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Collaborative Departure Queue Management

An Example of Airport Collaborative Decision Making in the United States

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***Abstract*—The management of airport surface operations to provide shared situational awareness and to control taxi times through the use of 'virtual queues' has become an important component of Air Traffic Management (ATM) research and development in both Europe and the United States. Airport Collaborative Decision Making (CDM) has been implemented at a number of airports in Europe, and multiple departure metering concepts have now been tested in the US National Airspace System (NAS). This paper provides a review and comparison of the different airport surface departure management concepts, and describes one such concept in detail that has been evaluated operationally in the field in the US, the Collaborative Departure Queue Management (CDQM) concept. CDQM has been developed and evaluated by the Federal Aviation Administration (FAA) under the Surface Trajectory Based Operations (STBO) project. This paper provides a description of the operational field evaluation of CDQM that was conducted in Memphis, Tennessee, during 2009 and 2010. An analysis of the effectiveness, accuracy and benefit of CDQM in managing departure operations during the field evaluation is presented. CDQM was found to provide reduced taxi times, and resultant reduced fuel usage and emissions, while maintaining full use of departure capacity. Additional operational findings regarding the use of CDQM by the Air Traffic Control Tower (ATCT) and by the flight operators are also included.**

Keywords-airport surface traffic management; departure queue management; scheduling algorithms; collaborative decision making; equitable rationing of capacity

I. INTRODUCTION

Currently, during periods of high departure demand at busy airports, long queues of aircraft often form at the departure runways. Aircraft frequently wait in a queue for 30 minutes or longer. These queued aircraft are running their engines (or at least one engine) and, therefore, burning fuel. This unnecessary fuel consumption has a substantial cost to the flight operator as well as a substantial environmental impact. However, to reserve a spot in the departure sequence, each aircraft must leave its parking gate and physically occupy its place in the line. This physical first-come, first-served (FCFS) queuing also prevents a flight operator from altering the sequence of its flights from the order in which they are ready.

A number of different efforts in both the United States and Europe have addressed this problem through the use of decision support capabilities that meter the flow of aircraft from the parking gates to the runway.

The European Airport Collaborative Decision Making (CDM) concept [1] has been tested and deployed at a number of busy airports in Europe. The Airport CDM approach is based on the exchange of data between stakeholders to improve shared situational awareness. A centerpiece of the Airport CDM concept is the milestone approach that describes the discrete events and statuses of a departure flight as it progresses from preparing to load passengers (or cargo) all the way to take-off. Through the use of a common definition of the departure process, and through information sharing about milestone events for each flight, Airport CDM provides a framework within which the departure operation can be proactively managed. Using the shared information, additional components of Airport CDM assign Target Start Up Approval Times (TSATs) to flights to meter the flow of departures toward the runway for take-off. Tests of the European Airport CDM concept have been conducted in Brussels [2], Munich [3], Frankfurt [4], and at many other European airports as well.

In the US, the principles of the European Airport CDM concept have been adopted, while recognizing the differences in airport operations that exist between Europe and the US National Airspace System (NAS). Some of the significant differences that exist in the US are:

- Parking gates are assigned by flight operators
- Ramp areas are controlled by flight operators, or uncontrolled in some cases
- No availability of line-of-flight information
- A highly flexible control structure is required due to the dynamic environment

The operational concepts that have been developed for surface management in the NAS have leveraged the lessons learned by the European Airport CDM effort, while recognizing the differences between the two operations. In the US, the Surface CDM Sub-Team of the CDM government/industry initiative has developed a Surface CDM

Concept of Operations [5] that describes the procedures for data exchange and collaborative management of departure operations to reduce taxi times, fuel usage and emissions.

Although the Surface CDM Concept of Operations has not yet been directly implemented or tested, it provides an overall framework for departure metering concepts in the US that has received significant input from a broad array of Federal Aviation Administration (FAA), flight operator, airport operator and industry representatives. A comparison of the European Airport CDM concept and the Surface CDM Concept of Operations is provided in the next section of this document.

One of the approaches to management of surface departure operations that has been implemented and tested in the NAS is the Collaborative Departure Queue Management (CDQM) concept [6]. CDQM manages the length of the runway departure queues so that aircraft experience minimal physical queuing while ensuring the runways are used fully. Necessary delays when demand exceeds capacity are shifted from a queue at the runway to the parking gate or ramp area. In the CDQM concept, the flight operator receives an allocation of slots to enter the Airport Movement Area (AMA) rather than specific assigned times for flights at the departure runway. This allocation of slots is based on the Generalized Ration by Schedule (GRBS) [7] algorithm as implemented for CDQM. The flight operator may use these AMA entry slots without coordination with other flight operators or ATC. Once flights enter the AMA, the ATCT controls the flights using the same procedures as in current operations.

CDQM has been implemented within the Surface Decision Support System (SDSS) as part of the Surface Trajectory Based Operations (STBO) project. The FAA and NASA have worked collaboratively on airport surface operations research, including technology transfer of NASA's Surface Management System (SMS) [8, 9] to the FAA in 2004, which formed the foundation of the current FAA SDSS. The FAA has tested CDQM in the field in 2009 and 2010 at the Memphis, Tennessee airport [10]. Additional field tests of CDQM continue in 2011.

An additional component of the STBO project is a concept called Collaborative Departure Scheduling (CDS). Whereas CDQM provides an aggregate allocation of slots to enter the movement area to the flight operator, the CDS concept provides a specific assigned time for each flight. In order to maintain the flexibility required to handle dynamic changes, the CDS concept allows flight operators to substitute one flight for another in the use of the flight operator's assigned movement area entry times. The flight operator must communicate this substitution electronically to ATC so that compliance can be properly monitored. The CDS concept will be evaluated in field tests by the FAA STBO project in 2011.

The 'N control' concept has been developed and analyzed over the last decade by the Massachusetts Institute of Technology (MIT) [11]. The N control concept utilizes statistical analysis of historical departure operations at an airport to determine the point at which the number of aircraft that are active on the airport surface saturates the expected departure flow rate. Gate hold procedures are applied to flights that request push-back if the number of aircraft on the surface has already reached this saturation point. The N control concept does not require any additional data exchange between flight operators and ATC. Recent field tests of N control at Boston Logan airport (BOS) have demonstrated the usability and benefit of the concept [12].

One of the most significant operational uses of departure queue management in the US has been conducted by the Port Authority of New York and New Jersey at the John F. Kennedy airport (JFK) in New York [13]. Due to the closure of one of the primary runways at JFK, significant departure congestion and delays were feared by the stakeholders at the JFK airport. To address these potential delays, a partially automated system for departure queue management was implemented to assign taxi start times to flights. Flight operators can swap assigned taxi start times between their flights through a mostly manual process. The JFK departure management procedures were used operationally at JFK from March through June, 2010. The results demonstrated significant savings in fuel usage and emissions over what would have occurred without the management of the departure process.

NASA has conducted research on the Spot and Runway Departure Advisor (SARDA) concept, which provides optimized sequences and times for entry into the movement area and take-off for departure flights [14]. In addition, the SARDA concept incorporates coordination of arrivals with respect to the requirement for arrival flights to cross runways that are being actively used for departures in the optimal sequence [15]. The SARDA concept has been evaluated in a Human-in-the-Loop simulation conducted by NASA [16].

II. Comparison of European Airport CDM and Surface CDM ConOps

In 2010, the Surface CDM Sub-Team of the CDM government/industry initiative in the US developed the Surface CDM ConOps [5]. This section provides a comparison of the Surface CDM ConOps and the European Airport CDM concept.

A. Data Exchange and Departure Process

Both the US Surface CDM ConOps and the European Airport CDM concept rely heavily on data exchange between flight operators, Air Navigation Service Providers (ANSPs), and other stakeholders in the airport surface and departure operation. The concept of the Target Off-Block Time (TOBT) is fundamental to both concepts. The TOBT is the flight operator's best estimate of the time at which the flight will be ready to push-back. In the European Airport CDM concept, line-of-flight information for an aircraft is used to update the TOBT for a subsequent departure upon receipt or generation of updated arrival time information for the associated arrival flight. In the US Surface CDM ConOps, no line-of-flight information is assumed to be available, so the establishment and accuracy of the TOBT is the complete responsibility of the flight operator.

Using the TOBT as the basis, both concepts involve the calculation of a Target Take-Off Time (TTOT) based on a Variable Taxi Time Calculation (VTTC). The VTTC provides an estimated taxi-out time that is specific to the flight's starting location, flight operator, aircraft type, and other flight-unique

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parameters. The TTOT for each flight is also exchanged amongst the stakeholders that are involved in the departure operation at the airport.

The operation of airports in the US also involves an additional control point between the parking gate and the runway, referred to as the 'Spot', at which departure flights transition from the ramp area, or non-movement area, of the airport into the movement area that is actively controlled by the ATC Tower. To address this additional control point, the US Surface CDM ConOps also includes estimated movement area entry times, which can be referred to as 'EMATs' for the purpose of this comparison. The EMAT is the time at which the flight is estimated to be positioned at the Spot ready to receive a taxi clearance and proceed immediately to enter the movement area.

B. Management of Departure Operations

In the European Airport CDM concept, the TTOT is utilized to determine the appropriate time for a flight to start engines and push-back from the parking location. The Target Start-Up Approval Time (TSAT) is established to communicate to all stakeholders the appropriate time for the flight to start to ensure an efficient and equitable departure operation.

In the Surface CDM ConOps, two different models for management of departure operations have been defined. The two different models provide differing control mechanisms, which each have unique features and characteristics associated with their specificity and flexibility.

In the Time-Based Departure Metering Procedures (DMPs), the Departure Reservoir Management (DRM) capability assigns a specific time for each flight to enter the movement area. This time is analogous to the European Airport CDM TSAT. However, because the time that is assigned is a time to enter the movement area, it is referred to as the Target Movement Area Entry Time (TMAT). In the Surface CDM ConOps, it is the responsibility of the flight operator to determine the appropriate time to start engines and to push-back a flight in order to meet the TMAT. The TMATs are assigned based on the Ration by Schedule (RBS) principle, or based on some appropriate enhancement to RBS. Flight operators can substitute flights by sending a message to the DRM capability.

In the Count-Based DMPs of the Surface CDM ConOps, rather than assigning a specific time to each flight, an aggregate allocation of the number of flights that can enter the movement area is provided to each flight operator. These counts are referred to as Target Movement Area Entry Counts (TMACs). The TMACs are assigned to each flight operator in established time intervals, where each time interval will generally be on the order of 10 minutes. Thus, for example, a flight operator may be assigned a TMAC of 5 flights between 1420 and 1430, and a TMAC of 3 flights between 1430 and 1440. Because times are not assigned to specific flights, substituting flights is easier to accomplish in the Count-Based DMPs. Thus, the departure process can be handled with greater flexibility to support the dynamic airport environment.

III. Description of Collaborative Departure Queue Management

CDQM manages the length of the runway departure queues so that aircraft experience minimal physical queuing while ensuring the runways are used fully. Necessary delays when demand exceeds capacity are shifted from a queue at the runway to the parking gate or ramp area. In the CDQM concept, the flight operator receives an allocation of slots to enter the AMA rather than specific assigned times for flights at the departure runway. The flight operator may use these AMA entry slots without coordination with other flight operators or ATC. It is not necessary for the ATCT to consider the metering process and flight operator allocations after the flights have entered the AMA, because the necessary delays are absorbed within the ramp area. Thus, the ATCT controls the flights using the same procedures as in current operations.

By assigning only a number of allocated slots, rather than specific slot times for specific flights, the CDQM concept provides the environmental and fuel-burn benefits of a managed physical runway queue while preserving air carrier flexibility. This will allow flight operators to become comfortable with the notion of collaborative departure management and confident that the airport system will not be over-constrained unnecessarily. Although flight-specific virtual queue concepts may provide somewhat larger benefits, the CDQM concept overcomes many of the issues that have prevented virtual queue concepts from being implemented.

The simplest application of CDQM would be at an airport with a single flight operator and a single runway. The Surface Decision Support System automation will compares departure demand and departure capacity. When demand will exceed capacity during a period of time resulting in a departure queue longer than the desired maximum queue time, SDSS informs the flight operator that departure queue management will be used during that time period. SDSS then provides the flight operator with the number of departures that may be delivered to the AMA during each 10 minute control interval during the time period for which queue management is required. The flight operator will manage the rate at which aircraft block out and approach the hand-off spot to request taxi clearance to meet the allocated number of AMA entry slots. SDSS will also provide messages to the flight operator regarding the number of allocated slots that SDSS has counted as being used and by which flights, so that the flight operator and the ATCT will have the same information.

The ATCT will also receive information from SDSS, including the time period during which metering is needed to manage the departure runway queue length. However, the ATCT will not "police" whether the flight operator is complying with the allocation. During metering, SDSS will use surface surveillance data to observe each aircraft as it leaves its parking gate and approaches a hand-off spot. SDSS will keep track of whether the flight operator complies with the allocation or delivers too many or too few flights to the spot during each control interval. Flight operator's performance in adhering to the CDQM allocations will be reported via a CDQM report card that will be shared amongst all flight operators.

In the CDQM concept, the term 'major participants' is used to describe the flight operators who have a significant amount of traffic at the airport, and that have agreed to perform their own control of the push-back processes to meet CDQM aggregate allocations. Note that this control may be implemented via a Ramp Tower or via any other means that the flight operator chooses to use. The term 'minor participants' is used to describe all other flights, which includes General Aviation, Business Aviation, Military, and other scheduled air carrier flights where the number of flights of the flight operator is not high enough to warrant aggregate allocations of departure capacity. Minor participants must be assigned the appropriate waiting time by the ATC Tower under the CDQM procedures.

Once flights enter the AMA, they are controlled by the ATCT in the same manner as current operations. Any flights subject to Traffic Management Initiatives (TMIs) will remain subject to those restrictions. Flight operators are responsible for taxiing a flight with an Expect Departure Clearance Time (EDCT), for example, in time for the ATCT to comply with that restriction. Because the flight operator can apply more control over the sequence in which flights enter the AMA, the flight operator will have an increased ability to influence the departure sequence.

In a multiple runway departure operation, additional considerations must be included in managing the departure queues. Because of the procedures that are used for departure runway assignment, it is not always possible for the demand to be balanced between the available runways. In some cases, one of the departure runways may be saturated with demand, while another runway is operating under its capacity. For this reason, CDQM performs its allocation of departure capacity to flight operators independently for each available departure runway. More generally, operational procedures and traffic management restrictions may create the need to meter certain groups of flights separately from other flights. For example, when a miles-in-trail restriction is applied at a departure fix, it may be appropriate to provide allocations for the group of flights subject to that restriction separately from other flights.

Another important consideration in the real world of airport surface operations is prediction uncertainty in the TOBT. If a flight has an unexpected mechanical situation or other delay, the TOBT must be updated. When updates to the TOBT are received, CDQM automatically re-assigns the sequence and times for flights to ensure appropriate use of the departure capacity. In order to ensure that a double-penalty does not result from these updated TOBTs, CDQM uses the GRBS algorithm, which includes automatic bridging of flights when necessary. More information on the GRBS algorithm is available in [7].

Note that if the update to the TOBT occurs with insufficient lead time, some push-backs of flights may have already been implemented. In this case, the number of flights that are actually delivered into the movement area during the time interval may not be enough to maintain the desired queue length. This uncertainty and its potential negative effects are handled in CDQM by establishing a target queuing time for flights that provides a sufficient buffer against such operational uncertainties. The CDQM allocations are updated in time intervals beyond the freeze horizon in order to automatically adjust the flow of flights into the AMA to maintain the desired queuing reservoir of flights.

A. CDQM Architecture

The airport environment involves a number of operations and processes that integrate activities of both the flight operator and the ATC system. For example, flight operators are responsible for loading, fueling, preparing and pushing-back a flight in preparation for departure. The ATC system provides taxi clearances on the airport surface and manages traffic flow based on the demand. The real demand is only known as the flights are actually pushed-back by the flight operator.

Flight operators maintain the responsibility and flexibility to decide how to achieve their business objectives – including which flights to prioritize and which flights should be cancelled; what routes should be flown and what speed profiles to fly while airborne. However, the ATC system maintains the responsibility to keep aircraft safely separated from each other, and to fairly allocate access to scarce airport and airspace resources amongst multiple flight operators that want access.

This decomposition of roles and responsibilities between ATC and the flight operators is implemented and respected by the CDQM concept. The CDQM algorithms model the airport operation, and assign an appropriate allocation of departure capacity to each flight operator. As shown in Figure 1, flight operators provide flight schedule information and updated push-back times to the ATC system.

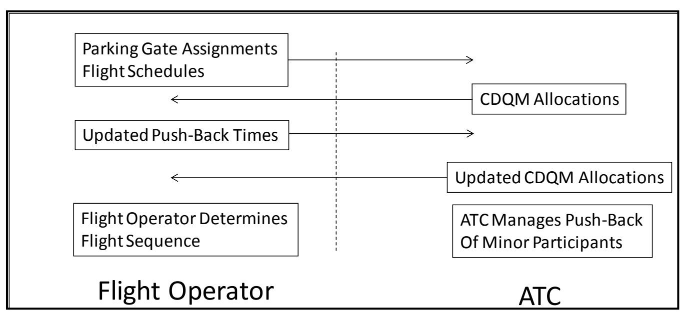

Figure 1. Flight Operator and ATC Roles in the CDQM Architecture

In the CDQM concept, ATC is responsible for allocating the departure capacity. This allocation is performed automatically through the CDQM algorithms in the SDSS system. Flight operators maintain the responsibility to determine which flights to push-back to meet the allocation of flights to enter the movement area. After the flights have entered the movement area, ATC performs their operation without any significant change from today's operation, including the authority and responsibility for all sequencing, maintenance of separation, and issuance of landing and take-off clearances.

IV. Comparison of CDQM and the Surface CDM Concept of Operations

The CDQM concept implements a significant portion of the Count-Based DMPs of the Surface CDM ConOps. In this section, a brief description of the similarities and differences between CDQM and the Surface CDM Count-Based DMPs is presented.

A. Data Exchange and Departure Process

Both CDQM and the Surface CDM ConOps require data exchange between the flight operators and the entity that administers the departure management process. This data exchange includes the TOBT being provided by flight operators, and the allocated number of slots in each time interval being provided back to the flight operators. Both CDQM and the Surface CDM ConOps utilize essentially the same departure milestone process, which includes the additional control point at entry into the movement area.

In the case of the Surface CDM ConOps, the entity that administers the departure management process is called the Departure Reservoir Coordinator (DRC). This terminology has been adopted to highlight the fact that the departure management process may not be administered by ATC in the Surface CDM ConOps. For example, the airport authority or one of the flight operators may run the departure management process by local agreement.

Although the CDQM capability has been developed under the assumption that ATC will operate the departure management function, all necessary information and tools required to support a DRC that is not ATC can still be provided by the CDQM concept and implementation. For example, if the airport authority is the DRC, it would be possible to simply provide a display of CDQM information to the airport authority to allow CDQM to be used to implement the Count-Based DMPs of the Surface CDM ConOps.

B. Management of Departure Operations

The Count-Based DMPs are directly applicable to flight operators with a large number of flight operations at an airport within a given period of time. For those flight operators with a low number of operations, there may not be enough flights to warrant an ‘aggregate’ allocation of departure slots during a time interval. The Surface CDM ConOps and CDQM handle this situation in different manners.

In the Surface CDM ConOps, it is assumed that the time intervals used in the Count-Based DMPs are short enough that a single allocation can be assigned for a flight operator with a low number of flights in the time interval. The flight that will use this single allocation can enter the movement area at any time within the assigned time interval to be considered compliant. For a flight operator with a low number of flights, the allocation may be zero or one for most or all of the time intervals. However, there will be exactly one allocation in the plan for each flight that the flight operator will operate.

In the CDQM concept, flight operators with a low number of flights are referred to as ‘minor participants’. Because these minor participants include general aviation flights and other unscheduled flight operators, the uncertainty in the departure demand and allocations due to minor participants must be considered. In the CDQM concept, minor participants receive an equitable delay when the flight calls the ATC Tower for approval to start engines, push-back or taxi.

In regard to the Time-Based DMPs of the Surface CDM ConOps, it is noted here that the Collaborative Departure Scheduling concept being evaluated in the STBO project is analogous to the Time-Based DMPs. Further information about the design and field evaluation of CDS will be provided in a future paper.

V. CDQM Field Evaluations

CDQM field evaluations were held at Memphis International Airport on 20 days between May 2010 and November 2010. These evaluations focused on the morning and afternoon departure pushes at MEM. Evaluations were held on the following dates in 2010:

- May 18 – 20
- June 22 – 24
- July 27 – 29
- August 31 – September 2
- September 28 – 30
- October 26 – 28
- November 9 – 10

The system as tested, as well as the operation of the system, evolved throughout these evaluations. From May through July only Delta actively participated in the evaluations. The evaluations during this period focused on the morning and afternoon Delta departure pushes. Starting in August, when FedEx began actively participating, the evaluations expanded to include the FedEx afternoon departure push. The May and June evaluations focused primarily on technical issues and the development of the required operational procedures. Significant departure metering began during the August/September evaluation period.

This analysis, taking a case study approach, focuses on several interesting departure pushes during the field evaluations. The first case looks at a departure push during which CDQM recommended metering but no metering occurred. The second case looks at departure pushes during which CDQM was used effectively to manage the departure queue.

In each case study analysis, a list of all the flights that are known to have been metering during the field evaluations was collected ‘by hand’ by the participants in the evaluations. Delta currently has no system for recording flights that are held at the gate, and while FedEx has such a system, currently there is no way to distinguish flights that were held at the gate for CDQM and flights that were held for other reasons. Extrapolation from these results to an estimate of the annual impact of CDQM at MEM is beyond the scope of this paper.

A. The June 24, 2010 Afternoon Departure Operation

By June 24, 2010 the components of the CDQM system were operating as expected, but the operational procedures for metering flights at the Delta ramp tower had not been fully established. FedEx was not yet participating in the evaluations. As a result, this day presented a good opportunity to study the impact of the over delivery of departures to the movement area on the departure queue. The morning departure push was not heavy, and CDQM never called for metering. During Delta's afternoon departure push, however, departure demand was high enough for CDQM to call for metering to avoid excessive departure queuing.

The Delta departure push started at approximately 1900 UTC and continued until approximately 2040 UTC, at which time the FedEx departure push started. From 1900 UTC to 2040 UTC departures were using runways 18R and 18C. When the FedEx departure push started the east departures transitioned from 18C to 18L. CDQM was configured for target departure queue delay of 6 minutes. CDQM called for departure queuing to begin on both runways at 1930 UTC and to continue through most of the FedEx departure push.

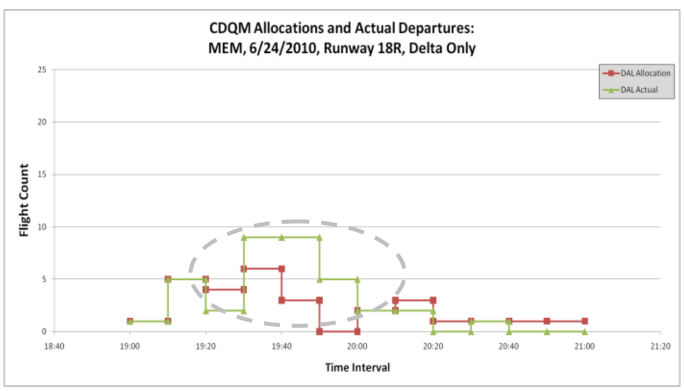

Figure 2 –Allocations v. Actual Delivery, 06/24/2010

Figure 2 above compares the slot allocations for Delta to their actual delivery of flights to the movement area. Note that between 1930 and 2000 UTC Delta substantially over delivered. Figure 3 below overlays the queuing delay that the flights experienced during this period. Note that as Delta exceeded the allocation, the CDQM algorithm adjusted by lowering Delta's allocation in future bins.

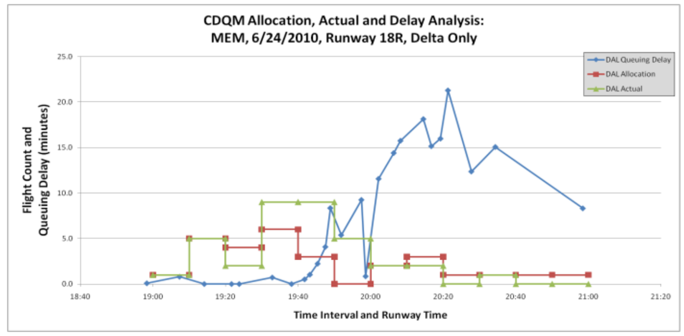

Figure 3 – Actual Delivery v. Departure Delay, 06/24/2010

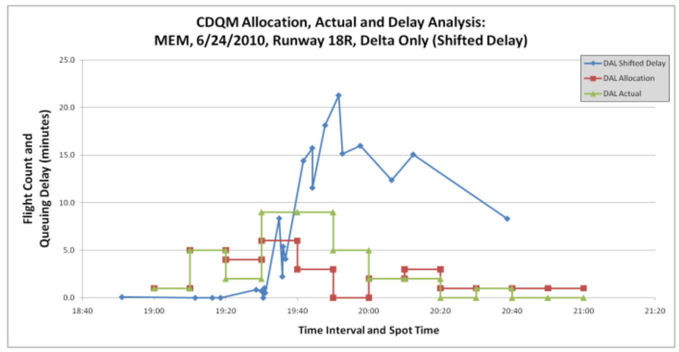

Figure 4 – Actual Delivery v. Departure Delay @ Spot Time, 06/24/2010

Since delivery is measured at the spot, and delay is measured at the runway, Figure 3 tends to exaggerate the lag time between over delivery and queuing delay. To better illustrate the impact of over delivery on queuing delay, Figure 4 above shifts the queuing delay that occurred at the runway for each flight to the time that the flight crossed the spot. This shift emphasizes the relationship between over delivery and queuing delay.

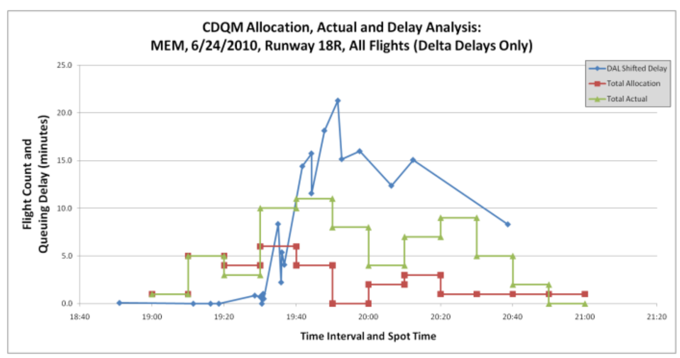

Figure 5 – Actual Delivery v. Departure Delay @ Spot Time, All Flights, 06/24/2010

Figure 5 above shows all flights delivered to the movement area, not just the Delta flights. Adding these flights helps explain why Delta's delays persisted when their delivery of flights to the movement area decreased after 2000 UTC. Finally, Figure 6 below shows a similar picture, but with departure queue length substituted for departure queue delay.

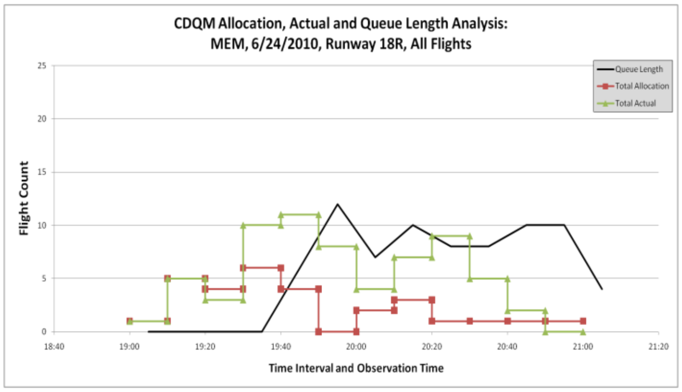

Figure 6 – Excess Delivery v. Queue Length, All Flights, 06/24/2010

B. The October 27, 2010 Afternoon Departure Operation

As previously discussed, the typical afternoon departure scenario at MEM involves a Delta departure push that is followed with some overlap by a FedEx departure push. In a south operation, during the Delta portion of the push departures typically will use runways 18R and 18C. When the FedEx push begins departures will transition from runway 18C to runway 18L. (Runway 18R will be used for departures throughout the push.)

On October 27, 2010 the afternoon departure push at MEM produced a more extended metering period. The 18C/18L operation was relatively light. The 18R operation, however involved an extended metering period, from 19:40 – 21:10, and a substantial number of flights held. While Delta didn't hold any flights, FedEx held 15 flights for a total of 68 minutes.

Figure 7 below shows the total allocations and actual flight delivered for runway 18R during this push. Figure 8 shows the allocations and actual deliveries for Delta and FedEx. The timing of the push, with Delta departures first followed by FedEx departures will some overlap can be seen in this figure. The metering period is again highlighted in yellow.

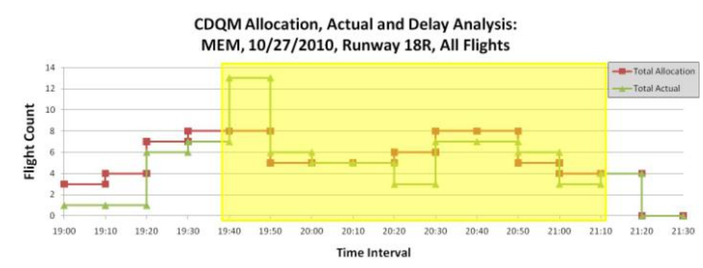

Figure 7 –Allocations v. Actual Delivery, 10/27/2010

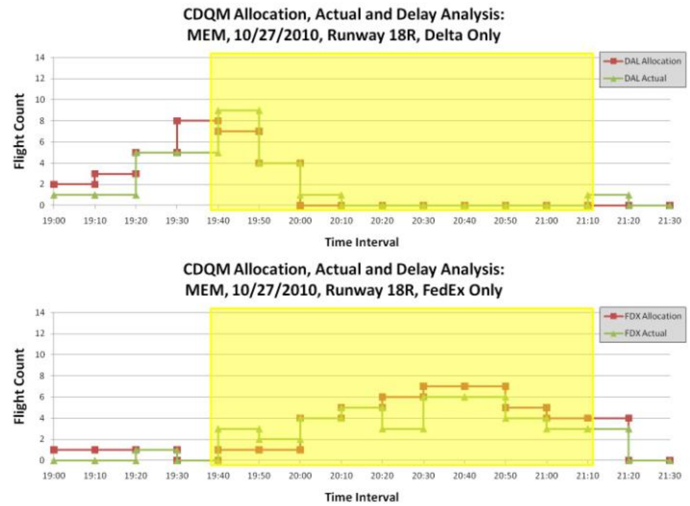

Figure 8 –Allocations v. Actual Delivery by Flight Operator, 10/27/2010

Figure 9 below shows the Time in Queue metric overlaid on the total allocations and actual flights delivered. The Time in Queue values are shown at the spot crossing time for the flights. Figure 10 breaks down the Time in Queue values for Delta and FedEx.

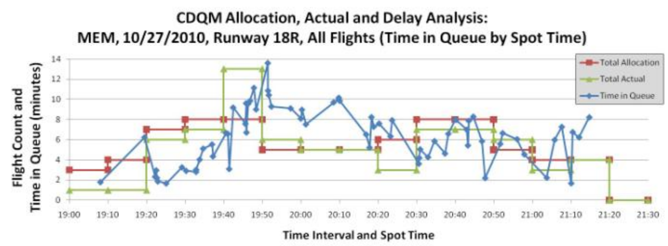

Figure 9 – Actual Delivery v. Time in Queue @ Spot Time, 10/27/2010

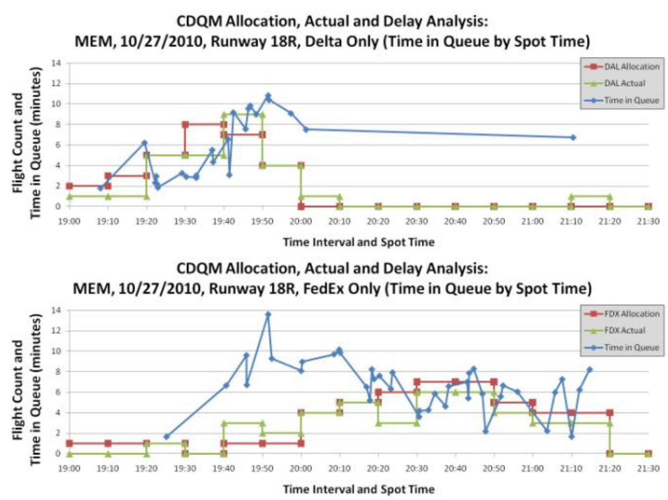

Figure 10 – Actual Delivery v. Time in Queue @ Spot Time by Flight Operator, 10/27/2010

Note the spike in the queuing delay that results when both Delta and FedEx exceed their allocations in the 19:40 – 19:50

bin. After that spike, however, the operation settles down, with departure queue delays generally in the 4-7 minute range. Note also that between 20:20 and 21:00 there were a number of periods of under delivery. This resulted in delays that were below the target, but in the end there was never a time when the runway was ‘starved’ of departures.

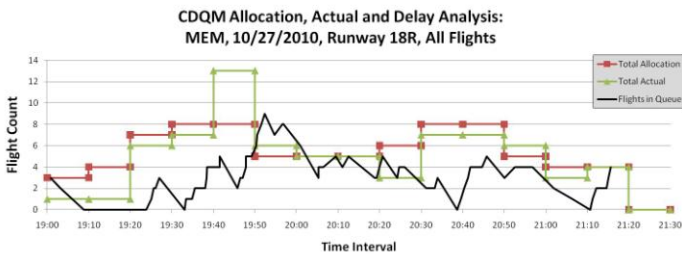

Figure 11 – Actual Delivery vs. Queue Length, 10/27/2010

Figure 11 **Error! Reference source not found.** show the queue length during this period. While the count of flights in the queue twice goes to zero during the metering period – with both times corresponding to periods of under delivery – separation constraints meant that no departure capacity was lost. The FedEx fleet is predominantly heavy aircraft, and as a result a brief period with no flights in the queue doesn’t impact departure throughput, since heavy aircraft are separated by 2+ minutes on departure.

VI. CONCLUSIONS

Both European and US organizations are currently working toward airport queue management to reduce taxi times, fuel usage and emissions. Data exchange and shared situational awareness are core components of most of the concepts being evaluated.

Similar concepts and approaches are being used in Europe and the US, although key differences do exist that reflect the differences in operational structure and procedures.

The CDQM concept implements much of the Surface CDM Concept of Operations. CDQM has been developed and installed in the Memphis, Tennessee airport and ATC facilities.

Successful operations of the CDQM prototype system was shown in field evaluations to allow ATC personnel and flight operators to avoid excess departure queuing resulting in direct savings to the flight operators and reduced departure delays.

Additional research and development of the Surface CDM Concept of Operations, CDQM and the Collaborative Departure Scheduling concept will occur in 2011.

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