Modeling Functional Specifications of Ground Systems in the National Airspace System

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The Federal Aviation Administration (FAA) is projecting tremendous growth in air traffic demand and complexity with the integration of unmanned aerial systems (UAS) in the National Airspace System (NAS). To meet this demand, the FAA is working to a 2025 goal of a system-wide autonomous optimized air traffic management (ATM) system that is safe, resilient, and agile enough to adapt to the ever changing business models and operator demands in the NAS. Modeling ATM to understand the change impact of automation and human computer interfaces on safety and performance is critical to achieving the 2025 goal. Necessary to any such modeling effort are abstractions of complex automated ground systems; wherein the abstractions represent the functional specifications of those systems. To that end, this paper presents an abstract functional model of the Terminal Sequencing and Spacing (TSS) system that provides automation to support Terminal Radar Approach Control (TRACON) in sequencing arrival traffic at airports. The model employs simplified flight dynamics under visual meteorological conditions (VMC) to create a schedule for arriving flights that is free of conflict at meter fixes, merge points, and runway thresholds. The utility of the TSS model is evaluated in a study of airspace around the LaGuardia airport (LGA) to understand the change impact of Departure-Sensitive Arrival Spacing (DSAS) automation for TRACON controllers. DSAS improves departure throughput under high traffic conditions at LGA, but different deployment configurations have different workload impact on controllers. The study suggests that the TSS model scales to a level sufficient to recreate scenarios from the published human in the loop simulations (HITL) of DSAS at the LGA. It also suggests that models of the complex automation at a high-level of abstraction enables the tractability of more general system-wide model analysis.

I. Introduction

Current techniques for evaluating and verifying automated ground systems in the National Airspace System (NAS) do not precisely characterize the human role in safety assurance beyond recognizing the need for the human to mitigate system anomalies and unanticipated events. The safety of any automated system, including ones that have some degree of autonomy, cannot be characterized or evaluated in isolation with disregard to the performance of the overall system or the capabilities of the human operators. The ability to efficiently design and perform verification, validation, and certification of automated systems in the context of human operators and other systems is of interest to the various stakeholders in civil aviation.

The development process for safety and mission critical systems often uses Model Based Development (MBD). MBD refers to the use of domain-specific modeling notations that can be analyzed for desired behavior before a digital or control system is built. There are several commercial MBD tools, including SCADE,[1] IBM Rhapsody,[2] iLogix StateMATE,[3] Simulink[4] and Stateflow[5] from Mathworks. Existing work using these modeling notations do not provide the high-level description of the system or how it would interact in the context of other systems and human operators. Typically the models in these tools are intended to represent the implementation, and they are used in some human in the loop (HITL) study to assess the larger system. Unfortunately, such HITL studies with models take place late in the design process where the cost to make changes to the system is extremely high.

In this work it is argued that being able to create
functional specification models of automated systems opens avenues to the development of methods that can assess the safety of automated systems within a larger context. This paper describes the modeling exercise of the The Terminal Sequencing and Spacing (TSS) system which is currently being deployed across different regions in the US and is being used by Air Traffic Controllers (ATC) to assist with the complex task of scheduling and controlling aircraft during periods of congestion. It is then described how integrating it within a larger model allows for evaluation of the safety and performance of the system with respect to other systems and human operators.

A. LaGuardia Airport

LaGuardia Airport (LGA) is one of four major airports in the New York metropolitan area. In November 2015 the total number of movements by the end of the year was projected to be over 361 000, carrying just over 28 million passengers. Of these flights 90% are domestic, and 92% of the passengers are traveling domestic.

LGA is amongst the airports in the NAS suffering from the highest rate of delays. Between 2007 and 2012 the average departure delay was greater than 14 minutes. Due to the majority of the flights being domestic, these delays spread in throughout the network to other airports.

The traffic at LGA consists of mainly large aircraft with a few additional smalls and Boeing 757s (B757s). The traffic begins at 6 a.m. local time and remains as a steady peak throughout the day until 8 p.m. in the evening. Between these hours the scheduled number of arrivals can be over 50 aircraft per hour. Due to the large amount of traffic and the limited infrastructure, the airport becomes congested if one-for-one operations (one arrival for one departure) are not maintained.

1. Layout

As seen in Figure 1, LGA features a crossing runway configuration. The two main runways 04-22 and 13-31 are both 7000 ft long. The runways intersects near the northern part of the airfield, close to the threshold of runway 13. There are two areas with history of potential risk of collision or runway incursions, so called Hot Spots (HS). Due to the asymmetry of the runway layout, some configurations are more efficient than others, as departing aircraft must wait until landing aircraft have passed the runway intersection before beginning their takeoff roll (and vice versa).

B. New York Airspace

The following section describes the airspace surrounding LGA. This airspace configuration is the same as the one used for the modeling and simulation described in Section II.

1. Sectors

The airspace surrounding an airport (stretching approximately 50 NM out from the airport) is called Terminal Radar Approach Control (TRACON). Because LGA is located in a very crowded area and surrounded by Newark Liberty Intl. Airport (EWR), John F. Kennedy Intl. Airport (JFK) and Teterboro Airport (TBR), this airspace is very narrow. As seen in Figure 2, the airspace consist of three sectors. Haarp and Empyr being the north and south feeder sectors respectively, and Final being the one closest to, and surrounding, the airport.

2. Arrival Routes and Points of Interest

The sectors contains three Standard Terminal Arrival Routes (STAR). These are BAYSE from the north, MILTON from the west and KORRY from the south. The STARs are predefined published routes, imposing a set of position, speed and altitude restrictions that aircraft has to meet on their way to the runway. These constraints are shown in Figure 2.

Arriving traffic is handed over from Center Air Traffic Control (ATC) to TRACON ATC at specified points called meter fixes. These are marked as red triangles in Figure 2 and are VALRE, FINSI and KORRY.
Figure 2. Overview of the TRACON airspace showing the sectors, STARs, meter fixes and merge points. Speed and altitude restrictions are shown under the name of the corresponding waypoint.

Other points of interest are the merge points (the points where STARs merge). There are two merge points, TYKES in Empyr, and OMAAR in Final.

C. Terminal Sequencing and Spacing

The TSS system was developed as a part of NASAs Air Traffic Management Technology Demonstration - 1 (ATD-1). Todays operations becomes inefficient during periods of intense traffic as controllers mainly make use of visual aids (static markings on the radar screen) and their own judgment to guide aircraft safely to the runway. During peaks in traffic the airspace needs to absorb some delay to allow for adequate separation between aircraft. The main technique used for this is rerouting of aircraft (also known as vectoring). This leads the aircraft away from their most efficient routes, increases fuel burn, noise pollution, pilot- and controller workload. TSS improves efficiency within the TRACON area by distributing the workload amongst the different controllers and taking a more global approach in controlling the airspace.

Using TSS controllers are able to use speed commands (metering) instead of vectoring. Arriving aircraft are scheduled according to a modified First-Come-First-Served (FCFS) basis. "Modified" means that the system considers the flights first in line, inbound to each meterfix, and then make use of a Center/TRACON Delay Distribution Function (DDF) to calculate how much delay each aircraft could absorb within the TRACON airspace and then decides on the order to improve efficiency. The schedule is guaranteed to be conflict free. The use of tools like the TSS is called Time-Based Flow Management (TBFM) and shifts the focus for ATC to work schedule oriented (maintaining the schedule set by the TSS system), instead of conflict oriented (resolving potential conflict violations between aircraft).

1. Slot Markers

The interface between the TSS system and ATC are a number of visual aids. This section will describe one of these - the slot markers.

Slot markers are presented on the controller’s radar screen. They represents the desired position and recommended speed of its corresponding aircraft to reach conformance with the generated schedule. An example is shown in Figure 3. In this figure the aircraft is represented as a yellow "Z", with a label above it informing the controller about flight number, altitude information (assigned and current), suggested speed, and next waypoint or heading. Below the aircraft symbol is the speed of the aircraft. Connected to the slot marker, represented as a green circle, is the speed of the slot marker.

The task of ATC is to put the aircraft inside the slot marker using metering. This will guarantee safe separation and conformance with the schedule.

Figure 3. Image of a slot marker as it is presented to ATC on a radar screen. The aircraft is represented as a yellow "Z". Above the aircraft symbol is the label containing information about flight number (CCA983), assigned altitude (FL143), current altitude (FL349), suggested speed (265 kts) and heading (inbound BAYST waypoint). Under the aircraft symbol is the speed of the aircraft (260 kts). Under the slot marker is its speed (280 kts).
2. Time line

A compliment to the slot markers is the time line. The time line which is a visual aid, like the slot markers, can be seen in Figure 4. The time line gives an overview of the current traffic situation by displaying a flights Estimated Time of Arrival (ETA) and the corresponding Scheduled Time of Arrival (STA). The ETA is displayed on the left side, in the middle is the time, and the corresponding STA on the right side. As time progresses flights move downwards on the timeline and the bottom line represents the runway threshold.

![Figure 4. The time line. In the middle, the time is displayed as minutes of the hour (:00, :55, :50 etc.). On the left are the arriving flights ETAs and on the right the corresponding STA. Progression downwards on the time line corresponds to the flights getting closer to the runway threshold, and their ETA/STA.](image)

D. Departure Sensitive Arrival Spacing

DSAS is a prototype system developed at the Human-Systems Integration Division at NASA Ames Research Center. It is a system that is to be used together with TSS, see section C. Although the TSS system guarantees a conflict free schedule according to FAA Wake Vortex Standards and TRACON separation minimums [12, 13], it is not optimized considering departure throughput.

DSAS tries to optimize the arrival schedule considering departure throughput, without affecting the arrival schedule in a negative way [8]. This means to make up for slack in the schedule, a gap is created upstream in the time line, allowing for a double departure, hence increasing departure throughput without delaying any arrivals.

![Figure 5. The principle of DSAS. On the left is the time line before intervention of DSAS, and on the right, time line after intervention.](image)

During operations at LGA using a runway 22-31 (where 22 being the landing runway, and 31 the one used for departure) the minimum time between two arrivals that allows for one-for-one operations, see section A, is 75 seconds [14]. The gaps needed between arrivals to depart one, two, three, four and B757 are shown in Table 1.

<table>
<thead>
<tr>
<th>Departure</th>
<th>Gap [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td>75</td>
</tr>
<tr>
<td>Double</td>
<td>120</td>
</tr>
<tr>
<td>Triple</td>
<td>170</td>
</tr>
<tr>
<td>B757</td>
<td>180</td>
</tr>
<tr>
<td>Quadruple</td>
<td>220</td>
</tr>
</tbody>
</table>

Table 1. The minimum gap required for a specified number of departures in between two arrivals at LGA during runway 22-31 operations.
II. Model

This section describes the main features and design choices of the model. The model implements simplified flight dynamics under Visual Meteorological Conditions (VMC), and uses high-level descriptions of the ground-based ATC systems as foundation for the modeling [6,15,16].

An interface is used connecting the different parts of the model. Although the model currently very deterministic, the interface makes it flexible and points of non-determinism can be inserted. The flexibility allows for example exchanging systems, algorithms and traffic scenarios and evaluating how the design choices impacts performance and safety. A schematic of how the model architecture can be seen in Figure 6.

![Figure 6. Schematic of the Human System Integration Model.](Image)

A. Input data

All agents and objects, such as flights, flightplans and waypoints, used in the simulation were generated using Multi Aircraft Control System (MACS) log files from a HITL.

B. Aircraft

This section describes how the aircraft are modeled. Every aircraft agent holds six attributes or states. These are: Calibrated Air Speed (CAS), Vertical Speed (V/S), Altitude, Bearing, Latitude and Longitude. An aircraft is given initial conditions and then flies along geometric paths according to the segments specified in the flightplan.

1. True Air Speed

Conversion from the CAS specified in the flightplan to True Air Speed (TAS) uses a model of the International Standard Atmosphere (ISA) [19,20]. The CAS is converted to TAS according to [21]

\[ v = v_c \frac{f}{f_0} \sqrt{\frac{\rho_0}{\rho}} \]  

(1)

where \( v \) is the TAS [m/s], \( v_c \) is the CAS [m/s], \( f \) is a compressibility factor (defined in Equation 2) at the current altitude, \( f_0 \) is the compressibility factor at sea level, \( \rho \) is the air density at sea level [kg/m^3] and \( \rho_0 \) is the density at sea level [kg/m^3].

The compressibility factor in Equation 1 is defined as [21]

\[ f = \sqrt{\frac{\gamma}{\gamma - 1}} \left( \frac{q_c}{p_0} + 1 \right)^{\frac{\gamma - 1}{\gamma}} - 1 \]  

(2)

where \( \gamma \) is heat capacity ratio for air, \( p \) is the air pressure [Pa] and \( q_c \) is the dynamic pressure [Pa] expressed in terms of the CAS as [21]

\[ q_c = p_0 \left( 1 + \frac{\gamma - 1}{2\gamma} \cdot \frac{\rho_0}{\rho_0} \cdot v_c^2 \right)^{\frac{\gamma}{\gamma - 1}} - 1 \]  

(3)

where \( p_0 \) is the air pressure at sea level [Pa].

2. Position Update

The position of the aircraft is updated with the frequency \( f_{\text{update}} \) [Hz]. The first step is calculating the bearing to the next waypoint in the flight plan according to [22]

\[ \theta = \arctan2(\sin(\lambda_2 - \lambda_1) \cdot \cos \phi_2, \cos \phi_1 \cdot \sin \phi_2 - \sin \phi_1 \cdot \cos \phi_2 \cdot (\lambda_2 - \lambda_1)) \]  

(4)

where \( \theta \) is the bearing [rad], \( \lambda_2 \) is the longitude of the waypoint [rad], \( \lambda_1 \) is the current longitude of the aircraft [rad], \( \phi_2 \) is the latitude of the waypoint [rad] and \( \phi_1 \) is the current latitude of the aircraft [rad].

Using the TAS described in Equation 1 the distance \( d \) [m] traveled during the time interval \( 1 / f_{\text{update}} \) is calculated. The angular distance traveled \( \delta \) [rad] is calculated as

\[ \delta = \frac{d}{R + h} \]  

(5)

where \( R \) is the earth radius [m] and \( h \) is the altitude of the aircraft [m].

The new latitude, given the bearing from equation 4 and the angular distance from equation 5 is then [22]

\[ \phi_2 = \arcsin(\sin \phi_1 \cdot \cos \delta + \cos \phi_1 \cdot \sin \delta \cdot \theta) \]  

(6)

and the new longitude is [22]

\[ \lambda_2 = \lambda_1 + \arctan2(\sin \theta \cdot \sin \delta \cdot \cos \phi_1, \cos \delta - \sin \phi_1 \cdot \sin \phi_2) \]. \hspace{1cm} (7)

The V/S, which is set to reach the next waypoint at the altitude specified in the flightplan, is calculated according to

\[ v_{\text{vert}} = \frac{h - h_{\text{wpt}}}{ET_{A_{\text{wpt}}}} \]  

(8)
where \( h \) is the altitude of the aircraft [m], \( h_{\text{wpt}} \) is the altitude in the flight plan at the next waypoint [m], and \( \text{ETA}_{\text{wpt}} \) is the calculated ETA (see section \( D \)) to the next waypoint [s].

C. Compression and Spacing

As aircraft approach the airport, they have to comply with the separation requirements\( [12, 13, 23] \) in the TRACON area set by the Federal Aviation Administration (FAA). Separation requirements becomes less constraining closer to the airport. While getting closer to the airport the aircraft are also descending with a constant or decreasing CAS or ground speed (see section \( 1 \)) in accordance with the flightplan. The constant or decreasing CAS means an even greater reduction in TAS in accordance with Equations \( 1 - 3 \). These two factors contributes to a compression of the distance between aircraft as they approach the runway threshold, and often makes this point the constraining one when adjusting the trajectories of the aircraft.

D. ETA Calculations

The flight time for each segment in the flightplan is estimated using the average speed for the segment and the segment distance calculated as:

\[
\begin{align*}
a &= \sin^2(\Delta \phi/2) + \cos \phi_1 \cdot \cos \phi_2 \cdot \sin^2(\Delta \lambda/2) \\
c &= 2 \cdot \arctan2(\sqrt{a}, \sqrt{1-a}) \\
d_{\text{seg}} &= (R + h) \cdot c
\end{align*}
\]

where \( \Delta \phi \) and \( \Delta \lambda \)[rad] is the difference in latitude and longitude between the start- and end point of the segment, \( h \) is the aircrafts current altitude and \( d_{\text{seg}} \)[m] is the distance of the segment.

E. TSS

The goal of the TSS model is to create conflict-free schedules for arriving flights at meterfixes, runway thresholds, and any other merge points. In this section it is described how a high-level model for TSS was designed and created based on descriptions in published literature\( [6, 17] \). The publications describing TSS do not provide any low-level implementation details of the deployed TSS system, but, rather present the functional specification of the system. The design choices of the model and its level of abstraction are determined by how the TSS model is to be used in a larger system; this larger system in this case is a Departure-Sensitive Arrival Spacing (DSAS) concept being evaluated within the LaGuardia airspace\( [8] \).

There are two key differences in the TSS model created in this work compared to that described elsewhere\( [14] \). In this TSS model the generated trajectories are simplified; the TSS model does not generate a 4D trajectory prediction based on latitude, longitude, altitude, and time; rather it generates 3D trajectories based on latitude, longitude, time. Altitude is interpolated from the aircraft’s flight plan. Furthermore, the Center/TRACON Delay Distribution Function\( [6] \) is not implemented, instead, the flights are scheduled on a first-come-first-served (FCFS) basis.

In order to create a conflict free schedule for arriving flights on a FCFS basis, the TSS model computes sequences of the flights based on estimated time of arrival (ETA). Next it checks whether the generated sequence meets the specified minimum separation at meterfixes, different merge points, and runway constraints. If the schedule violates the separation requirement, the TSS algorithm performs a trajectory adjustment to create adequate separation. Controllers use generated trajectories to meter or vector planes into positions in order meet the schedule. An illustration of the algorithm can be seen in Figure 7.

![Figure 7. Simplified TRACON airspace, illustrating the algorithm used by TSS and DSAS. The aircraft are scheduled in sequence 1-5. Adjustments are then made to the trajectories to conform with the schedule.](image-url)

1. Generating a schedule

The TSS first sequences and schedules planes to their corresponding meterfixes. The TSS model generates a single global timeline for all arriving and depart-
When adding a new flight, the ETAs are computed based on standard operating procedures (SOP) for the given class of aircraft. When adding a new flight, \( f_n \) to the timeline, if the timeline contains no other flights, \( f_n \)'s STA becomes the same as its ETA. In the case the when timeline is not empty, the flight \( f_n \) is assigned an STA based on its earliest possible ETA or the time required to ensure in-trail separation to the flight ahead of it in the schedule. This is done repeatedly until all the flights in the sequence are conflict free and conform to the in-trail separation constraints. Note that this same process is used to create conflict free schedules and sequences at other merge points.

The global timeline contains all the scheduled departures and the inbound flights. After the freeze horizon the arriving flights are no longer altered; the freeze horizon is approximately 20 minutes from the meter fix. The departures are scheduled based on the FAA’s minimum vortex spacing and TRACON separation requirements.\(^{13,23}\) The scheduled departure time is not frozen, and is changed according to the needs of the schedule. The flight is scheduled at its earliest ETA to the runway threshold meeting the separation requirements. If the flight is the first in the sequence, it is assigned an STA equal to its ETA. In the case, however, when there are flights ahead in the sequence, it computes the required separation to the preceding flight and adjusts the trajectory to modify the schedule.

2. **Trajectory Adjustment**

The trajectory adjustment is done by comparing the predicted flight paths (according to the flight plan) of two flights. When comparing, the necessary adjustments are made to the flight plan of the trailing flight to ensure separation and in-trail constraints at all times.

The flight plans of these flights are compared to find the first common waypoint. The ETA of the respective flights to this waypoint is then calculated. If the separation requirement is not met, the trailing flight trajectory is adjusted. When separation is ensured at the merging point of the two routes, the ETA to each following waypoint is compared, and if required, then the trajectory of the trailing flight is further refined. Note that currently the trajectory adjustments are only based speed adjustments that are within the specified range of a certain aircraft’s operational limits.

### F. DSAS

The DSAS system is modeled separately from TSS to enable comparison with a baseline scenario with DSAS not activated while still running TSS. As DSAS is still a prototype the algorithm was modeled according to publication\(^{8}\) and consultation with subject matter experts.

The system intends to optimize the timeline by adjusting the gaps between flights to improve departure throughput without having a negative impact on the schedule.\(^{5}\) The flights are compared pairwise in sequence, starting with the two first in the schedule. If the STA separating them at the runway threshold falls between what is specified in Table 1 and if aircraft operational limits allows, the gap is adjusted to compress the schedule. This propagates any slack upstream in the timeline and the gaps will be set in accordance with the gaps allowing for an integer number of departures in between arrivals.

If the gap is found to be bigger than Quadruple (220 s) it is adjusted to

\[
\text{Gap} = \text{Single} + n \cdot (\text{Double} - \text{Single})
\]

where \( \text{Single} \) and \( \text{Double} \) are the gaps specified in Table 1 and \( n \) the largest integer making the gap \( \leq \) the current gap.

The STA of the trailing flight is then adjusted and verified to be conflict free at meterfixes, runway thresholds, and any other merge points.

### III. Integration

The DSAS concept provides the ability to maximize departure throughput at LGA without impacting the flow of the arrival traffic; it was part of a research effort to explore NextGen Trajectory Based Operations (TBO) solutions to problems in the New York metroplex. The concept was prototyped in an HITL performed in 2014 that considered operational procedures related to co-ordination, timing, TSS schedule, and other display features available to controllers and supervisors at Center, TRACON, and Tower. The HITL results demonstrate that the DSAS operations have the potential to increase departure throughput at LGA by nine aircraft per hour with insignificant impact on arrivals.\(^{3}\) The goal was to replicate the results of the study within the agent based modeling and analysis framework of Brahms.\(^{20,21,22}\) Brahms is a multi-agent modeling and simulation environment, consisting of a number of software tools: a multi-agent programming language for modeling people’s behaviors, geographical environment, movements, communications, systems and tools.\(^{27}\)

The planes, the pilots of the planes, the different controllers, the interactions amongst the humans
(controllers, pilots, and supervisors), and the interactions between human operators were successfully modeled in Brahms. Data logged by the Multi-Aircraft Control System (MACS) tool was used to create aspects of the model; the MACS software was used to setup and run the simulations in DSAS HITLs. Information about arrival traffic flow, flight plans, and departures from MACS data logs was used to automatically generate Brahms constructs for airplanes, the flight plans for the airplanes, the waypoints, the departures, the configuration of the sectors, and the various controllers directing the approaching traffic. Models of four center controllers, three TRACON controllers, and one tower controller in the LGA airspace was manually created. The Center and TRACON controllers perform handoffs when planes cross sector boundaries. In the model, controllers maintain the required separation based on the specified rules. The rules were derived from discussions with retired controllers. The auto-generated parts of the model (e.g., constructs that are different for each scenario such as traffic flow, airplanes, departures) was combined with the static parts of the model (e.g., how planes fly or how hand-offs are performed) to generate the final models. A mechanism to compute ETAs for airplanes based on standard operating procedures (SOPs) was implemented in the model.

The TSS model described in Section 2 was integrated into this larger Brahms model in order to generate schedules and sequences for flights in lieu of using the real TSS software. Integrating the actual TSS software would pose significant challenges since it demands several hardware requirements to execute and expects the input to be in a certain format. Moreover, the goal of performing analysis on the high-level Brahms would become intractable if the model had to interact with a large and complex piece of software such as the TSS. The output of the TSS is a schedule for the flights with corresponding STAs, and also a TSS timeline with time and positions. These are mapped to slot markers in the Brahms models. The controllers also perform tasks to get the flights to meet their schedules, and put them in their corresponding slot markers.

IV. Results

The model successfully implements an abstract functional model of the TSS system. The created schedule is verified to be conflict free at all times during the simulation run, using a logging function measuring the distance between aircraft and logging any separation violations.

The DSAS system was modeled according to the high-level description provided by Lee. The system showed slight improvements in traffic throughput during some traffic scenarios.

Both the TSS and DSAS models scales to sufficient level. The benchmark run used log files from 1.5 hours of simulation time, generating 104 flights and took about one minute to run.

A visualization of the simulation was created, mainly for debugging purposes, see Figure 8.

The TSS and DSAS systems were integrated with a larger Brahms model which incorporates models of ATC and pilots.

Figure 8. The visualization of the simulation. Two flights are shown, JBU6365 and SWA1837. The slot-markers showing SWA1837 being ahead of schedule.

V. Conclusion

This paper presents an abstract functional model of the Terminal Scheduling and Sequencing (TSS) system that provides automation to support TRACON in sequencing arrival traffic at airports. The model employs simplified flight dynamics under visual flight rules to create a schedule for arriving flights that is free of conflict at meter fixes, merge points, and runway thresholds. The utility of the TSS model is evaluated in a study of the LaGuardia airspace to
evaluate the impact of using the DSAS automation for TRACON controllers. The study suggests that the TSS model scales to a level sufficient to recreate scenarios from the published human in the loop simulations of DSAS at the Laguardia airport. It also suggests that models of the complex automation at a high-level of abstraction enables the tractability of more general system-wide model analysis.

VI. Discussion

The abstract model of the TSS system was able to generate a conflict free schedule. This was true for any scenario where flights were inserted into the simulation with realistic initial spacing. In some test cases when flights were loaded inside the TRACON ahead of, and to close to, other already existing flights, the system failed to generate a viable schedule. This is acceptable as unrealistic scenarios never will be simulated. Though it stresses the need for generating traffic scenarios that are realistic with flights arriving from Center to TRACON in sequence. Solving unrealistic or extreme situations is something the real TSS system would not cope with, as the maximum delay that could be absorbed within the TRACON area is 1 to 2 minutes.

The simplified flight dynamics are deemed to be adequate for this model. However, in future work, class- or model specific flight dynamics should be introduced. Due to the architecture of the model, the interface can be used to add this feature without any major alterations to the model.

ETA estimations using the average speed of each segments resulted in good estimations. The largest difference in the estimation was 4 seconds per hour. As the ETA is updated continuously, and the time inside the TRACON area for a flight is approximately 20 minutes, this is considered to be sufficient.

The model currently uses IMC conditions, without any weather modeling. However not necessary at this point, the capability to insert weather should be added, along with airport- and aircraft specific procedures corresponding to the inserted weather scenario.

The traffic scenarios used at the moment are generated from MACS log files. This provides a good starting point for generating flights. The limitation of this is that the scenario have a finite time horizon, and the simulation stop when it runs out of flights. To be able to study specific mechanism of the airspace design, a feature could be added to the model which automatically generates traffic according to the specifications of the user. For example, a specification could be 80% large traffic, 10% small traffic, and 10% B757s. This feature could combine the use of information from the same log files as previously and a probabilistic model to generate valid flightplans, but would alter attributes and states like flight number, initial altitude and starting time.

Points of non-determinism should and will be inserted into the model. These could be things like missed or misunderstood radio transmissions between ATC and pilots, pilots misjudging the approach forcing go-arounds and variances in how pilot operates their aircraft.

Introducing DSAS showed some improvements in traffic throughput. However, more simulations runs are needed, preferably with auto generated traffic and points of non-determinism to be able to measure the actual gain of this system.

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* NASA Ames Research Center
† BYU Brigham Young University
‡ KTH Royal Institute of Technology
§ ESA European Space Agency
II OSFK Ostra Sormlands Flygklubb
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1 Chart over LGA displaying the crossing runways 04-22 and 13-31. The Hot Spots, marked as "HS 1" and "HS 2", are both located near the intersection of the runways. .......................... 2

2 Overview of the TRACON airspace showing the sectors, STARs, meter fixes and merge points. Speed and altitude restrictions are shown under the name of the corresponding waypoint. .......................... 3

3 Image of a slot marker as it is presented to ATC on a radar screen. The aircraft is represented as a yellow "Z". Above the aircraft symbol is the label containing information about flight number (CCA983), assigned altitude (FL143), current altitude (FL349), suggested speed (265 kts) and heading (inbound BAYST waypoint). Under the aircraft symbol is the speed of the aircraft (260 kts). The slot marker is represented as a green circle. Under the slot marker is it’s speed (280 kts). .......................... 3

4 The time line. In the middle, the time is displayed as minutes of the hour (:00, :55, :50 etc.). On the left are the arriving flights ETAs and on the right the corresponding STA. Progression downwards on the time line corresponds to the flights getting closer to the runway threshold, and their ETA/STA. .......................... 4

5 The principle of DSAS. On the left is the time line before intervention of DSAS, and on the right, time line after intervention. .......................... 4

6 Schematic of the Human System Integration Model. .......................... 5

7 Simplified TRACON airspace, illustrating the algorithm used by TSS and DSAS. The aircraft are scheduled in sequence 1-5. Adjustments are then made to the trajectories to conform with the schedule. .......................... 6

8 The visualization of the simulation. Two flights are shown, JBU6365 and SWA1837. The slotmarkers showing SWA1837 being ahead of schedule. .......................... 8

All figures were created by the author using InkScape or inserted with reference to NASA’s Media Usage Guidelines. 

References


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