new influences. The researchers point out that although solving the conflict detection problem is complex, they discerned a number of constrained special cases, which simplify the 4D problem. Recent efforts to remove structure from the system have been proposed in Free Flight have raised safety concerns (Nunes, 2003).

Researchers at MIT (Davison, Histon, Ragnarsdottir, Major, & Hansman, (2003); Histon, Hansman, Aigoin, Delahaye, & Puechmorel (2002)) examined the concept of structure in airspace and procedures to support the reduction of cognitive complexity for controllers. Structure constrains the dynamic changes in the environment and, thus, reduces the cognitive load for controllers. When taskload increases to a point that controllers feel loaded, they will impose more structure of their own by flying aircraft strictly by their flight plans and declining requests for change wherever possible.

Histon et al., (2002) noted that much of the structure in air traffic today is codified in standard procedures, regulations, airways, and airspace boundaries. Thus, application of the structures helps limit and simplify cognitive complexity. For example, airways limit the number of entry and exit points in a sector. These researchers examined the use of structure to reduce cognitive complexity through subjective measures, system state measures, examination of the codified structure, communications, and an empirical probe. Through interviews with controllers at a number of facilities, the researchers identified key factors influencing complexity within three categories of airspace, traffic, and operational constraints. From the interviews, they identified hard and easy sectors. Using Enhanced Traffic Management System (ETMS) data from the sectors, they demonstrated that the hard sector had more crossing and vertical transitions than the easy sector. They also observed, however, that a higher percentage of traffic was on standard routes (43%) in the hard sector than in the easy sector (20%). The researchers found this to be consistent with the reduction of complexity through use of standard routes. They noted controllers develop an abstraction based upon an aircraft's membership in a standard traffic flow, which is the foundation for managing high-density traffic. This allows the controller to manage the stream, rather than each individual aircraft, reducing cognitive complexity. The authors presented the approach pattern to Chicago O'Hare and demonstrated that there are three or four major merge points in the flow patterns. These points reduce the multidimensional aspects of merging numerous aircraft to a single dimension of separating by time over the merge point. Within the codified aspects of the NAS, the authors note that much of ATC is explicitly designed and documented in charts, as well as procedures and even dynamic elements, such as traffic management restrictions.

To validate the structural abstractions, the researchers conducted an empirical probe in which the structural basis was manipulated as an independent variable. Using a simplified ATC task, participants were asked to use only speed control to achieve miles-in-trail separation when leaving the sector. The researchers manipulated the number of incoming streams and merge points. They either had one collocated merge point or multiple points. While college students were the participants, the results demonstrated that collocated merge points resulted in fewer separation violations, fewer speed changes, and lower difficulty ratings.

It would seem that from a controllers perspective simpler is better. Also they see structure as a powerful tool to help them maintain control. Movement away from structure and towards more flexible resectorization will undoubtedly face resistance unless developers can show controllers how it improves their situation rather than making it more complex.

#### 1.1.4.2 Situational Awareness

The previous section addressed the mental model in which we focused on structure of the airspace to support the model. This section addresses SA to focus on the involvement of time and prediction. Endsley (1988) defines SA as the "perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." She indicated that the basis of a controller's SA is derived from the elements in the environment, such as displays, readouts, and communication channels (Endsley & Rodgers, 1996; Endsley & Smolensky, 1998). She additionally noted that SA is moderated by his or her capabilities, training, experience, preconceptions, objectives, and taskload.

The MIT (Wilhelmmsen et al., 1999b) report provides some requirements for supporting SA in any DR system. They cite Endsley's three levels of SA and the importance of providing support for each level in any system that uses DR. The first level of SA involves perception of the elements in the environment. Therefore, to ensure adequate SA in any DR system, the system must be able to display the status, attributes, and dynamics of relevant elements in the environment. They emphasize that the controller must be able to clearly see the airspace on the screen for which he or she is responsible. The second level of SA is comprehension of the current situation. This involves understanding the meaning and significance of the elements in the environment. The MIT authors emphasize that it is necessary to facilitate the relationship of traffic to the new boundaries through enhancing attention and comprehension. Level 3 SA is the projection of future status and behavior of the elements in the environment. With DR, aids must ensure that decisions are made on the basis of the sector currently in operation as well as any history and prospective issues that will need to be handled regardless of sector geometry (i.e. clearing an aircraft to a new altitude at a time or location the controller planned for to avoid a potential conflict and not being distracted by the resectorization process). Maintaining SA requires effort on the part of the controller, which can add to his or her workload. DR may increase or decrease load depending on its implementation.

Visual display of sector maps may become an issue for both the reestablishment of correct mental models and SA. As sector geometry changes in resectorization a change in the map provided to the controller could reduce mental workload centered on trying to code and store new geometry. Unfortunately, according to Cochran et al. (1999a), both Host and the Direct Access Radar Channel limit the number of available on-line maps. There are also map size limitations in the Design System Replacement (DSR) system. This could have a direct impact on controller SA when trying to work traffic in transition and hold the map boundaries in working memory. This issue may or may not have been resolved through a NAS change request in the time since the MIT reports were written.

#### 1.1.4.3 Workload

A key concept of DR is to offload controller's workload by redistributing traffic in a dynamic fashion. With today's traffic management tools, it is more possible than ever to dynamically distribute traffic. Again, Wilhelmsen et al., 1999b, defined guidelines for a DR system to mitigate or avoid a workload overload situation for a controller. The authors note that a sector demand metric must map reliably and consistently to controller workload under all conditions and must be relatively insensitive to variations in unpredictable aspects of the traffic.

Hadley et al., (2000) raised a critical question that interrelates system dynamics and the human decision making process of when to resectorize. They expressed this question as follows:

> However, several studies are needed to explore different approaches to dynamic resectorization. In addition, there are a number of operational and technical questions

> that need to be addressed. In particular, when should you resectorize? The goal of investigating this question is to determine the optimum point for resectorization to occur. Too early, is an inefficient use of resources, while changing airspace after the controller(s) is/are already busy may have negative consequences in terms of his/her ability to safely and efficiently control traffic. A predictive capability, such as a measure of airspace complexity (i.e., dynamic density), would not only have to account for the sector complexity at some predetermined look-ahead time but would also be required to incorporate the transition time of the system to accommodate the resectorization process. For example, if a dynamic density index indicated that the sector complexity was going to exceed a given threshold in xx minutes and the transition period for the resectorization process is 30 minutes, then the controller working this sector should receive notification 30 +xx minutes in advance. Is this amount of time sufficient for the controller to work in and become comfortable with this new airspace configuration before the predicted rush? This amount of time may be more than adequate, or controllers may require considerably more time to become accustomed. It is this period of time that needs to be addressed in simulation. (p. 25)

Human workload is an important issue in any person-machine system. Psychologists have been studying the construct for over 50 years. We know that controllers are motivated professionals and that they will continue to work harder as taskload increases. However, even they can be overwhelmed and at that point performance declines. DR may help manage taskload under some specific conditions and assist planners in optimizing workload. We know that workload can be too high, and history demonstrates it can also be too low since most systems errors occur at low-to-moderate levels of traffic. When DR is used it will have to consider both current levels of demand and how that demand is redistributed between the new sectors as defined by the system.

1.1.4.4 Communications

Communications take many forms in an active ATC facility. Requirements for communication and coordination are inherent in the job of the controller. According to Wilhelmsen et al. (1999a):

> The sector controller must maintain a current awareness of all activities, events, and conditions in his/her airspace, such as flight restrictions, reroutes, military operations, etc. He or she must also coordinate aircraft movements with adjacent sectors and facilities as required. This coordination may be done by landline, by interphone, or by direct verbal communication if the control position of the adjacent sector is close enough. Coordination activities related to traffic crossing, or flying close to, sector or facility boundaries can make up a large part of a controller's workload. They include handoffs, point-outs, interfacility coordination, and ground-to-air communication. The need to limit this boundary-related coordination and communication workload is an important consideration in the sector design process. While it is possible to take this into account when there is consistent structure in the traffic flow, it becomes increasingly difficult to do so when the traffic is more variable. (p. 13)

Any change to sector structure whether preplanned or dynamic influences who the controller needs to talk with and when. If the changes and points of contact are not completely and instantly, apparent there is the possibility that coordination may break down leading to systems errors. The more dynamic the system the more important it will be to provide the controller with the critical information he/she needs during or preferably before any sector transition occurs.

1.1.4.5 Some Proposed Work Arounds

Cochran et al. (1999b) interviewed controllers in operating facilities and proposed some technology work arounds that may facilitate the use of resectorization at least on a limited basis. Controllers are generally very bright and often creative people; this is especially true when they are told to use systems and procedures that may not be all that they could have wanted if they had been involved in the original design.

One controller proposed using a dummy data tag on a radar display as a memory jogger that an airspace change would occur at a point in time. This would involve starting a track on an aircraft with no velocity and entering text in the tag as a reminder that for example a piece of SUA would be activated at time “x.” This would only be useful for anticipated actions that might be foreseen under LDR for example.

Some controllers in the past used grease pencils directly on the PVD surface to indicate altered boundaries and other relevant information. Apparently they cannot do this on DSR monitors, but some use a dry erase marker, which is discouraged but undoubtedly used by some controllers.

Given additional requirements with no underlying technology, controllers will often find a way to make it work and stay within safety parameters. However implementing procedural change without supporting technology is not a systems engineering approach. It can lead to unique solutions that are not transportable to other facilities and operations.

1.1.4.6 The Search for Resectorization Triggers

Over the years both within the human factors community and beyond, researchers and mathematicians have been looking for a method to operationalize decisions to manage the load and the subsequent workload of controllers. First line ATC supervisors routinely watch the traffic flow to determine if they need to add people to sectors or combine or decombine those sectors. This is a subjective process honed by years of experience working as an operational controller then as a supervisor. While there are checklists to compute complexity (which generally is interpreted uniquely by each controller), supervisors make decisions based on what feels right for the moment. After interviewing many controllers, Mogford, Guttman, Morrow, and Kopardekar (1995) drew the conclusion that complexity, despite an official FAA definition, is and was a subjective construct used by control personnel in their own unique way.

Dynamic density (DD) is another construct that materialized in the 1990s with various formulations by different researchers. Developers looked for a math model that could capture current operations and anticipate the future so that both controllers and TMUs could better balance the operation for smooth functioning and eliminate bottlenecks or choke points. Laudeman, Shelden, Branstrom, and Brasil (1998) developed one model at NASA. Their definition was as follows:

> The definition of metric of air traffic controller workload based on air traffic characteristics is essential to the development of both air traffic management automation and air traffic procedures. Dynamic density is a proposed concept for a metric that includes both traffic density and traffic complexity. It was hypothesized that a metric that includes terms that capture air traffic complexity will be a better measure of air traffic controller workload than current measures based only on traffic density. A weighted linear dynamic density function was developed and validated operationally. The proposed dynamic density function includes a traffic density term and eight traffic complexity terms. A unit-weighted dynamic density function was able to account for an average of 22% of the variance in observed controller activity not accounted for by traffic density alone. A comparative analysis of unit weights, subjective weights, and regression weights for the terms in the dynamic density equation was conducted. The best predictor of controller activity was the dynamic density equation with regression-weighted complexity terms. (Abstract)

Kopardekar and Magyarits (2003) defined DD as "… the collective effect of all factors, or variables, that contribute to the sector level ATC complexity or difficulty at any given time" (p. 1.). They noted that DD was a construct with much in common with "Complexity" and or the difficulty of operating the sector. These researchers collected traffic samples from a number of centers a ran linear regressions between DD variables in various combinations against complexity ratings of the same sectors at the same time frames. The results indicated, "A unified DD metric composed of variables from several organizations performed the best. The results indicated that DD represents instantaneous sector complexity better than aircraft count, which is the currently used method. The results also indicated that the prediction of complexity using DD is somewhat better than the prediction using aircraft count most likely due to the inherent inaccuracy of predicting aircraft count" (p. 1).

Smith, Scallen, Knecht, and Hancock (1998) used the DD concept to predict collision risk within a sector of airspace. While their model evaluated using a series of sensitivity analyses focused on the cockpit, the authors believed it was applicable to en route ATC. They proposed that TMUs in ARTCCs could use the technique for adjusting the criteria they use for computing the critical capacity of sectors.

The FAA does have a strategic planning tool used by traffic management coordinators for planning purposes. This is called Monitor Alert (M/A) and is a component of the ETMS. M/A analyzes traffic demand for airports, sectors and reporting fixes. It compares current and projected demand against capacity and provides alerts when the load may exceed capacity (NASA, 2005). The criterion for an alert is known as the Monitor Alert Parameter (MAP). These are computed based on average sector flight time. The longer the flight time the less efficient and more loaded is the sector. This leads to a higher MAP more likely to trigger an alert. For the more serious alerts the coordinator may notify the area/sectors affected. Primarily traffic management coordinators who take strategic actions to avoid sector overload use this information. It does not appear that tactical supervisors routinely have the information or use it currently to make resectorization decisions (Phillips, personal communication, April 15, 2005).

There was an interesting addendum to this issue of automated planning and alerting tools. A near miss situation occurred in airspace that was using the M/A tool a number of years ago.

National Transportation Safety Board (NTSB) investigators noted that the MAP is supposed to be updated and adjusted periodically to reflect current conditions, but it had not been done so the controller working the Bradford sector may have been overloaded. The investigators said:

> The FAA is increasingly relying on the use of automated systems, such as ETMS, for traffic monitoring and demand assessment. Much of the data used by ETMS to perform trajectory estimation and other predictive tasks are sent to the system as an indirect result of NAS computer entries made by controllers. However, air traffic controllers questioned about ETMS and monitor alerts appeared to have very little knowledge about ETMS processing and what information it uses to produce its predictions. The Safety Board is concerned that if controllers do not understand the effects that their actions have on the data made available to ETMS, they may inadvertently mislead the system and reduce its effectiveness, as occurred in this case. Therefore, the Safety Board believes that the FAA should provide air traffic controllers with annual refresher training designed to ensure that they understand the relationship between NAS and ETMS, including an overview of ETMS predictive functions, the data flow and message types exchanged between NAS and ETMS, and the various factors that may affect the accuracy of ETMS predictions.
>
> The excessive traffic level in the Bradford sector was discovered only as a consequence of the subsequent operational error investigations and would possibly not have been discovered or received management attention if the error had not occurred. The FAA appears to have no formal process for the identification and investigation of situations in which a sector is subjected to excessive traffic demand when no otherwise reportable event takes place. The Safety Board is aware that the FAA has implemented a process for reporting and tracking ATC equipment problems through Unsatisfactory Condition Reports (UCRs); however, no similar system exists for procedural problems. Therefore, the Safety Board believes that the FAA should establish a formal method for ATC personnel to report instances in which sectors become overloaded (similar to the UCR process), so that the circumstances causing or permitting overloading can be identified and addressed. (NTSB 2000, p. 5.)

It appears that automated tools without both initial and recurrent training may not do what is expected of them. Further, facilities using the tools require clear procedures for implementation and updating of the required data fields as the situations change.

## 1.2 Discussion

NAS is a complex person-machine system, which will undoubtedly evolve as the demand for airspace and services continues to grow. Predictions are in accordance with projections from the FAA and other affiliated organizations such as RTCA (2002).

The NAS is built upon the performance of humans in both the cockpit and ATC. In the current system, it takes En route controllers an average of about 3 years to certify as CPCs. Thus, both the agency and the individuals have invested quite a lot in achieving the workforce we have today. They do what they do quite well given the technology they have and the training that is used to certify them. There are many organizations and individuals who have a stake in airspace and how it is used.

RTCA (2002), a private, not-for-profit interest group, focused primarily on the airspace users. The authors of their documented concept of operations for the future indicated that while human operators in a ground control function perform best at higher order decision making, they have finite limits in terms of the number of aircraft they can monitor and control at any point in time. RTCA anticipates that automation will increase efficiency to the point that controllers would only intervene by exception while maintaining responsibility for separation and higher order decisions. It is somewhat ironic that these same words or words of the same intent appeared in documentation on the Automated En route ATC system over 20 years ago when predictions for the capabilities of computers suggested that controllers would be obsolete in a few years. Yet controllers still make tactical decisions in today's system, and when they reach a load point where things are too busy or too slow, there are manual techniques for rebalancing the load.

In the current system resectorization exists and is used effectively in response to changing traffic flows and weather. The system provides some guidelines and procedures for how this is done, and controllers know what to expect based on past experience in airspace with which they are familiar. In today's system resectorization decisions are made by first level supervisors based on their experience with the airspace and the people working in it. Guidelines are often implied rather than written and despite the idiosyncratic aspects of this, it seems to work rather well. In the future it may be possible and even feasible to expand low technology resectorization under the limitations that structure is maintained, and controllers expectations are not violated. Written procedures and standardized training may facilitate this. However, further use of limited or unlimited DR with more dynamics may require additional system innovations and new technology. Issues concerning the appropriate triggers for resectorization remain to this day. While there are math models that attempt to identify current system demand and anticipate future demand, they generally emphasize system variables and essentially discount the human operator. Math models applied systematically are likely to be better than completely arbitrary or from-the-gut decision processes, but they fail to capture both the strengths and weaknesses of the operators currently working. It seems likely, as resectorization plans and procedures develop along with new technology, that both better models and decision criteria will be needed. The final decision on when and where to resectorize will likely remain with the supervisor on duty who hopefully has the best understanding of the people working the traffic and what they can and cannot do effectively. This involves a balancing of the technology and the human factor on an individual basis that likely will provide the best system performance so that resectorization decisions are not accomplished too early or too late.

Some believe that the primary answer to all the airspace issues will be that:

> Automation technology must be fully exploited in order to increase the traffic handling capacity of the airspace while at the same time giving the controllers and other ATC specialists the tools they need to ensure the safe, orderly, and expeditious flow of traffic. DR is one element of this new automation technology. Properly implemented and used, DR will allow the threshold between free flight and organized traffic to shift in the direction of free flight. Such a shift is likely to produce significant economic benefits. (Wilhelmsen 1999a, p. 16)

In today's NAS environment, DR provides a valuable tool for air traffic managers to maintain traffic flows while accommodating equipment outages, weather systems, and such. However, in the current system, the application of DR is limited by a number of factors, including limited fix posting areas in the Host computer and limited numbers of frequencies. Within this limited DR, the application is highly structured. Airspace is completely defined. The Host adaptation databases are modified. New maps are presented to the controller. Letters of agreement and memoranda of understanding incorporate procedures for implementation. All controllers are trained. All parties coordinate the time of the switch.

The operational concept for DR, however, is much more expansive than today's limited implementation to include unlimited DR. We can certainly imagine a day when the computer's limits could accommodate real-time adjustments of sector boundaries. Today's controllers build expertise of the specific airspace they work, which includes knowledge of obstacles, radar coverage, traffic patterns, and adjacent frequencies. Dynamically changing their control risks loss of situational awareness.

As we move forward toward more flexibility in the NAS, we must support the controllers' SA. Athenes, Averty, Puechorel, Delahaye, and Collet (2002) suggested that controlling air traffic might not be so much problem-solving task, but more a perceiving and decision-making task. Therefore, an unlimited DR must clearly indicate what airspace a controller is responsible for at all times. That means a real time adjustment to sector boundaries must be displayed in real time to the controller. The controller must know what new frequencies to change aircraft to as they transition out of the new sector. Controllers in surrounding areas must know they have lost airspace to a new DR and know precisely and graphically what they control. This is problematic, because today's sectors are not neatly shaped. Some have shelves and extensions that must be clearly depicted. In addition, the two-dimensional displays do not indicate altitude strata under a controller's responsibility.

Adding structure and constraints to the resectorization can assist the controller's SA. For example, if a traffic flow must avoid a weather system dynamically, limit the controller's responsibility to just that flow. Block the altitudes and inhibit crossing traffic. Ensure that surrounding controllers don't clear anyone into the new airspace.

To avoid the situation in which a controller may not be aware of obstacles or other airspace constraints, ensure that the DR occurs only in areas in which the controller has knowledge of the airspace. Training and practice in DR is critical in order for controllers to build expertise about potential problems.

As the NAS develops, we need to off-load secondary tasks from the controller. For example, one of the problem today's controllers express about unlimited DR is the frequency change. Moving boundaries would leave the controller not knowing exactly which frequency to switch an exiting aircraft to. We could envision a day where frequency switches are automatic between ground and the flight deck so that this task could be off-loaded from the controller and leave the controller to separate aircraft. Likewise, off-loading verbal communication to the flight deck through a data link technology would also free controller cognitive resources to manage separation tasks. In fact, to accommodate an unlimited DR, even more supportive methods of communication, such as the ability for a controller to just draw a new route and have it up linked to an aircraft, would off-load communication and typing requirements for the controller, as well as ensuring precise accuracy in the new route.

The key to avoiding both controller underload and overload is a combination of good design and training. Training only supplements design and should not be used as a patch for a system that was not adequately thought out. The current use of resectorization in facilities is structured and scripted. It appears that controllers are trained to transition to combined and decombined sectors and have done this frequently. As the MIT reports point out advanced use of DR and unlimited DR will require new technology in addition to training. The technology will need to provide the controller with the information and SA he/she needs to safely move traffic in an expeditious manner.

Most researchers and airspace developers agree that change will be necessary, and there will be continuing requirements for airspace management. They are unanimous that above everything safety has to come first, and that planners should consider all relevant variables when proposing changes. Change for its own sake is not desirable. Both structured change within Limited DR and Unlimited DR pose challenges for the controllers in terms of workload and situational awareness. As long as controllers are in the loop and responsible for the outcomes, they will need both current and anticipated information so they can hang onto their accurate pictures in their working memories.

Working memory is a limited capability. Experts have greater capacity than novices because in part they have learned how to organize the information, how to filter the extraneous, and methods or schemas that work most of the time within their realm of experience. LDR, which is trained for and expected, can build new schemas that once again will likely work most of time. Exceptions when anticipated can also be worked safely. It is the unanticipated, especially in an overload or underloaded condition, that could be very problematic. When underloaded the controller may simply operate on rote and miss key indicators. When overloaded, which can happen even in today's system, controllers can reach a point where they have no cognitive resources left to give.

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## Acronyms

| | |
|---|---|
| AATT | Advanced Air Transportation Technologies |
| AOC | Airline Operations Center |
| ARTCC | Air Route Traffic Control Center |
| ATC | Air Traffic Control |
| ATWIT | Air Traffic Workload Input Technique |
| CAASD | Center for Advanced Aviation System Development |
| CPC | Certified Professional Controller |
| CS | Resector Command |
| DD | Dynamic Density |
| DIRECT | Dynamic Resectorization and Route Coordination |
| DOD | Department of Defense |
| DR | Dynamic Resectorization |
| DSR | Display System Replacement |
| ETMS | Enhanced Traffic Management System |
| FAA | Federal Aviation Administration |
| FL | Flight Level |
| FPA | Fix Posting Areas |
| HITL | Human-In-The-Loop |
| IPT | Integrated Product Team |
| LDR | Limited Dynamic Resectorization |
| LOA | Letter of Agreement |
| M/A | Monitor Alert |
| MAP | Monitor Alert Parameter |
| MDS | Multidimensional Scaling |
| MIT | Massachusetts Institute of Technology |
| MOA | Military Operations Area |
| NAS | National Airspace System |
| NASA | National Aeronautics and Space Administration |
| NTSB | National Transportation Safety Board |
| RTCA | Radio Technical Corporation of America |

| | |
|---|---|
| SA | Situational Awareness |
| SUA | Special Use Airspace |
| TMU | Traffic Management Unit |
| TRACON | Terminal Radar Approach Contro |
| UCR | Unsatisfactory Condition Reports |
| WJHTC | William J. Hughes Technical Center |
| ZJX | Jacksonville ARTCC |
| ZMA | Miami ARTCC |
| ZMP | Minneapolis ARTCC |
| ZOA | Oakland ARTCC |
| ZTL | Atlanta ARTCC |