Kip Smith and Lauren Murphy

Department of Psychology
Kansas State University

Introduction

This report presents descriptive and explanatory analyses of (a) the sources and uses of information and of (b) the organizational structure at the Traffic Management Units (TMUs) of several Air Route Traffic Control Centers (ARTCCs) as they existed during the summer of 1999.

The descriptive analysis addresses the nature of TMU tasks, the allocation of those tasks across Traffic Management Coordinators (TMCs), and the sources and uses of information for performing those tasks. The discussion of the sources and uses of information focuses on the interaction between the TMCs and the Traffic Situation Display (TSD). It pays particular attention to TMC interaction with the Monitor Alert Function (MAF) of the TSD. The discussion of TMU tasks focuses on TSD utilization in support of collaborative decision-making (CDM). The analysis is intended to serve as a baseline for future analyses of the impact of CDM on TMC decision making and of the technology that will support it.

The explanatory analysis builds upon the theoretic framework for ARTCC decision making and action proposed by Smith (1999). That framework described the tasks performed at the TMU as cycles of feedforward control that anticipate and regulate traffic flow for the purpose of managing sector controller workload. The analysis presented here elaborates the account of feedforward control by examining the differential allocation of tasks across TMUs in the light of the disparate constraints on the air spaces they manage. When integrated with the framework for feedforward control, the analysis forms the first comprehensive account of a truly collaborative, distributed decision-making system.

Terminology

This document assumes the reader is familiar with air traffic terminology and acronyms. The appendix lists all cited acronyms and abbreviations. In this document, the phrase ‘air traffic management’ subsumes all decision making regarding the management of airspace capacity and the flow of aircraft. The word ‘center’ refers to an ARTCC. The phrase ‘command center’ refers to the Air Traffic Control System Command Center (ATCSCC) in Herndon, Virginia. The word ‘users’ refers to all non-military users of the airspace and, in particular, to the commercial airlines participating in the joint Airline Transport Association (ATA) - Federal Aviation Administration (FAA) initiative on collaborative decision making (CDM). The phrase ‘collaborative decision making’ has two meanings which should be distinguishable by context. The broader definition of CDM refers to any and all types of supportive interaction by decision makers pursuing a mutual goal. The narrower definition of CDM aligns with the usage by the ATA-FAA working groups. The narrower meaning of CDM refers to collaboration between the FAA and users for the purposes of conveying intent and of using the airspace both equitably and predictably. The phrase ‘air traffic management system’ encompasses all FAA and user decision makers involved in CDM.

Findings and Organization of the Report

There are three findings. First, there are five classes of TMU tasks. Each task uses the TSD in specific and characteristic ways. Second, the allocation of tasks and the workspace arrangements varies from center to center. Third, airspace geometry, ATCSCC advisories, and traffic flow are three sources of constraint that largely determine the allocation of tasks at a TMU. The three sources of constraint are the content of the three classes of CDM information identified by in the first report in this series (Mafera and Smith, 2000).

The sections in this report alternate between descriptive and explanatory accounts of these findings. The first section describes the five types of tasks in the TMU. The second argues that all five tasks exercise a form of feedforward control that aims to manage sector controller workload. The third section describes the allocation of tasks at individual TMUs and their everyday usage of the TSD. The fourth section identifies three sources of constraint - airspace geometry, events and advisories, and traffic - that shape the allocation of tasks. It maps these constraints onto the three classes of CDM information discussed by Mafera and Smith (2000). It argues that the differential allocation of tasks across centers reflects regional differences in the tightness of the three sources of constraint. The alternative TMU structures are shown to be responsive adaptations to disparate traffic environments.

1 TMU Tasks and Uses of the TSD

The TMU is responsible for five tasks. The names of tasks reflect the duties to be performed: En-route Spacing Program (ESP), Metering, Severe Weather Avoidance Program (SWAP), the Monitor Alert Function (MAF), and the Traffic Management Coordinator in Charge (TMCIC). This section describes the tasks and their duties.

1.1 En-route Spacing Program (ESP)

The TMC working an En-route Spacing Program (ESP) is responsible for anticipating and regulating streams of traffic to help sector controllers meet miles-in-trial (MIT) restrictions. The TMC takes charge of sequencing departures from airports within the center's airspace into streams of air traffic. ESP enhances safety by reducing the sector controllers' preoccupation with MIT restrictions and by reducing their involvement in sequencing departures.

Uses of the TSD

The TSD is one of the two primary sources of traffic information for a TMC working an En-route Spacing Program. The other is the Main Display Monitor of the Display System Replacement (the MDM of the DSR), the large square screen that replaced the round Primary Visual Display (PVD)[1].

[1] The DSR transition was in full swing during our rounds through the centers.

The TMC commonly takes full advantage of the TSD's filtering functions to customize displays so that they differentiate streams of traffic. Typically, streams are color-coded by arrival fix or destination and type of aircraft. The TMC uses this display to monitor specific streams of traffic and to anticipate sector demand. The streams of traffic are generally overflights but may include departures from airports without Terminal Radar Control Centers (TRACONs) within the center's airspace. To mitigate or balance controller workload, the TMC issues spacing instructions to adjacent sectors and/or facilities.

The TSD has a 'Select Weather' command that allows the TMC to select, view, and adapt weather overlays and to track lightning[2]. The most popular combination of weather overlay options for TMCs working an ESP is NOWRADS with lightning.

1.2 Metering

The responsibilities of the metering task are (a) to issue spacing restrictions to aircraft landing at a major airport within the center's airspace and (b) to coordinate those restrictions with the TRACON controllers responsible for guiding those aircraft to the ground. The goal of metering is to distribute workload across controllers working approach control at the ARTCC and at the TRACON. TMCs use the word "metering" both as a gerund and a verb.

The update rate of the TSD is too slow to support the metering task. Metering requires highly precise information about aircraft location, heading, and velocity. Accordingly, a TMC metering an

---

[2] There are four weather overlay options: NOWRADS, Lightning, Radar Tops, and Jet Stream. (1) The NOWRAD overlays show areas of precipitation that might cause traffic flow problems. (2) The Lightning overlay shows areas where lightning strikes have occurred. Strike areas are shown as cross icons (+). (3) The Radar Tops overlay displays numeric labels to indicate the altitude of cloud tops in hundreds of feet (i.e., 300 indicates 30,000 feet). (4) The Jet Stream overlay shows winds aloft that are moving at speeds of 70 knots or more. This overlay shows the wind speed in knots, the altitude at which these winds are strongest, and the direction in which the winds are moving.

airport primarily uses the MDM to monitor specific streams of arrivals and to anticipate demand for the airport.

Metering must balance the demand for the airport with the airport's current aircraft acceptance rate (AAR). When the demand exceeds the acceptance rate, the TMC issues spacing restrictions that (1) delay flights but (2) enable them to proceed to the airport in an orderly, planned sequence. Ideally, metering enables aircraft to absorb arrival delays during the en-route phase of flight under relatively fuel-efficient conditions.

1.3 Severe Weather Avoidance Program (SWAP)

The goal of the Severe Weather Avoidance Program (SWAP) task is to issue reroutes for departures from a major airport within the center's airspace whenever severe weather threatens the airport or blocks departure routes. The reroutes vector traffic away from the weather. Ideally, SWAPed departures eventually rejoin their original flight plan, once clear of the weather.

Uses of the TSD

The TMC working SWAP makes extensive use of TSD's filtering and weather options to anticipate departure routes that will have to be shut down and to identify and plan available reroutes.

1.4 Monitor Alert Function (MAF)

Ideally, TMCs would use the Monitor Alert Function (MAF) of the TSD to anticipate congestion and, specifically, sector saturation. Congestion occurs when there are too many airplanes in too small a space. Operationally, sector saturation occurs whenever the demand for a sector exceeds that sector's "capacity." Sector demand is defined as the number of aircraft that either are or are expected to be within a sector in a 15-minute window. Sector capacity is fixed value that defines the maximum number of aircraft a controller working that sector can be expected to keep separated. The fixed value is based on the average sector flight time and is subject to the concurrence of the TMU and sector specialists.

If the weather is clear and traffic is flowing smoothly, there is little call for the MAF task. However, during bad weather and at times of high traffic volume, the TMC working with the MAF can become quite busy. Whenever demand exceeds capacity, the MAF automatically highlights that sector in red. A 'red alert' indicates that the MAF has received information that suggests that the current level of controller workload may be dangerously high.

When the MAF receives information that suggests demand for a sector may exceed the sector's capacity sometime in the future, the MAF highlights that sector in yellow. A 'yellow alert' indicates that levels of controller workload are likely to become dangerously high.

Uses of the TSD

Of the five tasks, monitoring the MAF is the task where the use of the TSD and the goal of managing sector controller workload are the most intertwined and conspicuous. TMCs monitor the MAF to examine sectors that have 'gone yellow' to anticipate workload and to identify aircraft that can be rerouted around the sector. Adept rerouting distributes the workload more evenly across sectors and controllers.

The MAF enables the TMC to create and examine a graphic display of sectors filtered according to altitude[3]. There are several steps in examining sector saturation. In the case of a 'yellow alert,' the TMC uses the MAF to obtain a list of active (airborne) flights and proposals (aircraft that have not yet departed) that are projected to be in the sector during the alerted time period. The next step is to identify specific flights in the list that can easily be rerouted around the sector. The decision making that guides this search is described in Murphy, Knecht, and Smith (2000). The final step is to advise controllers to issue reroutes, holding patterns, or ground-stops (i.e., whatever is necessary) to specific flights to mitigate the anticipated trouble.

---

[3] Sectors have both vertical and lateral extent. There are two schemes for differentiating sectors vertically: (1) superhigh, high, and low, and (2) high, low, and superlow. Different centers use different schemes.

In the case of a 'red alert,' the TMC informs the area supervisor that one of her sectors that has 'gone red.' The area supervisor relays that information to the controller working that sector. While the information that sector demand is heavy rarely surprises the controller, the actual count of aircraft and the estimated duration of peak demand is often welcome.

1.5 Traffic Manager Coordinator in Charge (TMCIC)

Every TMU has a Traffic Manager Coordinator in Charge (TMCIC) but responsibilities vary across them. Generally, the duties of a TMCIC are to supervise the operations of the TMU and to assist the TMCs during periods of hectic traffic. The major responsibilities of the TMCIC are (1) to maintain a liaison with the command center and adjacent facilities, (2) to develop traffic flow plans with these facilities, and (3) disseminate advisories to the TMU and sector controllers.

To maintain a liaison with ATCSCC, the TMCIC answers the ATCSCC and Severe Weather (SW) phones. These are dedicated phone lines from particular desks at the command center. ATCSCC uses these line to hold conference calls with multiple TMUs. The TMCICs from adjacent centers often use these calls to develop plans for streams of traffic crossing a shared boundary. This collaboration develops programs and restrictions that ATCSCC then issues. The TMCIC then passes information about the restrictions along to the supervisors of the sectors that will have to implement them.

Part of the liaison responsibility is participation in System Outlook teleconferences. The ARTSCC runs these 'Telcons' every morning and afternoon. Another part is preparation and presentation of regularly scheduled TMU briefings. The briefings cover anticipated and implemented advisories and are generally held in conjunction with the morning and evening Center Weather Service Unit (CWSU) weather briefings. Another part of the liaison responsibility is to use the phone link to ATCSCC to report when and why arrival, departure, or en-route delays escalate or de-escalate.

Since the FAA has an agreement with the airlines to try to avoid rerouting National Route Plan (NRP) flights, many TMCICs use the TSD to highlight overhead flows of traffic and to differentiate flights that have filed NRP flightplans. In addition, TMCICs are generally responsible for maintaining the TMU logs. The logs are a complete and accurate documentation of advisories and restrictions that had an impact on traffic flow through the center.

2 Managing Sector Controller Workload

The preceding discussion of the five TMU tasks focused on the unique duties each performs. This section argues that all five tasks have the same goal: to manage sector controller workload. The different tasks manage different sources of workload and attend to different sources of information. However, their approach to managing sector controller workload is much the same.

Figure 1 illustrates the cycle of steps in TMC decision making when ‘skies are blue,’ that is, when traffic is flowing as expected and nothing untoward is on the horizon. The first step involves monitoring information about traffic, events (weather), advisories, and sectors. TMCs working all five tasks monitor either the DRS or the TSD or both.

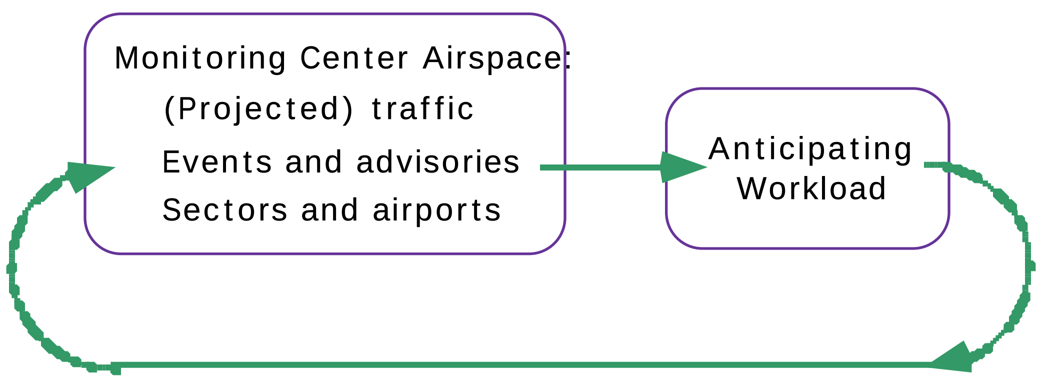

Figure 1. The cycle of TMC decision making when skies are blue

The claim here is that the second step in TMC decision making involves anticipating the implications of this information on sector controllers. For example, the TMC working ESP uses the TSD to monitor streams of overflying traffic. These steams often converge or cross within particular sectors. The TMC monitors the locations and velocities of aircraft in those steams to infer whether any two aircraft are likely to be in the same vicinity at roughly the same time. This inference projects aircraft minutes to hours into the future. It anticipates traffic situations that might contribute to sector controller workload. When skies are blue, the TMC is usually able to infer that they will continue to be blue, that traffic will continue to flow smoothly and that controller workload will remain at acceptable levels. As shown in Figure 1, the TMC continually cycles between monitoring information and anticipating levels of controller workload.

Similarly, metering uses the MDM to monitor streams of arrivals into an airport. These streams necessarily converge within particular sectors. The TMC monitors live radar data to anticipate traffic situations that might contribute to sector and TRACON controller workload. The SWAP task focuses on weather and the demand for departures from an airport to anticipate when and where a situation may develop that will require deviations from filed flightplans.

TMCs use the MAF to monitor the current and predicted levels of sector demands. The relative levels of demand and sector capacity constitute the FAA's official metric of controller workload. Ideally, TMCs use MAF data to anticipate when and where a situation may develop that will push workload above acceptable limits.

In contrast, when weather threatens or when the projected (or actual) levels of traffic are heavy, the TMU shifts into a longer and more complex cycle of decision making. This cycle is shown in Figure 2. Whenever the anticipated level of workload threatens to become too high, the TMU starts to develop compensatory plans. These plans are generally made collaboratively with decision makers at the command center and other TMUs. The plans ultimately take the form of advisories issued by the command center. The TMCIC then distributes the new advisory to the TMU and throughout the ARTCC. The cycle continues until all needed advisories have been developed and disseminated. The cycle then reverts to the shorter, two-step cycle shown in Figure 1.

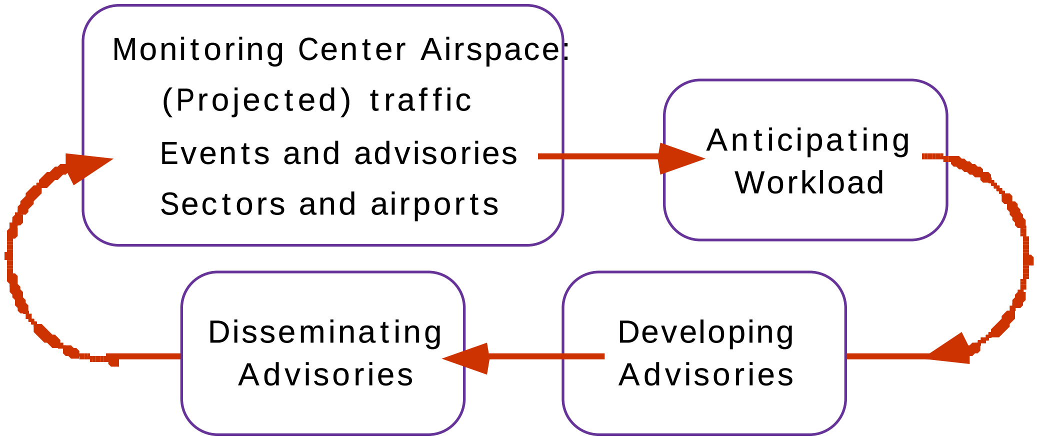

Figure 2. The cycle of TMC decision making when levels of sector controller workload threaten to become too high.

The SWAP, ESP and metering tasks manage sources of controller workload associated with different stages of flight (departure, en-route, and arrival, respectively). They focus on different displays and think about different flight situations but engage in the same steps of decision making.

A TMC using the MAF often anticipates when and where reroutes will be needed in order to reduce demand for a particular sector. Rerouting traffic away from one sector invariably increases the workload in another sector. Developing acceptable reroutes and the associated advisories necessitates collaboration with other centers and with the command center. The TMC using the MAF and TMCIC often collaborate in the process of managing the workload incurred by controllers at other centers as well as their own.

The cycles of decision making shown in Figures 1 and 2 define a process known as ‘feedforward control.’ Feedforward control is the process of making decisions and taking action in response to anticipated events (Smith, 1999). It is a standard component of managerial behavior in evolving, dynamic systems (Bainbridge, 1974; Brehmer, 1992; Eisenhardt, 1989; Woods, O’Brien, and Hanes, 1987). Feedforward control stands in contrast to ‘feedback control’ in which the decision maker responds to the current state of events, takes action, and receives feedback on that action relatively quickly. Sectors controllers engage in feedback control. They monitor their sectors, issue instructions to aircraft, and within seconds see the implications of their decision.

It is important to note that no one at the TMU ever actively controls ‘live traffic.’ As a result, TMCs receive no immediate feedback from the fruits of their labor. The workload they anticipate is an informed prognosis of some future state. The plans they develop aim to ameliorate those states. TMCs performing any of the five tasks continually cycle through decisions about the impending disposition of a highly dynamic air traffic system. They all exercise feedforward control for the purpose of managing sector controller workload.

3 Tasks, Positions, TMU Structure and TSD Usage

This section describes the allocation of tasks at the four TMUs we visited during the spring and summer of 1999: Kansas City, Minneapolis, Fort Worth, and Cleveland Centers (ZKC, ZMP, ZFW, and ZOB). It also describes their everyday usage of the TSD. The discussion moves from center to center in the order of our visits. Table 1 indicates the distribution of tasks across centers.

Table 1. The allocation of tasks across four TMUs.

Tasks: TMU	ESP	Metering	SWAP	MAF	TMCIC
ZKC	X	X	X	X	X
ZMP	X	X	X	X	X
ZFW	X	X	X	X	X
ZOB	X		X	(X)	X

The classic “One man, one job” of scientific management does not apply to a TMU. In most TMUs, some tasks are combined; in some TMUs, more than one TMC is responsible for a particular task. Each TMU organizes the five tasks differently. The distribution and allocation of tasks defines the “positions” at a TMU. Each position occupies a separate and distinct location in the TMU. Because some positions are responsible for more than one task, TMCs think of their jobs as working the positions, not the tasks. The argument being made here is that the allocation of tasks into positions defines the structure of the TMU and largely determines how the TMU functions.

3.1 Kansas City Center (ZKC)

The major sources of concern for the TMU at the Kansas City Center (ZKC) are St. Louis (STL) arrivals and overflights headed to Chicago O'Hare (ORD) and Cincinnati (CVG) airports. The ZKC TMU operates with four main positions: the ORD/CVG ESP position, the STL ESP and MAF position, the STL metering and SWAP position, and the TMCIC, Table 2. Each position and its use of the TSD is described in turn.

ORD/CVG ESP position

The TMC in the ORD/CVG ESP position is responsible for coordinating how sector controllers institute MIT restrictions on (1) streams of traffic crossing into Chicago Center (ZAU) and terminating at ORD and on (2) streams of traffic crossing into Indianapolis Center (ZID) bound for Cincinnati (CVG).

Table 2. Positions, equipment, and default mode of the TSD at the ZKC TMU.

ZKC Positions	ORD/CVG ESP	STL ESP & MAF	STL Metering & SWAP	TMCIC
Equipment	TSD	MDM TSD (MAF)	MDM ASB	TSD Phones
TSD/MAF default mode	ORD arrival fixes CVG arrival fixes Weather	STL arrival fixes Sectors filtered by altitude MAF log Weather	STL arrival fixes Weather	Advisory log NRP through ZKC Telcons and conference calls Weather

The TMC uses the TSD to customize several graphic displays that filter and color-code traffic according to arrival fixes for ORD and CVG. The TSD typically contains three windows, one for each airport. Each window shows four streams of color-coded traffic headed for the four arrival fixes. Preferences of color, icons, and weather options differ across TMCs.

STL ESP and MAF position

The second ESP position at ZKC is called the St. Louis ESP position. The TMC in this position is primarily responsible for coordinating how sector controllers institute MIT restrictions on aircraft bound for the St. Louis airport (STL). The STL ESP position usually relies on both the TSD and the MDM. The TMC uses the TSD to create a graphic display of STL-bound traffic filtered according to arrival fixes. The TMC uses the ‘quick-look’ function of the MDM to monitor the composite live radar returns for sectors actively controlling STL arrivals.

During bad weather and times of high traffic volume, the STL ESP position assumes MAF position responsibilities. The TMC uses the MAF to customize a display of ZKC sectors according to altitude (superhigh, high, and low) and to obtain lists of flights that are projected to contribute to excessive levels of workload. The lists of flights are the basic data used to anticipate sectors where controller workload is likely to become unacceptably high.

STL Metering and SWAP position

The STL metering position is responsible for partitioning STL arrivals into one of four arrival streams (northeast, northwest, southeast, and southwest) into the St. Louis Airport. The TMC uses the Arrival Stream Balancing (ASB) tool to generate a graphic display of the minute-by-minute arrival rate at STL. The ASB is not part of the TSD; its interface varies markedly from and is superior to a similar-looking display that is part of the MAF. Integration of ASB technology into the MAF is one of the recommendations made by Murphy, Knecht, and Smith (2000).

During severe weather at or near STL, the TMC at the STL metering position implements SWAPs for STL departures.

TMCIC position

The TMCIC at ZKC supervises all the positions in the TMU and supports them when operations in the TMU become busy. Other responsibilities include developing programs and restrictions with ARTSCC, keeping an advisory log, conducting TMU briefings, and participating in System Outlook Telcons.

The TMCIC uses the TSD to update the daily advisory log, to display all NRP flights in the United States, and to highlight NRP flights filed through ZKC. The nation-wide display enables the TMCIC to anticipate trends in the traffic situation across the United States.

3.2 Minneapolis Center (ZMP)

The traffic flow through the Minneapolis center (ZMP) primarily consists of Minneapolis/St. Paul (MSP) arrivals, Denver (DEN) arrivals, Detroit (DTW) arrivals, ORD arrivals, and international overflights. A major concern is blending the multiple streams of flights headed for ORD.

ZMP receives many “dynamic restrictions” that as regularly as clockwork. The TMCs know when to expect them and what they will contain. The restrictions concern ORD, New York Kennedy (JFK) , Newark (EWR), and DEN arrivals and other traffic going through ZAU, ZDV, and ZKC. Their proximal cause is sector demand in other centers. The ultimate cause of the dynamic restrictions is the airlines’ hub and spoke system and the associated banks of arrivals and departures. For example, inbound banks of EWR arrivals create traffic rushes with regular schedules. The rushes regularly overload sectors in ZOB. The ZOB TMU issues restrictions to ZAU (Chicago center) to manage their controllers’ workload. ZAU will often need to pass those restrictions on to other centers including ZMP. The restrictions offload part of the workload at ZOB and ZAU onto controllers at ZMP. This is an efficient and effective method for distributing work.

The ZMP TMU is structured in a way that enables the TMCs to manage sector controller workload in the face of unpredictable weather and daily restrictions. The four positions at the TMU are the ESP, Metering, SWAP and MAF positions. A summary of these positions is shown in Table 3. They are discussed in turn.

The ZMP TMU is unique in that it downplays the role of the TMCIC and allots many TMCIC responsibilities to the TMC at the ESP position. Every TMC rotates through all four positions and assumes TMCIC-type duties at least once per shift.

ESP / TMCIC position

The first position is called ESP or ‘flow.’ The ESP position is responsible for managing the flow of overflights through the Minneapolis ARTCC airspace. Restrictions are important to this position because they constrain the airspace and are instrumental to traffic flow management. The ESP position usually answers the Command Center and Severe Weather calls to receive information about restrictions or to participate in developing them. Hence, the ESP position assumes most of the responsibilities usually performed by a TMCIC.

Table 3. Positions, equipment, and default mode of the TSD at the ZMP TMU.

ZMP Positions	ESP/TMCIC	Metering	SWAP	MAF
Equipment	TSD MDM	MDM (Delay Mgr.) TSD	MDM TSD MAF	MAF TSD
TSD/MAF default mode	ORD/JFK/EWR/DEN arrivals Traffic to ZDV/ZKC through ZMP Weather	ZMP arrival fixes Weather	‘No-SWAP Zone’ east- and west-bound departures Weather	Sectors filtered by altitude: superhigh, high. low

The TMC at the ESP position uses a MDM to view individual sectors and a TSD to display the flow of overflights. The default mode of the TSD usually consists of flights filtered by color according to destination (e.g., flights going through ZMP scheduled to arrive at ORD, JFK, EWR, and DEN). A separate window shows flights through ZMP headed for ZDV and ZKC. Both windows generally contain information about weather.

Metering position

Metering is the position responsible for balancing the four streams of arrivals into MSP. The TMC at this position uses a MDM to view individual sectors and the Delay Manager function of the TSD to view arrival rates. The Delay Manager is a graphical tool used for displaying the frequency of arrivals in 15 minute increments. This information is used to help maintain the MSP arrival rate. The TSD displays weather and streams of traffic filtered by arrival fixes.

Northwest Airlines (NWA) is a major carrier at MSP. The Metering position is often in close communication with ATC Coordinator at NWA and answers a designated NWA telephone. It is not unusual to see collaboration between the Metering position and the NWA ATC Coordinator. The focus of communication is often on individual flights that need special attention from controllers. Reasons for special attention are diverse. Some of the more common are fuel concerns, runway restrictions, and medical emergencies. Mafera and Smith (2000) provide a detailed review of the ATC coordinator position.

SWAP & MAF position

Weather in Minneapolis airspace can be unpredictable during the thunderstorm season. The SWAP position is often busy. The TMC at the SWAP position is responsible for rerouting streams of departures from MSP to any one of several pre-constructed routes that vector aircraft away from the weather.

ZMP has an agreement with NWA which states that NWA dispatchers are advised not to reroute MSP departures for weather inside of a 216 nautical mile ring around MSP. The ring is referred to as the 'No SWAP Zone.' The agreement states that the ZMP TMU will SWAP MSP departures so that they may rejoin their original flight plan once clear of the weather. It is a concept unique to ZMP and NWA that deserves emulation and replication elsewhere.

The TMC at the SWAP position uses a TSD to filter departing flights that need to be 'SWAPed' clear of weather. The TMC uses the MAF to highlight sectors affected by the SWAP routes to gage the additional workload the SWAP routes produce.

When weather is not an issue, the SWAP position is responsible for the MAF position. The TSD is set to show a display of all the sectors in ZMP airspace filtered by altitude (superhigh, high, and low). The MAF duties include examining the alerted sectors, obtaining lists of flights, rerouting flights, and alerting the area supervisors. The goal of the activity is to control sector volume and manage sector workload.

There is no particular position in the ZMP TMU that is responsible for the Advisory Log. Accordingly, the responsibility is divided among the TMCs. The designated TMC prints the Advisory Log at the end of the workday.

3.3 Fort Worth Center (ZFW)

Maintaining smooth operations at Dallas/Fort Worth airport (DFW) is the central concern of the TMU at ZFW. Daily restrictions usually concern the traffic flow though ZFW to ZME (Memphis Center), to ZAB (Albuquerque Center), and to ZKC. Like ZMP, ZFW gets its share of unpredictable weather during the thunderstorm season. The TMU has five positions: ESP, MAF, SWAPS, TMCIC, and Metering. A summary of the positions is provided in Table 4. They are discussed in turn.

ESP position

During nice weather, the TMU only needs two TMCs to operate efficiently. These TMCs work the ESP position and the MAF. The ESP position manages the flow of overflights in ZFW airspace and monitors restrictions on that flow. The restrictions generally concern traffic into ZME, ZAB, and ZKC. The TMC uses the TSD to display overflights, NRP overflights, all NRP flights nationwide, and weather.

Table 4. Positions, equipment, and default mode of the TSD at the ZFW TMU.

ZFW Positions	ESP	Metering	SWAP	MAF	TMCIC
Equipment	TSD	CTAS	MDM TSD	MAF/TSD MDM	TSD Phones
TSD/MAF default mode	Traffic for ZME/ZAB/ ZKC through ZFW Weather	DFW arrivals	East-, west-bound departures Weather	Sectors filtered by altitude: high, low, superlow	Advisory log National traffic Telcons and conference calls Weather

MAF position

The responsibilities of the MAF position at ZFW are the same as those of the MAF at ZKC and ZMP. The TMC at the MAF position uses a MDM to monitor sector demand and to examine individual sectors. The TSD is used to display the sectors filtered according to altitude (high, low, superlow). The MAF is customized to produce lists of flights that are projected to contribute to unusually high levels of controller workload.

SWAP position

When weather occurs in ZFW airspace, the SWAP position plays an active role in the operations of the TMU. The SWAP position reroutes DFW departures (eastbound and westbound) into streams away from the weather. The TSD is used to obtain lists of flights scheduled to depart on routes affected by the weather.

TMCIC position

The TMCIC actively participates in the operations of the ZFW TMU by answering the designated Command Center and Severe Weather phones and by keeping the Advisory Log. The TMCIC uses the TSD to display a nationwide picture of traffic flow. The TMCIC presents a TMU briefing at the morning and evening weather briefings and participates in System Outlook Telcons.

Metering position

The Metering position at ZFW is unique. It uses equipment called the Center TRACON Automation System (CTAS). CTAS provides a very precise graphic display of the arrival rate into the four DFW arrival fixes. Because the CTAS tool is so efficient and reliable, the TMCs need only to monitor it periodically and to confirm with sector controllers and TRACON that arrival rates are being maintained and remain manageable. Everyone involved with CTAS at ZFW considers it to be a valuable tool. Its test at the ZFW TMU appears to be resounding success.

3.4 Cleveland Center (ZOB)

Cleveland Center (ZOB, Oberlin, Ohio) has a complex airspace. The three major airports located in ZOB airspace - Cleveland (CLE), Pittsburgh (PIT), and Detroit (DTW) - are a major source of this complexity. Other factors contributing to complexity include (a) poor sector design, (b) compact traffic flow patterns, (c) NRP disruptions of regular traffic flow patterns, (d) numerous altitude transitions, and (e) special procedures specified in Letters of Agreement (LOA) with adjacent centers.

Because of the complexity of its airspace, the ZOB TMU is structured very differently than the TMUs discussed above. As shown in Table 5, there are five main positions at the ZOB TMU: ESP CVG/ORD, ESP NYC, ESP CLE/PHL, ESP DTW/DC Metro, and TMCIC. The relatively small size of ZOB airspace and the relatively large number of airports in and near its airspace make it impractical for the TMU to perform metering. Thus, metering is done by the individual TRACONs rather than at ZOB.

Table 5. Positions, equipment, and default mode of the TSD at the ZOB TMU.

ZOB Positions	CVG/ORD ESP & SWAP	NYC ESP & SWAP	CLE/PHL ESP & SWAP	DTW/DC Metros ESP & SWAP	TMCIC
Equipment	MDM TSD Phones	MDM TSD Phones	MDM TSD Phones	MDM TSD Phones	MDM TSD Phones MAF Logs
TSD/MAF default mode	CVG arrival fixes CVG arrivals going around ZOB ORD arrival fixes Weather	EWR/JFK/ LGA arrival fixes Weather	CLE arrival fixes CLE props PHL arrivals PHL satellite arrivals Weather	DTW arrival fixes DTW props DC Metro: IAD/DCA/ BWI IAD arrivals going around ZOB Weather	Sectors filtered by altitude: superhigh, high, low Advisory log MAF log Telcons and conference calls Weather

The systemic view at the ZOB TMU is to structure the positions and their workstations in a way that fosters TMC autonomy. Each of the four ESP positions work specific streams of traffic and is responsible for scheduling release times for departures that must be merged into those streams of traffic. Many airports call the ESP positions for release times including, but not limited to, Akron/Canton, Buffalo, Cleveland, Columbus, Detroit Metro, Detroit City, Flint, Lansing, Pittsburgh, Rochester, Syracuse, Toledo, and Toronto. The TMCs are also responsible for initiating and performing SWAPs for those flights.

The CVG/ORD ESP and the NYC ESP positions share one TSD and the CLE/PHL ESP position and the DTW/DC Metros ESP position share another. Two additional TSDs would be most welcome. The five positions are discussed it turn.

CVG/ORD ESP position

The ESP CVG/ORD position is responsible for helping controllers maintain MIT spacing for streams of Cincinnati (CVG) and Chicago (ORD) arrivals. The TMC at the CVG/ORD ESP position uses the 'quick-look' function of the MDM to view individual sectors of interest. The TMC uses the TSD (shared with the NYC ESP position) to filter CVG and ORD arrivals by arrival fix and to display weather.

NYC ESP position

The ESP NYC position is similar to the CVG/ORD ESP position. It is responsible for helping controllers maintain the en-route spacing of arrivals into the three major New York City area airports: Newark (EWR), Kennedy (JFK) and LaGuardia (LGA). This involves sequencing arrivals into the one of the arrival fixes for each of the three airports.

The TMC uses both the MDM and TSD (shared with the CVG/ORD ESP position) to examine sectors. On the TSD, flights on routes through ZOB airspace are filtered by their airport of arrival (EWR/JFK/LGA).

CLE/PHL ESP position

The CLE/PHL ESP position is responsible for helping controllers maintain the en-route spacing of arrivals into Cleveland (CLE) and Philadelphia (PHL) airports. The TMC uses the TSD and MDM to monitor sectors handling those streams of traffic.

This position shares a TSD with the DTW/DC Metros ESP position. The default mode of one TSD window displays CLE jet/prop arrivals filtered by arrival fix. The default mode of a second TSD window displays PHL arrivals filtered by arrival fix and flights headed to PHL satellite airports. Weather is displayed in both windows.

DTW/DC Metro ESP position

The DTW/DC METRO ESP position is responsible for helping controllers maintain the en-route spacing of arrivals into Detroit (DTW) and the three Washington DC area airports: Dulles International (IAD), Washington National (DCA), and Baltimore-Washington (BWI).

The DTW/DC Metro ESP position uses the TSD and MDM to monitor en-route traffic flows and sectors of interest. It shares a TSD with the CLE/PHL ESP position. The default mode of one TSD window displays DTW jet/prop arrivals filtered by arrival fix. The default mode of a second TSD window displays DC Metro arrivals on routes through ZOB airspace. A third TSD window shows IAD jets going through ZOB. Weather is shown on all three windows.

SWAP position

Each of the four ESP positions initiate and perform SWAPs for their respective streams of aircraft. SWAP is initiated when severe weather prevents traffic from following their filed flightplans. The TMC uses the TSD to obtain lists of flights likely to be affected by the weather and uses the MDM to ‘quick-look’ at sectors of interest.

TMCIC position

The TMCIC at ZOB is active in the operations of the TMU. The TMCIC collaborates with ATCSCC, adjacent facilities, and ZOB area supervisors to develop and coordinate advisories and traffic restrictions. Many of these collaborations produce “historically validated restrictions” (HVRs) on the flow of traffic from adjacent centers. These restrictions offload part of ZOB controller workload to controllers at other centers. Developing and issuing HVRs is an effective stop-gap method for managing the high level of sector demand and the complexity of ZOB airspace. HVRs are not, however, attractive to the centers that receive them. The ultimate solution to ZOB’s chronic workload problem is a wholesale redesign of ZOB airspace.

The TMCIC maintains an activity board that itemizes and ensure the accuracy of information pertaining to ground stops, ground delay programs, and dynamic restrictions (for a discussion of advisories and traffic-flow restrictions, see Mafera and Smith, 2000). The TMCIC is also responsible for maintaining two logs. The first is a complete and accurate TMU (advisory) log documenting flow restrictions and messages. The second log is the Monitor Alert log. This log accurately documents the frequency of false yellow and red alerts, that is, the gross inutility of the MAF. Due to the complexity of the airspace and the multitude of LOAs with adjacent centers concerning altitude transitions, the MAF does not function accurately. As of January 2000, the MAF was making errors of both omission and commission. The pervasive misinformation makes it impossible for ZOB to use the MAF. This topic is the subject of third report in this series (Murphy, Knecht, and Smith, 2000).

3.5 Summary

This account of the positions and everyday operations of four different TMUs has underscored the similarities and differences across the four Centers. There are many more similarities than differences. Differences lie in the structures of the TMUs, the emphasis on certain positions, the absence of others, and the different equipment used for the metering position.

The account also described the uses of the TSD at the four TMUs. All four use the TSD to filter flights, display weather, and obtaining lists for additional information about flights.

4 The TMU as an Adaptive System

This section revisits the three classes of DCM information proposed by Mafera and Smith (2000) - static, episodic, and continuous - to create an explanatory account of the constraints that determine the structure of a TMU. The three classes of information are differentiated by the rate at which their information changes. Continuous information changes at a relatively high rate while static information rarely changes. Episodic information changes sporadically.

The account identifies the types of CDM information that dominate each class. It argues (1) that these data are constraints on TMC decision making, (2) that the constraints largely determine the efficient allocation of positions at a TMU, and (3) that the different structures seen at the ZKC, ZMP, ZFW, and ZOB TMUs are spontaneous and appropriate adaptations to different sets of prevailing constraints.

4.1 Classes of Information and constraints on TMC decision making

Mafera and Smith (2000) partition the information available to TMCs into three classes - static, episodic, and continuous - that are differentiated by the rate at which their information changes. In this section, the three classes are differentiated by content as well as by rate of change.

Continuous information – traffic flow, density and complexity

Mafera and Smith (2000) use the term ‘continuous’ to refer to information that can and usually does change from moment to moment. There are three types of continuous information: the flow, density, and complexity of traffic.

Traffic flow

Aircraft fly from points of departure to destinations. Each moves independently of the others. However, at the temporal and geographic scales of the TMU, the independent motions of individual aircraft often resembles a stream. The aggregate motion is termed “(air) traffic flow.” Aircraft in a flow appear to meld into chains of entrained automata that cluster, merge, diverge, and proceed to common destinations. Regulating this flow in order to manage sector controller workload is the overriding goal of the TMU (Smith, 1999).

The defining characteristic of the concept of flow is continuous spatial change. Information about flow needs to capture and update, as continuously as possible, the locations and velocities of elements in that flow. For the TMU, that information is provided by the MDM and TSD. These tools tell TMCs where aircraft are, where they are going, and how fast they are getting there. These continuously changing data are the central pieces of information that enable TMCs (and the entire ATC system) to manage the flow of air traffic.

All five TMU tasks rely on continuous information about who, where, where to, and how fast to anticipate how traffic flow will evolve. More precisely, TMCs use these data to anticipate whether, when, and where aircraft will cluster, merge, cross or otherwise interact in a manner that is likely to make it relatively difficult to keep them separated. These data drive the feedforward decision making process and constrain how air traffic management unfolds. The flow of traffic may be the most powerful constraint on TMC decision making.

Traffic density

Traffic waxes and wanes. The airlines' hub and spoke system is designed to promote surges of inbound flights followed by surges of outbound flights. One product of this system is temporal variability in the density of aircraft. The FAA operationally defines "traffic density" as the number of aircraft in a sector of airspace in a 15 minute window.

A controller's workload tends to increase as density increases. The more aircraft there are in a sector, the more difficult it tends to be to keep them all separated. This correlation has led the FAA to adopt traffic density as its operational proxy for controller workload. In fact, the MAF of the TSD is designed to keep track of both the expected and the actual traffic density and to alert the TMU to densities that are or may become unacceptably high. This continuously changing information often triggers the decisions to develop programs or restrictions. It too is a strong constraint on TMC decision making.

Traffic complexity

The correlation between density and workload is far from perfect. At one extreme, a formation of many military aircraft is usually no more difficult to control than any one aircraft. At the other extreme, it takes only two aircraft on a collision course to make the job dicey. TMCs universally acknowledge that density is an imperfect proxy for controller workload. What they need in its stead is a metric of traffic complexity.

Traffic complexity is not the same as traffic density; density is a component of complexity. Other dynamic components of complexity include, but are not limited to, the mix of flightplans, the mix of velocities, and the requirements for spacing between aircraft. For example, when the mix of flightplans is low, the flow of traffic resembles a string of beads. Such strings or streams are relatively easy to control. In contrast, when traffic crosses or merges or climbs into a stream, the mix becomes higher and the difficulty of keeping aircraft separated increases.

To manage controller workload effectively, TMCs need reliable and regularly updated information about traffic complexity. A valid metric of traffic complexity would take into account variability in flightplans, velocities, etc. These issues are discussed in some detail in the third report in this series (Murphy, Smith, and Knecht, 2000).

Static information – airspace geometry

Mafera and Smith (2000) use the term ‘static’ to refer to information that remains unchanged over extended periods of time. Many, if not all, of the sources of static information relevant to a TMU concern the geometry of the airspace. Examples include CENTER boundaries, sector boundaries, and the locations of jet routes, fixes, and airports. Changes to any of these data are rare. Once a piece of static information is known, it does not need to be referenced on a regular basis. Nevertheless, the static geometry of the airspace is major source of constraint on TMC decision making.

For example, all five TMU tasks are concerned with regulating traffic flow. The concept of flow is borrowed from physics. To extend the analogy, there is a source and a sink for every component of traffic flow. The sources and sinks for the flow of aircraft are airports. Aircraft enter and exit traffic flows at airports. Any deviation from that pattern constitutes an emergency. The locations of airports are a static constraint on TMC decision making.

Similarly, the geometric partitioning of the airspace into centers and sectors is source of static constraints. The continental United States is divided into 20 ARTCCs. The static locations of ARTCC boundaries are invisible to pilots, to users, and to the travelling public. However, they circumscribe each TMU's authority and form borders for internecine conflict. When CDM fails and TMUs adopt a siege mentality, center boundaries become impenetrable barriers to traffic flow. One of the goals of the CDM initiative is to establish a decision making process that will overcome the need for protectionist policies and break the artificial barriers erected along center boundaries.

Each ARTCC is divided into approximately 40 sectors. The static locations of sector boundaries influences the amount a time an aircraft spends within a sector. This time and the sector's shape limit the range of management options available to the sector controller, e.g., how many aircraft the controller can safely place into holding patterns. These geometric limitations shape controllers' decision making and limit the options available to TMCs for managing sector controller workload.

Jet routes are paths through the airspace. There are several hundred jet routes in the continental United States. Some jet routes are strictly dedicated to one-way traffic. Most are not. These paths connect, cross, and merge at points called "fixes[4]." The locations of routes and fixes are relatively static. Nevertheless, they strongly influence how sector controllers think about traffic flow. Routes and fixes are anchors in the continual flux of air traffic. Controllers expect aircraft to follow jet routes and to arrive at fixes on time. Routes and fixes are central elements in the controllers' set of expectations for traffic flow and in their repertoire of maneuvers for ensuring separation.

---

[4] Many fixes correspond to readily identifiable cultural or geographic features on the ground, e.g., Mustang, Nevada or Soo Sault Marie, Michigan.

It is no secret that many controllers dislike the NRP. Their enmity underscores how tightly static information about jet routes constrains controller decision making. Most NRP flights do not adhere to jet routes. The source of much of the controllers' discomfort is the resulting violation of their expectations for traffic flow. A secondary source is the need to craft novel maneuvers to ensure separation. The widespread resentment of NRP and its abandonment of jet routes underscores how tightly static information constrains controller decision making.

The locations of airports, of center and sector boundaries, and of jet routes and fixes are three different types of relatively static information about airspace geometry. They combine to define the relative difficulty of sector and center management. A sector with a single one-way jetway with no intersections is fundamentally easier to manage than a sector with crossing jetways and an airport that is continually generating aircraft to join the flow. While these sources of constraint are static, they combine in innumerable ways to limit controller and TMC decision making.

Episodic information – events and advisories

Episodic information happens. It comes in two types: events and ATCSCC advisories. Events are anything that disrupts the planned or routine flow of traffic. The most salient source of events is weather, especially convective weather systems – lines of thunderstorms. Other sources of events include, but are not limited to, low airport acceptance rates (AARs) and departure rates (ADRs) and equipment outages. Various weather phenomena such as high winds or low ceilings precipitate reductions in AARs and ADRs.

Events tend to impose limits on controller and TMC decision making. For instance, the airlines learned long ago that passengers do not like rough rides. Accordingly, pilots and controllers work to route aircraft around thunderstorms. Storms close decision making options and cause diversions. Similarly, changes in the rate of departures from and arrivals to an airport limit the controllers' options. Storms, AARs and ADRs do not follow a timetable. They happen when they happen. They are events that create contingencies and that force TMCs to develop and implement plans to work around them.

Events drive TMCs and the command center to develop and issue advisories. Advisories are explicit constraints on traffic flow (Mafera and Smith, 2000). They take the form of programs or restrictions. Every advisory is designed to make the flow of traffic smoother and more predictable. Smoother, more predictable traffic enables better anticipation and better traffic management and reduces sector controller workload. Accordingly, Smith (1999) identified advisories as enabling constraints, constraints that make decision making easier. In this regard, advisories have a unique status in world of CDM. Advisories are constraints that are both explicit and enabling. All other sources of constraint – static and continuous information and events – are implicit, are hidden in the data, and limit TMC decision making.

4.2 How constraints interact to shape the TMU

As shown in Tables 1-5, the TMUs allocate the five tasks differently, creating a variety of TMU structures and TMC positions. This section argues that the different structures and positions are adaptive responses to differences in the prevailing set of constraints on TMC decision making. The TMUs are structured differently because TMCs in different centers have to cope with different sets of constraints.

ESP Positions

The goal of the ESP task is to anticipate and regulate steams of traffic that cross the center's boundary and are headed for an airport in another center's airspace. To perform the task well, the TMC needs to respond to all three classes of traffic information: continuous information about traffic flow, static information about the locations of the center's boundaries and of its major airports and jetways, and episodic information about MIT restrictions. The need to perform the ESP task rises as departure rates from 'internal' airports rise and as the density of overflying traffic increases. Accordingly, the need is greatest at centers with relatively high volumes of overflying traffic and/or with many internal airports.

Cleveland center (ZOB) is said to have the highest volume of overflying traffic in the country. The streams of traffic head in four different directions: toward Chicago, New York, Philadelphia, and Washington DC. The jetways that these streams tend to follow cross over or near three internal airports that all serve as hubs: CLE, DTW, and PIT. Each airport is a source of many aircraft that must be merged into one or another of the four streams of traffic. The result is a strong interaction between departures from internal airports and traffic on co-located jetways.

This strong interaction between static (geographic) and continuous sources of constraint overwhelms all other TMU responsibilities in ZOB. The TMU's response is to create four ESP positions. Each position is responsible for one of the overhead streams of traffic and for one of the internal airports. ESP is the central task at each position except when weather makes it necessary to initiate SWAP for the internal airport for which it is responsible. The partitioning of traffic and airports across positions is a simple yet elegant solution to the problems caused by a strong interaction between static and continuous constraints.

In contrast, centers where the interaction of geometry and traffic flow is relatively weak get by with only one position that performs the ESP task. Minneapolis center has relatively few internal airports located directly under jetways with heavy traffic flow. Fort Worth center has relatively low volumes of traffic that crosses the center's boundary headed for an airport in another center's airspace. In both, the interaction between departures and overhead flow is intermittent and the demand for ESP can be handled by one TMC. Kansas City center occupies the middle ground. There, the demand for ESP can be handled by two TMCs.

Metering Positions

The metering task plays an important role for TMUs that have large airports well within their airspace, such as ZFW, ZKC, and ZMP. At ZKC, the metering position spaces the arrivals for STL using the Delay Manager of the TSD. The Delay Manager is also used at ZMP for arrival spacing into MSP. In contrast, during the summer of 1999, ZFW was using a different tool, the Center Terminal Automation

System (CTAS), to manage the arrival spacing into DFW. The ZFW test demonstrated that CTAS can be an efficient member of the TMU.

Metering takes space. To meter effectively, the TMU needs to exercise control over flights several hundreds of miles away from their destination. Metering is feasible only for airports located well within a center's boundary. The interaction between the static constraints of center geometry and of the locations of internal airports largely determines whether and how metering can be accomplished.

The major airports in ZFW, ZKC, and ZMP are all located several hundred miles from their centers' boundaries. All three TMUs have metering positions. ZOB does not. All four of its major airports are located near the ZOB boundary. The TMU at ZOB simply does not have room to perform the metering task. The interaction of static constraints precludes a TMU structure that includes a metering position.

SWAP

Weather is an episodic source of constraint on traffic flow. Episodes are more frequent during the convective weather (thunderstorm) season, late April though July. The SWAP task is responsible for rerouting departures whenever weather threatens to blockade an internal airport. When there is no weather at or near an internal airport, there is no call for the SWAP task. As a result of the episodic nature of this constraint, the SWAP task does not demand full-time TMC attention. TMUs that are able to make space available for a separate SWAP position do so, but assign a TMC to it only when weather threatens. At ZOB, ZMP and ZKC, where there are no spare MDMs, the SWAP task is performed by TMCs at ESP positions.

MAF

The MAF is designed to help TMCs anticipate the flow of traffic. At times and in certain centers, the MAF can be quite useful. While some centers have distinct MAF positions, the tool appears to be most useful when it supports a TMC at an ESP or TMCIC position.

Unfortunately, the MAF routinely makes errors both of commission and of omission (Murphy, Smith, and Knecht, 2000). The proximal causes of these errors are inadequacies in the TSD's data bases concerning (1) Letters of Agreement (LOAs) between adjacent centers, (2) estimated departure times for aircraft that have missed their scheduled departure time, and (3) the rates at which aircraft climb to cruise altitudes.

Many of the LOAs that give the MAF trouble have their origin in the same pair of static constraints discussed in the section on metering, the locations of airports and of center boundaries. Centers use LOAs to restrict and coordinate the flight plans of aircraft climbing out of or descending into an airport near a shared boundary. It is no accident that centers that do not have room to meter are the same centers that feel compelled to issue LOAs. The ultimate cause of the MAF's inability to take LOAs into account is neither its software nor the LOAs but the arbitrary and antiquated static constraints of center boundaries.

Another proximal cause of MAF error is its treatment of aircraft that, for one reason or another, have missed their scheduled departure time. The TSD assigns inaccurate times of departure to aircraft that are late to take off. The ultimate cause of the MAF's ignorance of departure times is its source of information. While many TMCs have devised (in)elegant ways to 'work around' this error, their continued discounting of the resulting MAF alerts make the MAF the most maligned piece of equipment in the TMU.

TMCIC

The TMCIC is responsible for coordinating with the command center and other centers. The TMCIC task unique in its relationship to airspace constraints. It alone issues rather than responds to episodic constraints in the form of advisories or restrictions. It is the TMCIC who requests that advisories or restrictions be issued to other centers. The requests are made to manage sector controller workload. The resulting advisories transfer a portion of that workload to controllers in other centers. This dispersion of workload is an effective method for coping with heavy traffic flow.

Advisories, like weather, are episodic constraints. They become effective when issued and expire some time later. Unlike weather, advisories have fixed locations, generally along center boundaries. By issuing advisories, the TMCIC imposes episodic constraints along static, invisible borders.

5 Summary

There are five types of tasks in the TMU: ESP, metering, SWAP, MAF, and TMCIC. All five tasks exercise feedforward control in order to manage sector controller workload. TMUs combine the tasks to form positions. The allocations of tasks and positions vary across TMUs.

There are three sources of information and of constraint on TMUs: (a) continuously changing information about traffic, (b) episodically changing information about weather and advisories, and (c) static information about the locations of airports, jetways, and center boundaries. The differential allocation of tasks across centers reflects regional differences in the tightness of the three sources of constraint.

The role of static constraints – especially of center boundaries - appears to be underappreciated. The ESP task responds to the interaction of the static locations of airports and the dynamics of traffic flow. The metering task is made impossible by center boundaries that are too close to an internal airport. Similarly, the MAF of the TSD is rendered useless by LOAs that are, in turn, adaptive responses to center boundaries that are too close to airports. It may be time to consider a wholesale redesign of arbitrary static constraints on TMC decision making.

The MAF of the TSD is widely distrusted. In some centers it regularly misrepresents the number of aircraft that can be expected within a given sector. The misrepresentation stems from inadequate databases on LOAs, climb rates, and of the disposition of aircraft that, for one reason or another, have missed their scheduled departure times. The problem is not the tool itself but the information it receives. The third report in this series (Murphy, Knecht, and Smith, 2000) addresses the issues associated with the MAF in greater detail.

Acknowledgements

This report is based upon more than 1000 hours of observations the Kansas City, Minneapolis, Fort Worth, and Cleveland centers (ZKC, ZMP, ZFW, and ZOB) and upon conversations with more than 50 TMCs during the 1999 convective weather season (April-August). The study was made possible by the voluntary cooperation of many ARTCC personnel. They shall all remain anonymous. Special thanks go to DH and CK who reviewed a draft of this document. The study was commissioned by the Office of the Chief Scientific and Technical Advisor for Human Factors, AAR-100, of the Federal Aviation Administration as part of FAA Grant 99-G-020. Dr. Thomas McCloy was the technical monitor. The opinions and errors are the authors'. None of the statements should be construed as positions taken by the FAA or by any of its employees.

References

Bainbridge, L. (1974). Analysis of verbal protocols from a process control task. *In* E. Edwards & F. P. Lees (Eds.), *The Human Operator in Process Control*. London: Taylor & Francis.

Brehmer, B., (1992). Dynamic decision making: Human control of complex systems. *Acta Psychologica, 81*, 211-241.

Eisenhardt, K. M. (1989). Making fast strategic decisions in high-velocity environments. *Academy of Management Journal, 32*, 543-576.

Mafera, P. and Smith, K. (2000). *Air Traffic Control Coordinator's Information Requirements for the NAS*. Kansas State University Human Factors Research Laboratory Report 99-G-020-1.

Murphy, L., Knecht, W. R., and Smith, K. (2000). *The Monitor Alert Function of the TSD: Baseline Use, Quick Fixes, and Recommendations for Redesign*. Kansas State University Human Factors Research Laboratory Report 99-G-020-3.

Smith, K. (1999). *Information Requirements for Traffic Flow Management*. Kansas State University Human Factors Research Laboratory Report 98-G-013.

Woods, D. D., O'Brien, J. F., and Hanes, L. F. (1987). Human factors challenges in process control: The case of nuclear power plants. *In* G. Salvendi (Ed.) *Handbook of Human Factors, Chapter 12.5*, p. 1724-1770. New York: Wiley.

Acronyms and Abbreviations

AAR	Airport Arrival Rate
ADR	Airport Departure Rate
ARTCC	Air Route Traffic Control Center
ASB	Arrival Steam Balancing
ATA	Air Transport Association
ATCSCC	Air Traffic Control System Command Center
Center	an ARTCC
CLE	Cleveland Airport
CTAS	Center TRACON Automation System
CVG	Cincinnati Airport
CWSU	Center Weather Service Unit
DEN	Denver Airport
DFW	Dallas/Fort Worth Airport
DSR	Display System Replacement
DTW	Detroit Airport
ESP	En-route Spacing Program
EWR	Newark Airport
FAA	Federal Aviation Administration
HVR	Historically Validated Restrictions
JFK	New York Kennedy Airport
LGA	New York LaGuardia Airport
LOA	Letters of agreement
MAF	Monitor Alert Function
MDM	the main display monitor of the DSR
MIT	Miles-in-trail restriction
MSP	Minneapolis Airport
NRP	National Route Program
NWA	Northwest Airlines
ORD	Chicago O'Hare Airport
PIT	Pittsburgh Airport
STL	St. Louis Airport
SW	Severe Weather (a position at ATCSCC)
SWAP	Severe Weather Avoidance Program
TMC	Traffic Management Coordinator
TMCIC	Traffic Manager Coordinator in Charge
TMU	Traffic Management Unit
TRACON	Terminal Radar Control Center
TSD	Traffic Situation Display
ZAB	Albuquerque Center
ZAU	Chicago Center (Aurora, IL)
ZDV	Denver Center
ZFW	Fort Worth Center
ZID	Indianapolis Center
ZKC	Kansas City Center
ZME	Memphis Center
ZMP	Minneapolis Center
ZOB	Cleveland Center (Oberlin, OH)