Integrated Demand Management: The FCA Balancing Algorithm

October 2020

POC: Nancy M. Smith
Human-Systems Integration Division
NASA Ames Research Center
Moffett Field, CA 94035

nancy.m.smith-1@nasa.gov

NASA Airspace Operations and Safety Program
Air Traffic Management - eXploration (ATM-X) Project, Integrated Demand Management Subproject

Contents

Overview of the FBA

A **Collaborative Trajectory Options Program** (CTOP) is a new Traffic Management Initiative (TMI) that resides within the Traffic Flow Management System (TFMS). The CTOP controls the distribution of traffic demand, both temporally and geographically, through a set of Flow Constrained Areas (FCAs). Each FCA is assigned capacity values, and CTOP controls demand to capacity by using Expect Departure Clearance Time (EDCT) directives, and/or rerouting flights to an alternate FCA or out of the CTOP completely. CTOP's decisions about which control options best meet system and user needs are based on the Trajectory Options Set (TOS) submitted by airline operators for each flight.

Figure 1 shows a simple example of a set of three FCAs that are controlled by a CTOP. By reducing the capacity settings on FCA_W, demand is redistributed to FCA_N and FCA_S. Capacity settings on FCA_N and FCA_S prevent these two alternative routes from being overloaded.

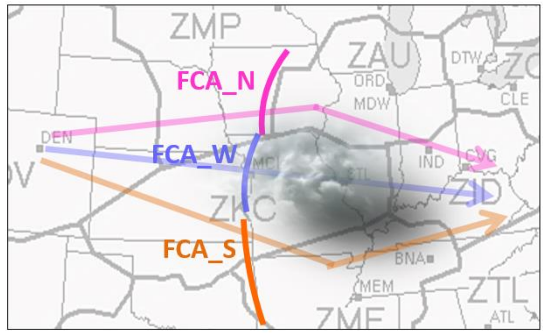


Figure 1.

The **FCA Balancing Algorithm** (FBA) is a proposed enhancement to the TMFS/CTOP software which addresses the added complexity of assigning FCA capacity values when setting up a CTOP TMI for a specific type of use case. More specifically, when multiple FCAs collectively control the traffic inbound to a common downstream resource (for example, FCAs used to control the flows feeding an airport, as shown in Figure 2), the FBA-computed capacity values insure that the **combined capacity** across those FCAs does not exceed the capacity of that downstream constraint. The CTOP is intended to reroute and/or delay flights as needed to manage demand across the FCAs controlled by the CTOP, while also delivering the desired demand to the downstream resource. The term "balancing" within the name indicates that the algorithm allocates each FCA a proportional share of the combined capacity based on its projected demand, in 15 minute bin increments. This means that flow volumes are modified no more than necessary, providing an **equitable distribution of impact**, in terms of delay and TOS route assignments to flights across all FCAs.

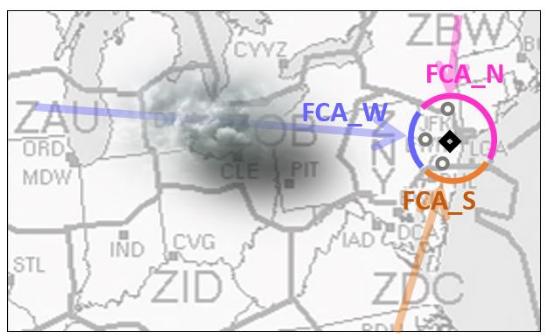


Figure 2.

Manually calculating and setting FCA capacity values for this situation is very labor intensive, time consuming, and prone to errors, particularly if the capacity values are entered in 15 minute increments. The FBA streamlines this process by providing initial capacity entries for the CTOP which the traffic manager can then review, model and modify before implementing the program. A study comparing manual and FBA-supported methods for setting FCA capacities (Hodell, et al.) showed that the FBA, when compared to two manual input conditions, was the fastest capacity setting method by far, had the best subjective scores on the mental and physical tasks, and was less difficult and complex in terms of task loading. In addition, there were no significant differences in overall system performance (ground delay and throughput) indicating that the FBA solution is comparable to that of an experienced traffic manager.

The purpose of the FCA Balancing Algorithm is to recommend CTOP capacity values for a set of FCAs that control traffic to a common downstream constraint. To do this the algorithm compares the predicted demand and maximum capacity for each FCA included in the CTOP, takes into account the capacity at the downstream constraint, then dynamically generates FCA capacity settings that allocate each FCA its proportional share of the **combined capacity**, that is, the total allocated capacity summed across all FCAs.

To summarize, the FBA's objectives are:

- Don't over- or under-deliver to the downstream resource
- Don't overload the airspace resources (flows, routes, arrival gates) controlled by the FCAs
- Assign FCA capacity values in proportion to the projected demand
- Provide an equitable distribution of delay across flights and across FCAs

Note that the FBA is necessary only when the objective is to manage the demand at one or more FCAs *and* at the common downstream constraint. If the downstream resource is not at risk of being overloaded, the combined capacity is not a concern and the FBA isn't needed.

FBA Process

Step 0. Traffic manager setup for FBA

Three FBA entries by the traffic manager: (1) FCA selection and ranking, (2) maximum FCA capacities, and (3) Combined Capacity.

Entry 1: FCAs are selected and rank ordered.

The traffic manager accesses the CTOP Configuration Window, selects the FCAs that feed the common constraint to be included in "CTOP COMBINED," and establishes their priority ranking (Figure 3). FCA rank order is used to determine how the FBA allocates any spare capacity across the FCAs included in the program, a process described in "Step 3" below.

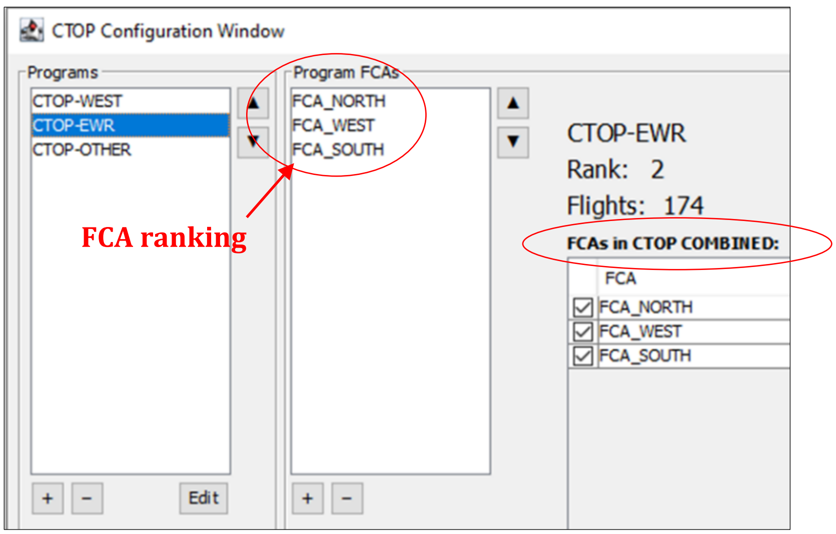


Figure 3.

Entry 2: FCA maximum capacity values are entered.

Next, **FCA maximum capacity** values are entered separately for each FCA, also in the CTOP Configuration Window. These values put an upper limit on the capacity assigned by the FBA. (Fig. 4).

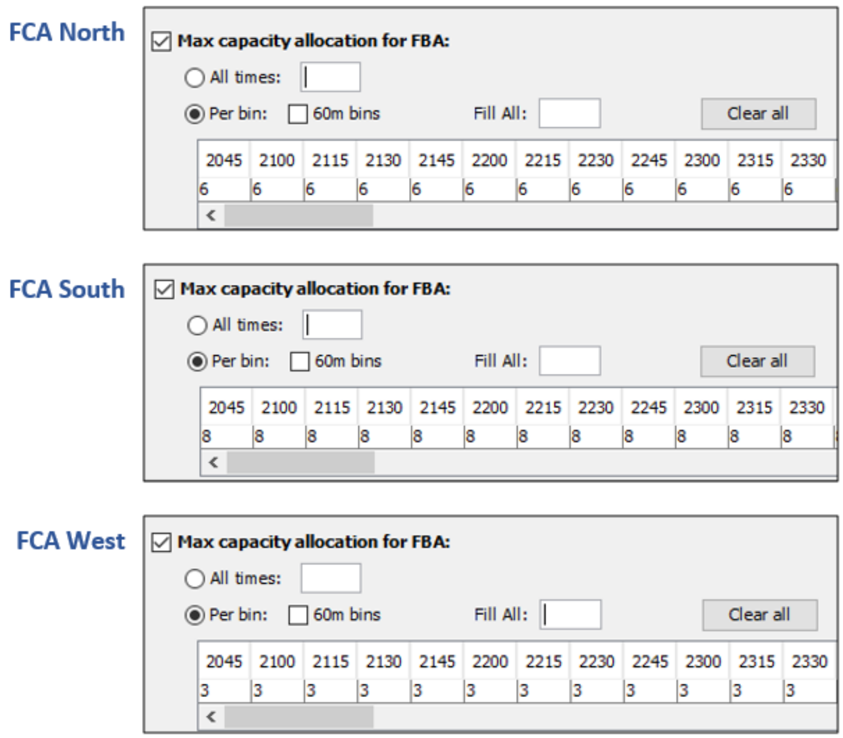


Figure 4.

Entry 3: The target rate is entered in the COMBINED Capacity table.

The last entry, the "Combined Capacity", is made in the FCA Parameters "COMBINED" table in the CTOP-ALL Window (Fig. 5). Combined Capacity is set to the desired **target rate** at the downstream resource. As an example, if the downstream resource is an airport, the target rate could be the airport acceptance rate (AAR). Setting the combined capacity to the AAR reduces the risk that the CTOP will over- or under-deliver to the airport. The 15 minute bin size is used by the FBA when allocating capacity to the individual FCAs, providing it finer control over the distribution of demand.

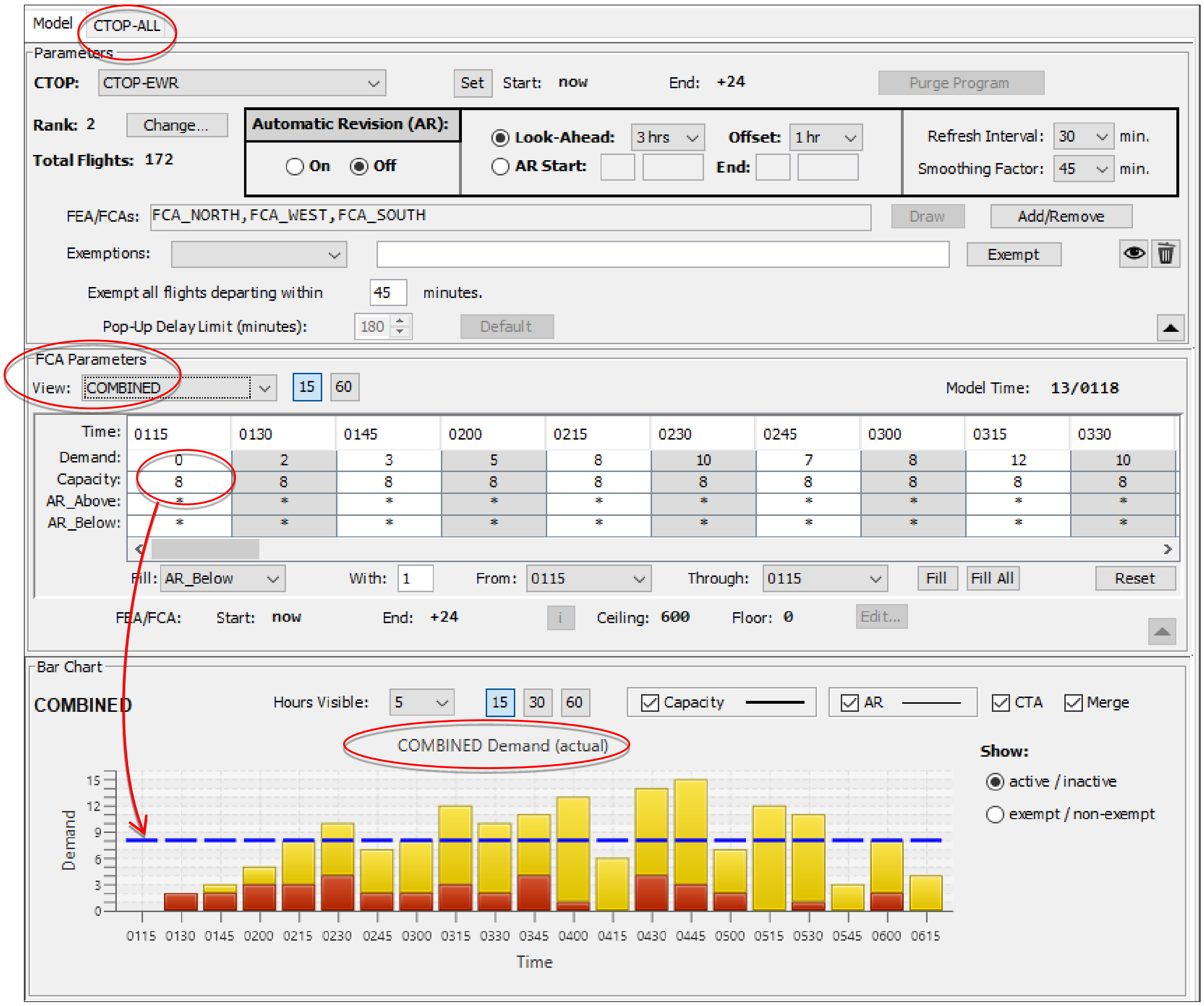


Figure 5.

Step 1. FBA determines proportional demand distribution across FCAs

After the target rate is entered, the FBA determines what proportion of the combined demand is projected for each FCA within each 15 minute bin. For example, assume three FCAs are used to control the three major flows that feed Newark Liberty International Airport (KEWR): FCA_WEST, FCA_SOUTH, and FCA_NORTH. The start time is 1400z, and 12 aircraft are expected to cross those

FCAs between 1400z and 1414z. The FBA determines what proportion of that demand will cross each FCA during that 15 minute interval as shown below:

- 6 / 12 = 50% over FCA_WEST
- 4 / 12 = 33% over FCA_SOUTH
- 2 / 12 = 17% over FCA_NORTH

Step 2. FBA assigns initial FCA capacity values

Assume the combined hourly capacity is set to 44 flights per hour, or 11 flights per quarter hour. Continuing with the example above, FCA_WEST with 50% of the demand would be allocated 50% of the available capacity, as follows:

- FCA_WEST: 11 × .50 = 5.5 (rounds to **6**)
- FCA_SOUTH: 11 × .33 = 3.6 (rounds to **4**)
- FCA_NORTH: 11 × .17 = 1.87 (rounds to **2**)

If an FCA's initially assigned capacity is greater than its maximum capacity setting, max capacity setting is used instead.

Step 3. FBA adjusts FCA capacities until the total assigned capacity equals the target rate

Notice that the initial total assigned capacity in this example is 12 (6+4+2), while the target rate is only 11. Because capacity values must be whole numbers, rounding in Step 2 can result in a total assigned capacity that differs from the target rate. Step 3 performs an initial adjustment that incrementally modifies assigned FCA capacities until the two values match.

Case 1. The total assigned capacity *is greater than* the target rate

In this case the assigned capacity must be reduced to avoid overloading the downstream resource. Proceeding from the lowest to highest ranked FCA, FCA capacity values are decreased in turn by one, until the total assigned capacity equals the target rate.

Case 2. The total assigned capacity is *less than* the target rate.

In this case additional capacity is available, so assigned FCA capacities are increased to avoid possible under-delivery to the downstream resource. The FBA first identifies FCAs whose initial assigned capacity is below their projected demand. Working from highest to lowest ranked FCA within this set, each has its assigned capacity increased by one, until either the total assigned capacity equals the target rate or all FCAs have capacity values that match their predicted demand. If the latter criteria is met with additional capacity still available, capacity is added one at a time to all FCAs, again starting with the highest ranked FCA, until the total assigned capacity equals the target rate.

Note that for the most part, the only time the initially assigned capacity total is greater than the target rate is when rounding comes into play (Case 1), and it should then only exceed the target rate by one. In the reverse scenario, when the initially assigned capacity total is less than the target rate (either due to rounding or to a maximum capacity cap that is lower than the computed allocation for one or more FCAs), ranking only affects the starting order in which additional capacity is distributed. So overall, the impact of ranking on FCA capacity allocation is modest. Proposed changes described in the “Recommendations” section below would allow additional capacity to be distributed in a more directed manner.

Step 4. FBA redistributes capacity to accommodate exempt flights

The last step in the FBA calculations adjusts the capacity values based on the exempt status of flights crossing each FCA. This step is needed because CTOP does not reroute or assign delay to exempt flights, i.e., those that are airborne or within 45 minutes of departure. Instead it reserves a slot for them as close as possible to their FCA entry time. If the number of flights assigned to a bin exceeds the FCA’s capacity, that slot may appear to “build a hole” in the following bin, since the demand will be over in one bin and below in the next.

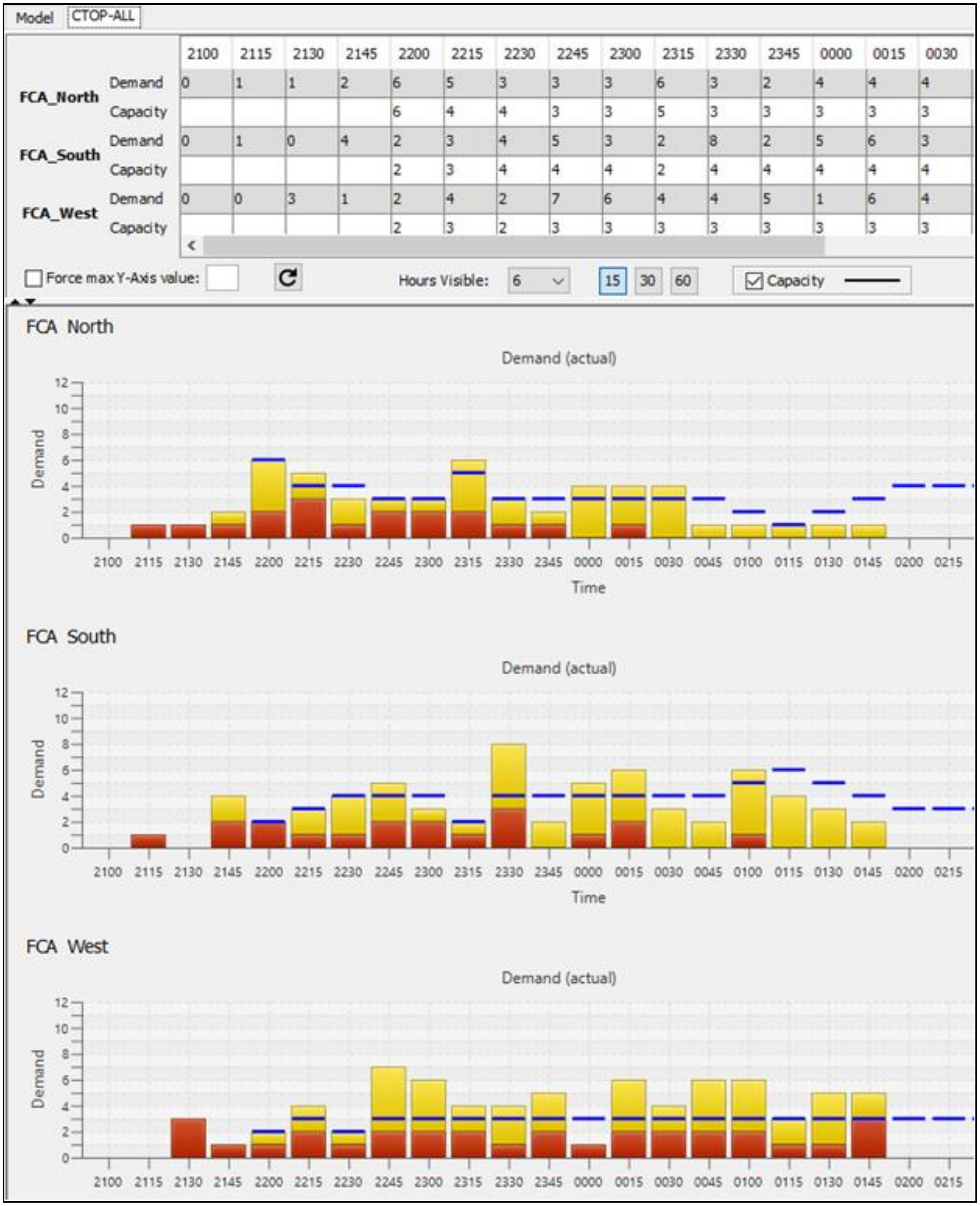
The FBA addresses this situation by adjusting the distribution of the combined capacity across FCAs if possible. When it detects that the number of exempt flights scheduled within a given time bin exceeds an FCA’s allocated capacity, it checks to see if a different FCA has capacity that was allocated for non-exempt flights during that same interval. This “non-exempt” capacity is then moved to the oversubscribed FCA.

The FBA does this as follows:

- First, it loops through each FCA to determine whether any have an exempt flight count which exceeds their current capacity allocation, and whether there is any capacity that has been allocated to non-exempt traffic at the same time. If no FCAs have exempt demand that exceeds their allocated capacity, no changes are made and the algorithm finishes.
- Then, if there is at least one FCA that needs additional capacity to accommodate its exempt demand, the FBA loops through each FCA in reverse rank order, transferring capacity allocated to non-exempt flights, starting first with the lowest rank FCA until it is depleted, then progressing to the next lowest ranked FCA, until the exempt demand in all FCAs is accounted for.

If the number of exempt flights across all FCAs exceeds the target rate, the FBA tries to reallocate capacity to the FCAs that need it. The FBA also displays a warning message when capacity redistribution could not provide adequate capacity for the exempt flights, indicating which FCAs will be overloaded and when.

Figure 6 shows the result of the FBA’s calculations, a set of capacity values provided for the three FCAs that feed EWR, in the table and the dashed blue lines on each FCA’s bar chart. CTOP will use these capacity settings when redistributing the demand.



		2100	2115	2130	2145	2200	2215	2230	2245	2300	2315	2330	2345	0000	0015	0030
FCA_North	Demand	0	1	1	2	6	5	3	3	3	6	3	2	4	4	4
	Capacity					6	4	4	3	3	5	3	3	3	3	3
FCA_South	Demand	0	1	0	4	2	3	4	5	3	2	8	2	5	6	3
	Capacity					2	3	4	4	4	2	4	4	4	4	4
FCA_West	Demand	0	0	3	1	2	4	2	7	6	4	4	5	1	6	4
	Capacity					2	3	2	3	3	3	3	3	3	3	3

Figure 6.

The chart in Figure 7 summarizes the FBA process flow described in this section.

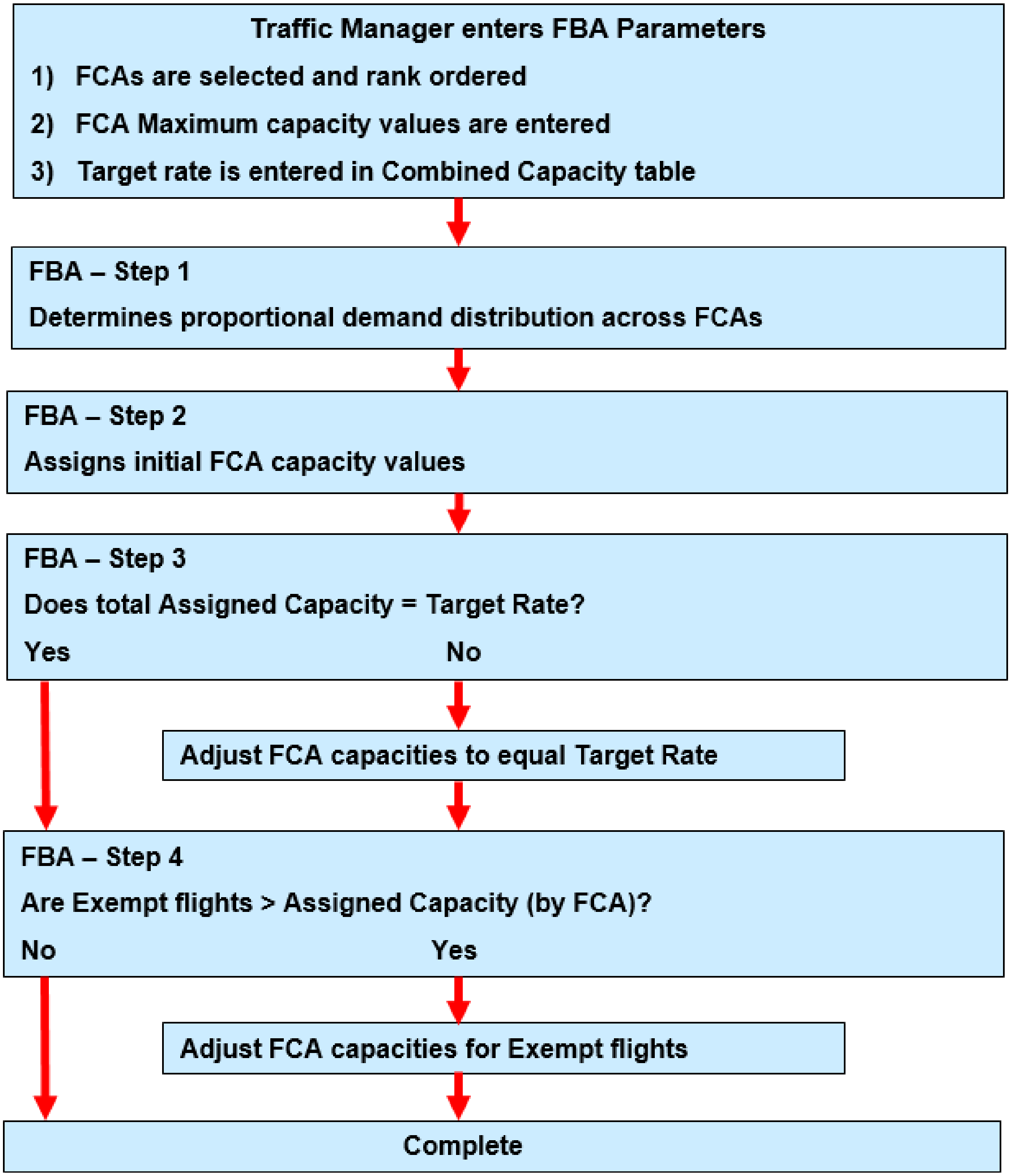


Figure 7.

Recommendations for future FBA research

Should the FBA be considered for use in field operations, the following improvements would be useful to explore.

Distribute any "spare capacity" based on airspace/route structure.

This enhancement would allow the Traffic Manager to determine how any "spare capacity" would be distributed between the FCAs in the CTOP based on airspace/route structure. Looking back to our discussion on rounding errors, the current FBA distributes any "spare capacity" by adding one to each FCA in a predetermined order. This enhancement would allow the Traffic Manager more flexibility in how that spare capacity is distributed. For example, let us look at our EWR scenario where we have FCAs for traffic entering from the North, West and South. If weather were to reduce the capacity on the West FCA, the CTOP will be assigning routes to the North and the South. However, the Traffic Manager might want to influence the distribution of these flights based on their knowledge of the airspace and route structure. Knowing that the airspace/route structure favors additional traffic be routed to the North, as opposed to the South, we would be able to instruct the FBA to distribute the spare capacity in this fashion.

This concept could also work in the reverse. In the event there was too much capacity allocated to the combined FCAs, capacity would be subtracted as determined by the Traffic Manager.

Distribute any "spare capacity" based on the TOS routes that are submitted.

Similar to the prior recommendation, the Traffic Manager might want to use the information the system has about the TOS routes that have been submitted. For instance, if in the above example the customers have submitted more TOS routes to the South, as opposed to the North, the Traffic Manager could instruct the FBA to distribute the spare capacity in this fashion.

This concept could also work in the reverse. In the event there was too much capacity allocated to the combined FCAs, capacity would be subtracted as determined by the Traffic Manager.

Better data for better demand prediction

This enhancement pertains to the use of the FBA when a CTOP is being revised (done when the capacity changes). During the initial implementation of the CTOP, the FBA uses raw demand to determine the allocation of capacity. This raw demand is based on the customer's first choice in regards to the route they would like to fly. This first choice is determined through a hierarchy but for now just think of it as the route known as the "Least Cost Trajectory Option". When the CTOP assigns routes, it does not always assign this option. Let us go back to our previous example. Looking at our EWR scenario where we have FCAs for traffic entering from the North, West and South. If weather were to reduce the capacity on the West FCA, the CTOP will be assigning routes to the North and the South. If the weather (which was restricting capacity on the West FCA) were to dissipate, allowing an increase in capacity, a revision to the CTOP would be performed. The current FBA would use the CTOP assigned routes (the assigned routes going to the North and South) to determine demand. The current FBA looks at these North/South routes as the customer's first choice when in fact the West route was the first choice. The enhancement to the FBA would change how it determines the customer's first choice of routes during a revision. The enhancement to the FBA would be that during a revision, the FBA would use the customer's Least Cost Trajectory Option to determine demand, as opposed to the CTOP assigned route to determine demand. This change would allow the FBA to distribute the revised capacity based on true demand.

Conclusion

The FCA Balancing Algorithm described in this document is a decision support capability that generates CTOP capacity entries for FCAs controlling traffic to a common downstream constraint. The FBA provides an equitable distribution of impact, and also greatly simplifies the Traffic Manager's task. Additional enhancements to the FBA described in the prior section could further improve its effectiveness.

While the FBA provides a useful solution to the capacity entry task, there are other setup decisions to be made when using CTOP in this context. These include:

- FCA locations
- FCA filter settings
- CTOP initiation time
- CTOP exemption settings
- CTOP program start and end times
- CTOP Automatic Revision settings

IDM researchers have explored some of the factors to consider when setting these parameters. Follow-up research might develop simple heuristics or additional decision support enhancements, similar to the FBA, which could further streamline the CTOP setup process.

Acronyms

AAR	Airport Acceptance Rate
AFP	Airspace Flow Program
ANSP	Air Navigation Service Provider
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
CDM	Collaborative Decision Making
CSP	Constraint Satisfaction Point
CT	Crossing Time
CTOP	Collaborative Trajectory Option Program
EDC	En Route Departure Capability (TBFM)
EDCT	Estimated Departure Clearance Time
ERAM	En Route Automation Modernization
ETA	Estimated Time of Arrival
FCA	Flow Constrained Area
FEA	Flow Evaluation Area
GDP	Ground Delay Program
GUI	Graphical User Interface
HITL	Human-in-the-loop
IDM	Integrated Demand Management
MACS	Multi-Aircraft Control System (NASA ATC simulation platform)
MF; MFX	Meter Fix (TBFM)
MIT	Miles in Trail
NAS	National Airspace System
nCTOP	NASA CTOP emulation
nm	Nautical mile
PGUI	Planview GUI (TBFM)
RTA	Required Time of Arrival (assigned to aircraft)
STA	Scheduled Time of Arrival
TBFM	Time-Based Flow Management
TBO	Trajectory Based Operations
TFMS	Traffic Flow Management System
TGUI	Timeline GUI (TBFM)
TMI	Traffic Management Initiative
TRACON	Terminal Radar Approach Control
XM; XMP	Extended Metering; Extended Metering Point (TBFM)