AIAA 5th Aviation, Technology, Integration, and Operations Conference (ATIO)
26 - 28 September 2005, Arlington, Virginia

AIAA 2005-7334

Development of Surface Management System Integrated with CTAS Arrival Tool

Yoon C. Jung[*] and Gilena A. Monroe[†]
NASA Ames Research Center, Moffett Field, California, 94035

The Surface Management System (SMS) is a decision support tool that helps tower traffic coordinators and Ground/Local controllers manage and control airport surface traffic in order to increase capacity, efficiency, and flexibility. SMS provides common situation awareness to personnel at various air traffic control facilities such as air traffic control towers (ATCTs), airline ramp towers, the Terminal Radar Approach Controls (TRACONs), and Air Route Traffic Control Centers. SMS also provides a traffic management tool to assist ATCT traffic management coordinators in making decisions regarding airport configuration and runway load balancing. The Build 1 of the SMS tool was successfully tested at Memphis International Airport. This paper reports the recent development efforts performed to integrate SMS with the Center-TRACON Automation System (CTAS) Traffic Management Advisor (TMA) to improve its prediction accuracy for arrival traffic and robustness under modeling uncertainties. The preliminary analysis results performed on the traffic data at the Dallas/Fort Worth International Airport have shown significant improvements in predicting runway assignment, runway arrival time, and arrival demand.

I. Introduction

As air traffic demand grows beyond the level that the National Airspace System (NAS) can handle, delays, in addition to passenger inconvenience, will increase. It is obvious that the airport surface becomes the bottleneck. Even under the current demand level, airport throughput is often limited due to the lack of efficiency and flexibility in controlling and managing surface traffic. Issues that currently impact airport surface operations include: controller/pilot communication limitations, procedural constraints, lack of information availability, and planning limitations.[1]

The Surface Management System (SMS)[2] was the decision support tool developed by NASA Ames Research Center in cooperation with the Federal Aviation Administration (FAA) to increase the efficiency and capacity of the airport operation without sacrificing safety. In order for a surface traffic decision support tool, such as SMS, to perform well in controlling and managing traffic on the airport surface, it is important that such a tool has the capability of accurate prediction of airport arrival times. To achieve this, the tool must have both the correct information on arrival runway assignments, and the accurate trajectory modeling capability. The SMS employs simple methods for runway assignment and arrival trajectory modeling, and often produces less accurate predictions of arrival times at the airport.

This paper discusses the performance of the arrival time prediction of SMS, and describes the development of an integrated system of SMS and the Center-TRACON Automation System (CTAS)[3] Traffic Management Advisor (TMA).[4] The TMA is an existing, proven arrival scheduling tool to provide both estimated and scheduled arrival times for arrivals at meter fixes and runways. The integration with TMA was suggested as a solution to improve the performance of SMS.

The organization of the paper is as follows. First, a brief overview of Build 1 SMS is presented. Basic displays such as a map display, timelines, and load graphs are the means of communication between users and the system. A general description on the advisory tools for controllers and managers is also provided. Next, the prediction of undelayed runway arrival times of the current system is described and the prediction accuracy of arrival times and

---

[*] Aerospace Engineer, Terminal Area ATM Research Branch, NASA Ames Research Center, MS210-6, Moffett Field, CA 94035, AIAA Member.
[†] Aerospace Engineer, Terminal Area ATM Research Branch, NASA Ames Research Center, MS210-6, Moffett Field, CA 94035.

runways are discussed briefly. In the following sections, both the development concept and the efforts of integrating TMA into SMS are presented. Next, results of the preliminary performance analysis of the integrated system are presented and improvement in prediction accuracies for arrival traffic is demonstrated. Lastly, a discussion on the remaining issues and future research is provided.

II. An Overview of Build 1 SMS

SMS assists air traffic controllers and managers in controlling and managing traffic on the surface of airports. Based on the users, SMS can be used as a 1) controller tool, 2) traffic management tool, and 3) NAS information tool. As a controller tool, SMS helps Local and Ground controllers construct efficient departure queues by providing advisories concerning departure runways and sequences at spot locations. SMS also helps ramp tower controllers in scheduling gate departures. As a traffic management tool, SMS aids traffic management coordinators (TMCs) in the air traffic control towers (ATCTs) in their decision making by providing information on future demand and its impact on the surface movement. The What-If tool and Runway Configuration Change Advisory Tool have been tested in an operational environment of MEM airport.[5] In addition, with installation at both the ATCT and the Center, SMS provides common situation awareness and an efficient way to communicate between facilities. As a NAS information tool, SMS was designed to provide surface predictions to the Enhanced Traffic Management System (ETMS) for use in traffic flow management (TFM) applications and further dissemination to NAS users. More detailed information about the system can be found in Ref. 5.

A. Map display, Timelines, and Load graphs

Figures 1 to 3 show the map, timeline, and load graph displays of Build 1 SMS. The map display shows the location of aircraft on the surface as well as in the terminal airspace. The Build 1 SMS receives flight information from three major sources: Enhanced Traffic Management System (ETMS) (or Aircraft Situation Display for Industry (ASDI)), surface surveillance, and the airline databases. Each aircraft's datablock on the map display shows detailed information regarding the flight, and the user can easily reconfigure the display.

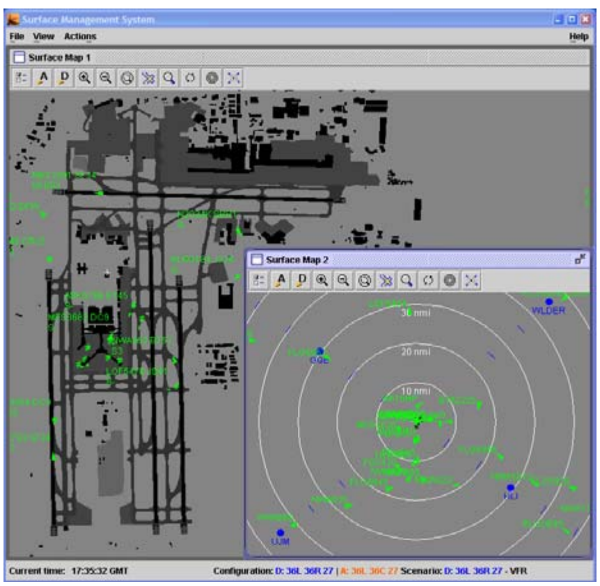

Figure 1. SMS map display of Memphis International Airport.

Second, the configurable timeline (Fig. 2) shows scheduled arrival times of individual aircraft at strategic points on the airport surface such as the runway threshold. Timelines also help traffic managers balance the loads among different runways. For example, if the timeline of departure flights at one runway is more loaded than the timeline of other active departure runways, the traffic manager can redistribute the loads by reassigning the runway for the departure flights of a heavily loaded runway.

Lastly, SMS provides different types of load graphs to help traffic managers assess the traffic load quantitatively and use the information in making strategic decisions. Figure 3 shows a load graph of the traffic count predictions of up to an hour in advance of both arrival and departure flights at their respective runways. This information can be used in determining changes to the airport runway configuration.

B. Advisory Tools for Traffic Managers and Controllers

SMS provides both a What-If and a Configuration Change Advisory Tool for traffic managers in ATCTs. The What-If tool performs an analysis of a particular future traffic situation based on the user scenario such as a runway configuration change or a new miles-in-trail restriction. The results show the comparison of throughputs, taxi time, delays, and number of runway crossings between the current conditions and the proposed scenario. This comparison assists managers in deciding whether or not to change to this new scenario.

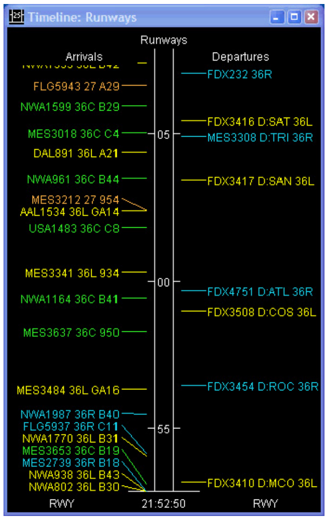

Figure 2. SMS timeline.

The Configuration Change Advisory Tool suggests to the traffic managers the best time to change the runway configuration. SMS's model predicts total delay of both arrivals and departures in 15-minute moving windows and finds the time when the analysis produces the minimum total delay.

For Ground controllers, SMS provides sequences at each spot as well as overall taxi sequence advisories. SMS assigns a departure runway for each departure flight based on the departure scenario at the time, but it can be overridden by the controller or manager.

C. APproval REQuest (APREQ) – Coordination between ATCT and ARTCC

SMS provides an electronic method of coordinating an Approval REQuest (APREQ) procedure between Center TMCs and ATCT controllers. The APREQ procedure involves the Center TMC assigning a release time for a specific flight depending on whether it can be incorporated into the airborne stream. The Center TMC then informs the ATCT controllers through the SMS APREQ interface, which sends the message to the SMS installed at the ATCT. The new release time request can be either accepted or rejected by the Ground controller.

III. Prediction of Runway Arrival Times of Build 1 SMS

In the current operational environment, Build 1 SMS helps controllers predict traffic information on the airport surface (such as status of aircraft, aircraft time to reference points, and future demand) under the given traffic condition and assumed control actions. The core of this tool is the capabilities of trajectory modeling (for both airborne and ground) and event detection/prediction. The Build 1 SMS adopts relatively simple models for trajectory prediction and scheduling of arrivals and departures. For arrival flights, arrival times at parking gates can be accurately predicted only if the tool can provide accurate prediction of runway arrival times.

In this section, the prediction accuracy of runway arrival times (ON times) of the current system is examined, and a new method to improve the accuracy is presented in the following section.

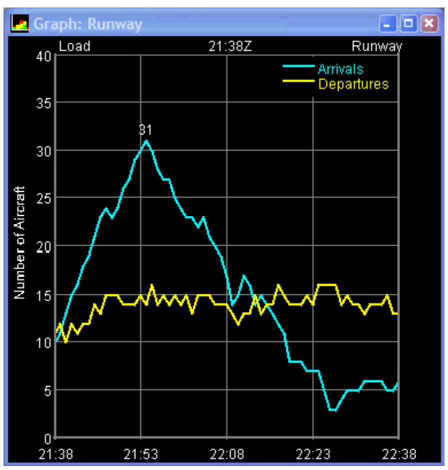

Figure 3. SMS load graph.

A. Arrival Runway Prediction

Knowing the landing runways of arrival flights in advance is important to SMS in many respects. First, prediction accuracy of ON time is dependent upon the accuracy of runway prediction. Second, prediction of taxi time, which is the elapsed time of an aircraft from exit from the runway to arrival at the designated gate, also depends heavily on which runway the aircraft will land. The ability to accurately predict gate arrival times (IN times) helpa airline ramp operators manage their resources efficiently.

When aircraft are outside the arrival fixes, SMS predicts arrival runways of each flight based on a series of prescribed criteria called the "runway decision tree." The criteria include the runway configuration, arrival fix, air carrier, ramp area, and whether traffic is low or high. When aircraft are closer to the airport, SMS provides the user with three options for arrival runway assignment:

- **Route segment method.** This method searches for the best runway, from the set of available runways, which would produce the shortest flight path. Predefined route segments (i.e., downwind, base, final) are used in calculation of the path distance within the TRACON airspace.

- **Backbone method.** This method relies upon a user-provided database containing approach paths inside arrival fixes. The database is searched to find the closest approach path from the aircraft's current position, and the runway that the searched approach path will lead to is selected.
- **Bayesian predictor method.** This method uses probability functions for determining the arrival runway. The backbone database is required to use this method.

Regardless of the runway selection method, the arrival runway is detected from the surveillance data if an aircraft is within a specified range from the airport. Also, the aircraft must be close to the extension of the runway centerline, and the heading must be aligned with the runway within a specified tolerance.

Figure 4 shows SMS runway prediction accuracy evaluated based on Dallas/Fort Worth Airport (DFW) data. (A detailed description regarding the data is presented in Section VI.) The plot shows the percentage of correct predictions as a function of time prior to actual landing. The plot indicates the prediction accuracy of the ON event to be fairly consistently near 57% until approximately 5 minutes before landing. During the remaining 5 minutes, the prediction accuracy increases dramatically as SMS corrects its previous runway prediction and finally predicts the actual runway. The route segment method was used for runway assignment. Other methods were not utilized because the backbone database was not available.

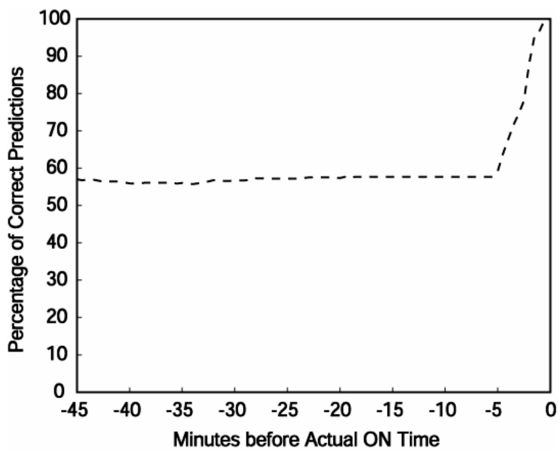

Figure 4. Arrival runway prediction accuracy of Build 1 SMS for DFW airport data.

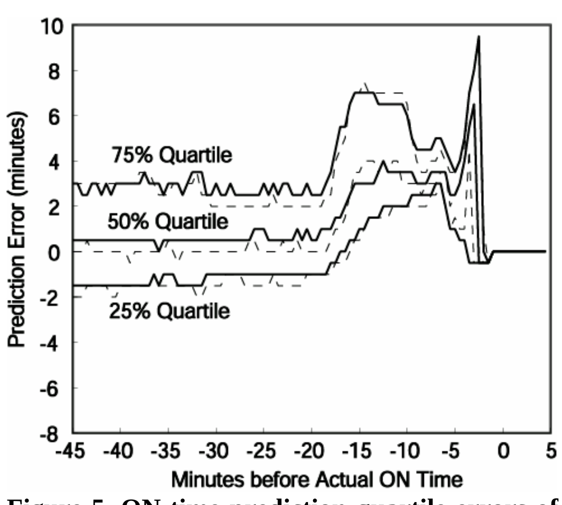

Figure 5. ON time prediction quartile errors of Build 1 SMS for DFW airport data (solid: all aircraft, dotted: aircraft with correct runway prediction).

Similar results were reported using Memphis International Airport field test data. In this analysis, with the Bayesian predictor method used, the overall arrival runway prediction accuracy was between 50-60% until 10 minutes before actual landing events, and 60-70% until 5 minutes prior to landing.[5]

Neither method described above produced satisfactory runway prediction accuracy.

B. Prediction of Arrival Time at Runway

Undelayed runway arrival time of each flight is computed by a simple trajectory model built into SMS. First, a 2-D route from the current aircraft position to the aircraft's predicted arrival runway is constructed either by straight line route segments or backbone approach paths, and then the path distance is computed. The runway arrival time is computed using descent speed profile and descent rate specified in the aircraft database, along with the current aircraft ground speed. As mentioned earlier, both the runway assignment and the trajectory model are two major contributors to the accuracy of ON times.

Figure 5 compares two statistics in ON time prediction errors given the same trajectory model. Again, the route segment method was used to build flight paths within TRACON airspace. The solid lines represent 25%, 50%, and 75% percentiles of ON time prediction errors of all flights and the dotted line represents the same quartiles of the prediction errors of flights for which runway prediction was correct throughout the prediction horizon. In the data analysis, SMS made wrong runway predictions for 91 aircraft out of 261 total aircraft. In both cases, the percentile prediction errors start to grow (i.e., flights are predicted to arrive significantly later than actual landing) at about 20 minutes prior to landing and reach the highest percentile prediction error at approximately 3 minutes prior to actual landing. This clearly indicates that the trajectory model using the route segment method needs improvement especially in TRACON airspace, regardless of correct runway prediction.

To improve the prediction of runway ON times, one can either: 1) implement a sophisticated 4-D trajectory synthesizer along with an elaborated route generation logic or 2) import accurate ON times from other systems, which may eventually replace SMS's own ON time calculation process. A decision was made to use ON time predictions from the CTAS TMA and integrate TMA with SMS.

Compared to expanding the capability of SMS independently, integration with a proven existing tool via a computer network was regarded as the better solution. Not only does sharing data between tools reduce the computational burden of individual tools, but it also provides a significant savings in the resources required for the development.

IV. Using CTAS Arrival Information for SMS

A. SMS Using CTAS TMA Information

As indicated previously, SMS needs the correct runway assignment for each arrival flight as early as possible. It is also important to have an accurate route building/trajectory synthesis at all times in order to predict runway ON times accurately. The way in which arrival aircraft's runways are assigned makes the runway prediction task difficult. As the aircraft enters TRACON airspace, the runway is assigned by the approach controller and, from then on, the aircraft is vectored to its final approach path according to the arrival procedure.

For SMS, although one can make efforts to improve the runway prediction to be more realistic by refining the runway decision tree, this is prone to error. For example, for DFW airport, the arrival traffic data of a typical day were examined, and it was found that almost 42 percent of arrival runway assignments initiated by the CTAS decision tree logic were changed by the TRACON controllers. Runway is assigned for each aircraft as the aircraft nears the TRACON airspace and, for DFW airport, this happens approximately 15 minutes before landing. Therefore, a better approach would be to obtain the TRACON controllers' scratchpad input directly from the Automated Radar Terminal System (ARTS) data feed and use the information in the trajectory computation. A even more practical approach would be to receive arrival times (at the runways chosen by the TRACON controllers), estimated or scheduled, directly from an existing, proven tool instead of investing resources to enhance the airborne trajectory model of SMS.

The CTAS TMA is an arrival scheduling tool that can provide such scheduling information to SMS for its prediction of runway arrival times. TMA is a decision support tool used to assist Center TMCs and controllers in scheduling arrival streams to meet the airport's arrival capacity. TMA utilizes the CTAS Trajectory Synthesizer (TS) module to generate accurate 4-D trajectories. This is used to compute unimpeded estimated times of arrival (ETAs) at the meter fix, final approach fix, and runway threshold for each aircraft. The ETAs are updated for every radar track, which gives SMS the latest information.

When arrival demand is greater than the airport's capacity, TMA's time-based metering scheduling capability is used to deliver aircraft more efficiently. Specifically, TMA's Dynamic Planner (DP) module computes the sequences and scheduled times of arrival (STAs) to those strategic points in the airspace for each aircraft to meet the sequencing and scheduling constraints entered by the TMC. The STAs are updated according to each ETA update until the aircraft is within some predicted distance or time away from the associated meter point to give controllers a stable metering schedule. The DP provides STAs for each arrival aircraft at the runway determined by the scheduler's runway allocation logic; therefore, it may not always be the same runway as that on which the aircraft will eventually land. However, as soon as the TMA system receives the TRACON controller's runway assignment input, the ETA and STA for the correct runway will be generated.

Table 1. Comparison of Data Available to SMS versions

Information		Build 1 SMS	Integrated SMS
Flight Plans		Available	Available
Tracks (update rates)	ETMS/ASDI	1 minute	1 minute
	Host	Not available	12 seconds
	ARTS	Not available	4.7 seconds
	Surface (ASDE-X)	1 second	1 second
Runway Assignment		Not available	Available
Runway Configuration Change		Not available	Available

A new solution was proposed to integrate SMS with TMA so that SMS receives accurate ETAs and STAs of arrival aircraft at correct runways at a faster update rate. This will allow the SMS Model to bypass runway prediction and trajectory computation processes. Instead, SMS will receive ETAs and STAs of much higher accuracy and update rate than it can currently. The Build 1 SMS update rate of runway arrival time was as slow as one minute. TMA, with both the Center Host and ARTS data connected, can generate ETAs and STAs until arrival aircraft are within a range of less than 2 n.mi. from the runway thresholds. In addition, the integrated SMS will receive the information of future runway configuration changes from TMA. Table 1 shows a comparison between current Build 1 SMS and the integrated SMS with TMA in terms of the quality of external input data. This solution is practical and also economically beneficial. In addition, TMA is a tool highly regarded by the FAA and ATC user communities. It is operational at eight ARTCCs in the US and is planned to be installed at the remaining ARTCCs by September 2007. TMA can also benefit from SMS by receiving information of internal departure flights in its scheduling and sequencing process, although this topic is out of scope of this paper.

V. Integration of TMA with SMS

Integration of TMA and SMS requires a server/client application that relays the data from TMA to SMS. As a relatively quick solution for developing a prototype integrated system, it was suggested to use the existing data server called the Collaborative Arrival Planner (CAP), which will provide a communication interface between TMA and SMS. Currently, efforts are underway for SMS to receive data from TMA using the CAP software developed by ARC.

The DFW airport was selected as the field site for the prototype integrated system. This decision was made for three reasons: 1) the surveillance data required are available at the ARC lab in real-time, 2) the NASA baseline TMA system and CAP server are running at both a field site and the ARC lab on a daily basis, and 3) the DFW airport is a prime area to conduct surface research. In 2004, the DFW airport was ranked as the third busiest airport in the US in terms of the number of operations.[6] The airport has seven runways and two operating ATCTs and, on average, the airport experiences over 1,700 runway crossings daily which may contribute to arrival/departure delays and runway incursions. The required surveillance data include the surface surveillance data out of DFW airport's ASDE-X (Airport Surface Detection Equipment Mode X) multilateration system. Real-time location and identity information about aircraft on the airport surface, which SMS uses, are directly accessed via a secured network.

This section briefly describes the CAP server and the high level system architecture of the integrated SMS/TMA system is outlined.

A. Collaborative Arrival Planner (CAP) Server

The CAP consists of a data server that parses binary messages from TMA and streams it as ASCII data for other users. The original intent of CAP was to provide airlines with real-time information from TMA,[7] which has now been expanded for use by SMS. The data in the CAP message streams include flight plans, tracks, ETAs and STAs, airport acceptance rate, airport configuration, etc. Currently, a CAP server is running at Fort Worth ARTCC (ZFW), and one of its displays is installed at American Airline's Systems Operation Control (SOC) facility for daily use. The enhanced situation awareness and accurate prediction of arrival times are two main attributes in increasing the efficiency of their operations. A version of the CAP server is also running in the ATC development lab at NASA ARC with connection to the TMA system for ZFW.

The CAP software was modified to include ASDI data since it provides estimated times for arrivals and departures, as well as other traffic flow management information that TMA lacks such as the Estimated Departure Clearance Times (EDCT) resulting from a ground delay program. The CAP server also relays runway assignments for arrival flights initiated by the TRACON controllers.

B. Architecture of the Integrated System

Figure 6 shows the architecture of an integrated SMS/TMA system. TMA receives both flight plans and tracks from ASDI, the ZFW Host, and DFW TRACON ARTS systems. TMA for ZFW normally receives flight plans for arrival flights up to 1.5 hours prior to landing, and TMA updates ETAs and STAs as tracks of flights are available. The TRACON controller's runway assignment information is sent to the ARTS computer and then relayed to the TMA system. ASDI data are another source of flight plans and track for aircraft positioned outside the Center boundary. ASDI data include rough estimates of runway arrival times as well as controlled arrival times for aircraft which are affected by the Ground Delay Program (GDP), a technique of traffic flow control initiated by the Air Traffic Control System Command Center (ATCSCC). Approximate track update rates of the ASDI, Host, and ARTS sources are 1 minute, 12s, and 4.7s, respectively and ASDI has an inherent delay (5 minutes) for security reasons. Weather information from one-hour Rapid Update Cycle (RUC) weather forecasts from the National Oceanic and Atmospheric Administration is used in 4-D trajectory calculations for TMA.

The integrated SMS consists of the Communication Manager (CM), Client(s), Model(s), and the interfaces with external data sources including ASDE-X for surface surveillance, airline data, and the data from the CAP server. Airline data provide SMS with information for the flights that belong to the specific airline, including the parking gate, expected pushback time, and the status of flights. The parking gate information is used for SMS to construct taxi routes, and pushback times are used to calculate predicted gate arrival (IN) times and takeoff (OFF) times.

Build 1 SMS requires communication interfaces specific to airlines in order to receive proprietary airline data. For example, SMS receives data from both FedEx and Northwest Airlines operating at MEM airport through separate communication interfaces. SMS also has an interface built for the communication with ACARS to receive data for UPS cargo flights operating at SDF airport. However, for SMS development using traffic data at DFW airport, SMS does not receive any data from major airlines operating at the airport. Considering the constraints imposed by a rapid prototype development cycle, it was decided to take airline information from a publicly available source instead of trying to obtain data directly from airline data servers. The DFW airport website (www.dfwairport.com) provides flight information such as gate, expected arrival time and departure time at the gate for most of the passenger flights operating at the airport. A website server/client application was developed and implemented for this purpose.

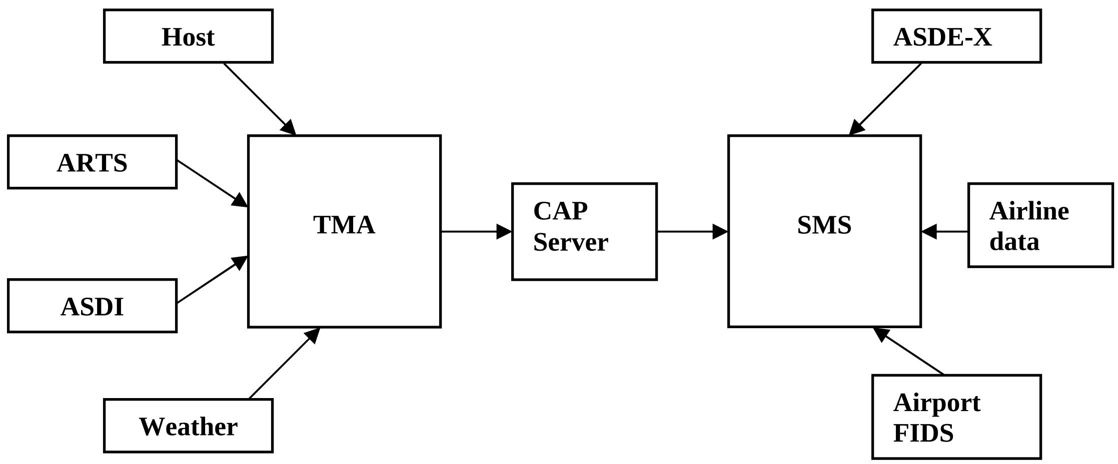

Figure 6. Architecture of integrated SMS/TMA

The CAP data parser was created in SMS to parse flight data received from the CAP server, transform it into a common flight data object and then send the data to the CM. The Model processes flight data to predict both undelayed and delayed arrival times at different strategic points on the surface from taxi route and speed determined by the trajectory model. The wake vortex separation criteria are used in scheduling departure times at the runway threshold. As mentioned earlier, predictions of arrival runways and computation of ETAs/STAs are skipped in the integrated system, since these data are available through the CAP server. The Client/GUI module provides a user interface, such as map display, to interact between the system and users.

While SMS is fully functional at the FedEx, Northwest Airlines and UPS airline facilities, work is presently completing an adaptation of the tool for the DFW airport. The adaptation involves developing a set of files that contain information specific to the DFW airport.[8] The display map is one of the tools that will be configured to represent the airport surface complete with its seven operational runways.

VI. Preliminary Results of the Integrated System

Although an SMS performance analysis was previously conducted to identify and validate useful functions for conventional operations,[5] recent analysis has provided a means to assess the performance of SMS with the integration of TMA data. For six months, researchers from ARC conducted data analyses on various function of SMS. This integration analysis, specifically, evaluated the accuracy of some of the SMS arrival functions, including runway arrival times, or ON times, arrival demand, and arrival runway assignments.

The analysis involved data collected in a two-fold process. The first of these utilized the tools built into SMS for the calculation of each function’s prediction accuracy, while the second process calculated the prediction accuracy using CTAS arrival information provided to SMS through the CAP server. Because of the CAP server’s connection to CTAS, the filtered messages it receives from the TMA system are made available to SMS through the integration structure.

The analysis was performed on the recorded traffic data at the DFW airport under visual meteorological conditions during peak arrival periods at the airport including the noon time arrival rush. A standalone SMS and integrated SMS/TMA system were running at the same time, and approximately four hours of data were recorded. The TMA system was running with ASDI, Host, and ARTS data feed including the TRACON controller's runway input. Weather updates were also available. On the other hand, the standalone SMS was running with ASDI and surface surveillance data only. The SMS log files were processed to obtain model prediction data for the aircraft that arrived at the airport during the recorded time.

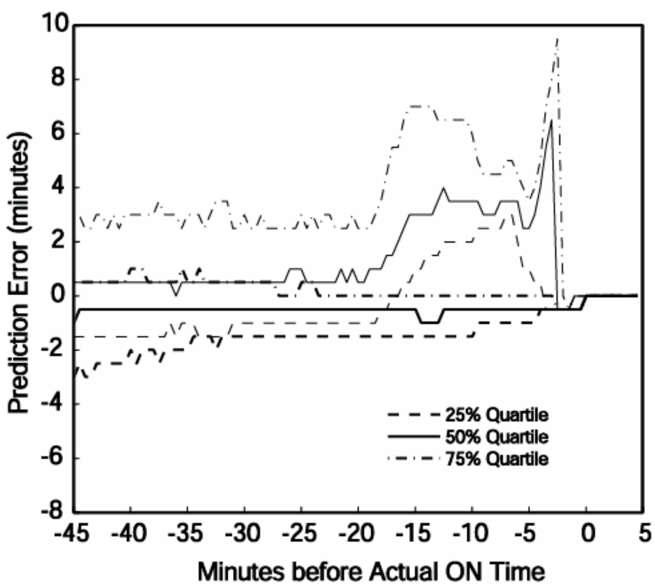

Figure 7. Comparison of ON time prediction performance (dark: SMS/TMA, light: standalone SMS).

The results of the data analysis, presented in the following sections, illustrate that SMS supplies more accurate arrival predictions when TMA data are incorporated into the computation process.

A. Prediction Accuracy of Runway Arrival Times

The data analysis was performed on the ON time function to determine the precision of the integrated SMS/TMA predictions on each arrival. The accuracy of the ON time predictions is measured by the error that exists between the predicted ON time and the actual time the aircraft arrived on the runway. When integrated, TMA supplies SMS with ON times for each flight on three levels: ETAs estimated by ETMS/ASDI, ETAs generated by TMA route analyzer, and STAs generated by the TMA scheduler. TMA also provides an arrival runway that is either estimated by TMA's runway decision logic or assigned by the TRACON controller. SMS, upon receiving this information, chooses the best arrival time based on the predetermined logic. For example, if there exists a runway assigned by the TRACON controller, SMS will take the ETA of that runway. If not, SMS will take the STA of the runway suggested by the TMA scheduler. It none of these data are available, SMS will take ETMS/ASDI's ETA of the runway predicted based on the flight plan of the aircraft. The order of selection affects the accuracy of the prediction. Actual landing events are detected by SMS from the surface surveillance data.

Figure 7 shows the 25%, 50%, and 75% quartiles of ON time prediction errors of two systems, i.e., standalone SMS and integrated SMS/TMA, as a function of time before actual landing overlaid with the result from the standalone SMS shown in Fig. 5.

As shown in the figure, the result from the integrated system clearly shows improvement over the standalone SMS throughout the entire prediction horizon. Especially during the last 15 minutes of prediction horizon, the integrated system outperforms the standalone SMS in all error distributions. This 15-minute interval roughly corresponds to the flight times of arrival flights within TRACON airspace. About 30 minutes prior to landing, the 25% quartile prediction error of the integrated system starts to grow. This is the time window where the availability of TMA's STAs is limited. In this situation, some flights may still be outside the Center boundary and ETMS/ASDI is the only available source of ETAs for those aircraft, whereas the standalone SMS continuously updates ON times using its own trajectory model.

The data also indicated that the integrated system shows a trend of under-prediction, meaning that aircraft are predicted to arrive earlier than actual landing, throughout the entire prediction horizon. This is partly due to TMA's route generation method, which has a tendency of underestimating the flight paths inside the TRACON airspace. An independent investigation may be required for a complete understanding.

B. Prediction Accuracy of Arrival Demand

The demand prediction accuracy can be described as operation count prediction accuracy. The SMS tool has the capability to predict the arrival demand for the airport. Given a particular 15-minute time interval where the actual number of arrivals during this interval are known, the demand prediction accuracy can be determined for a model run that takes place during a time frame, for example, 30 minutes, prior to the specified time interval. The predicted arrival count at the 30-minute prediction horizon is defined as the number of flights for which the model run computed the predicted ON time to fall within the 15-minute interval. The prediction accuracy of arrival demand is measured by the predicted arrival count with respect to the actual count.

Figures 8 and 9 illustrate the number of actual versus predicted arrival flights with absolute errors for 15-minute intervals over a three hour span. The data show that throughout the time span, there were intervals when SMS predicted more arrivals than the actual total and intervals when fewer arrivals were predicted than actual. For a 30-minute prediction horizon, the SMS/TMA system shows a slightly better prediction except for a few time intervals. For 45-minute prediction horizon, it is difficult to determine which system generates a better prediction judging from the prediction method used. It is also noted that the magnitudes of demand prediction errors of each system do not show any significant changes between two prediction horizons, which appears to be consistent with the result of ON time prediction errors shown in Fig. 7.

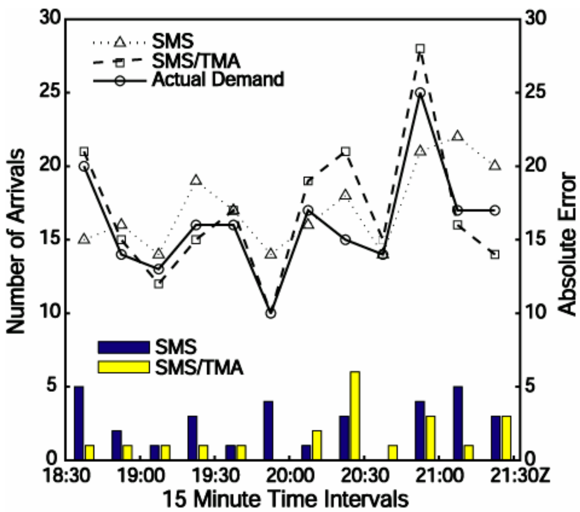

Figure 8. Arrival demand prediction (30 min. prediction horizon).

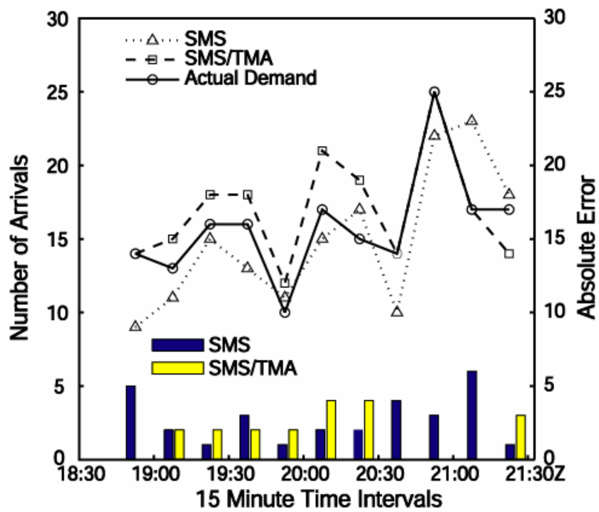

Figure 9. Arrival demand prediction (45 min. prediction horizon).

C. Prediction Accuracy of Arrival Runway Assignment

Figure 10 shows a plot of the runway prediction accuracy of two systems for all DFW airport runways for a 45-minute prediction horizon before the aircraft land on the runway, which is considered an ON event. The solid line represents the percentage of accurate runway prediction of the integrated system, and the dashed line is for the standalone SMS.

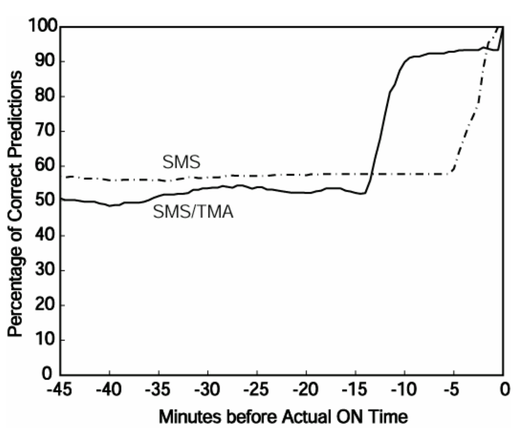

Figure 10. Comparison of runway prediction accuracy between two systems.

With the integration of TMA, SMS selects the estimated arrival runway from a set of available runways in the prescribed order: first, the TRACON controller's input, second, the TMA scheduler's estimated runway, and, lastly, the runway estimated from the flight plan.

The integrated system did not perform well compared to the SMS-only system over the first half hour of the prediction horizon for this particular data set. However, the percentage of correct runway prediction starts to grow as prediction horizon reaches approximately 15 minutes before landing and surpasses the correct prediction rates of standalone SMS. This is the time when DFW TRACON controllers normally assign runway for arrival flights. It is unclear, however, why the accuracy of correct runway prediction stays at about 92% during the final stage of flight and would not reach 100% earlier than the actual landing time. Logical explanations for this would be that: 1) runway changes were made by the tower controller without coordinating with TRACON controller, 2) the TRACON controller did not send his/her input to the ARTS system, or 3) SMS has erroneously rejected the controller input. As far as the runway changes made by the tower controller are concerned, the user interface of SMS must allow the controller to input runway changes manually. Also, SMS must be able to detect actual runway as soon as aircraft are on final and ON times must be updated. A further investigation is currently underway.

VII. Future Research

The concept of integrating TMA into SMS is straightforward and the benefit that SMS receives is significant as demonstrated in the previous section. The remaining technical issues are to 1) improve ON times of arrival flights flying beyond the airspace where TMA of a single Center is adapted, 2) make a seamless transition for the responsibility of ON time computation from TMA to SMS as the aircraft are about to land, and 3) make the data flow between the two systems more efficient and robust. Furthermore, it is a natural extension to have an integrated system with two-way communication by adding a capability for SMS to send information regarding departure flights to TMA for arrival scheduling. The remainder of this section discusses the above issues.

A. ON Time Predictions of Flights outside Center Airspace

Since TMA provides ETAs and STAs at metering points for each arrival flight within Center airspace only, SMS still needs to generate runway arrival times at the estimated runway while aircraft are flying outside the Center boundary. Instead of computing ETAs of those aircraft though the trajectory model, SMS has been modified to directly use the estimated arrival times received from ASDI’s RT messages, which are rough estimates. Although the requirement on the prediction accuracy at this flight stage (i.e., at least 45 to 60 minutes before landing) may not be critical to ATCT controllers and airlines, this area needs more investigation and a quantitative analysis.

B. Transition of Responsibility of ON Time Computation

The ATCT Local controller may issue a landing clearance to the pilot to a different runway than the one originally assigned by TRACON controller. This last minute runway change can be made for operational efficiency, emergencies, wake turbulence considerations, or runway crossing issues. If the change is made inside the final approach fix and does not affect the arrival sequence of the TRACON, no coordination with the TRACON is necessary. Since the runway changes made in such situations are not forwarded to the ARTS computer, TMA cannot account for this change in its ETA calculation. Therefore, SMS must calculate the ON time, since ETAs received from TMA will be no longer valid.

C. Standard Communication Protocol between SMS and TMA

In the current system, SMS receives every message sent from the CAP server, selects only necessary messages, parses them, and stores parsed data into specific data structures. This requires a high bandwidth for network communication between two systems and also, the SMS parser must know the exact data format. In addition, another similar data server/parser has to be created to send messages from SMS to TMA.

A new design is underway using a communication paradigm called a publisher/subscriber model which is adopted from the Multi-center TMA architecture.[9] A system wishing to receive data, called the subscriber, sends out a subscription message via its subscriber data server detailing the specific data it is requesting from another system. The data server sending out the corresponding data, called the publisher, receives the subscription message and routes the requested information from its database. SMS and TMA will be using the publisher/subscriber paradigm with XML (Extensible Markup Language) used as the primary communication format. It should be stressed that the TMA and SMS do not communicate directly with each other, but rather through their data servers. This architecture allows systems with entirely different data formats to communicate with each other. Also, this model aims to keep bandwidth consumption at a minimum by allowing servers to request only specific parts of the data to be sent.

In this approach, TMA will also achieve significant benefit in its scheduling from receiving information regarding internal departures from SMS. The accurate prediction of departure times made by SMS will greatly improve TMA’s scheduling capabilities.

VIII. Concluding Remarks

Integration of proven, existing air traffic decision support tools certainly provides more advantage over expanding each individual tool’s capability independently. Data sharing among tools provides processed information necessary to perform each system’s functionalities, thus reducing overlaps in functionalities as well as computational efforts of individual systems. A well-selected communication protocol mechanism can simplify such data sharing with a modest bandwidth requirement.

As the first step towards interoperability between decision support tools in the surface and terminal/en route airspace domains, the integration of SMS with CTAS TMA was attempted. The communication between the two systems was made through the CAP server.

In the integrated environment, TMA sends arrival data including flight plans, tracks, ETAs/STAs for each arrival flight, and runway assignment made by TRACON controllers to SMS. TMA also relays ASDI messages including EDCT data to SMS through the CAP server. As a result, SMS is not only exempt from computing arrival times of its own, but also is now able to provide more accurate runway arrival times to other surface functionalities within SMS. In the absence of a direct connection with airline data, the web-based FIDS data were subscribed for gate information.

DFW airport was selected as a test site for the development because of the technical challenges and the availability of surveillance data. An integrated system was installed in the ATC lab at NASA ARC, and data were collected for analysis. Prediction accuracies of ON times and runway assignments were compared with and without TMA integration. Accuracy of arrival demand prediction was also compared between two systems. As expected, results of the integrated system showed improved accuracy in all of three categories.

Some future development and research issues were discussed. The responsibility of the ETA calculation needs to be switched between TMA and SMS based on the flight stage and, also, the logic needs to be improved to provide seamless transition. A standardized communication protocol called publisher/subscriber mechanism is considered for efficient network communication among various tools.

Acknowledgments

The authors would like to thank staff of both the ARC CTAS V&V lab and software group for their valuable contribution in the software development, integration, and data analysis efforts.

References

[1]Capozi, B., Smith, P., Spencer, A., and Andre, T., “Capacity Improvement through Automated Surface Traffic Control: Phase Three Concept,” Metron Aviation, Herdon, VA, December, 2004.

[2]Atkins, S., Jung, Y., Brinton, C., Stell, L., and Rogowski, S., “Surface Management System Field Trial Results,” *AIAA 4th Aircraft Technology, Integration, and Operations Forum*, Chicago, Illinois, September 20-22, 2004.

[3]Anon, CTAS Description and Software Overview, www.ctas.arc.nasa.gov.

[4]Farley, T. C., J. D. Foster, T. Hoang, K. K. Lee, “*A Time-Based Approach to Metering Arrival Traffic to Philadelphia,*” AIAA-2001-5241, *First AIAA Aircraft Technology, Integration, and Operations Forum,* Los Angeles, California, October 16-18, 2001

[5]Raytheon, “CTO-05 Surface Management System, CTOD 5-24-1 Final Report,” 2004.

[6]FAA Aerospace Forecasts FY2004 – 2020, Federal Aviation Administration, March 2005.

[7]Quinn, C., and Zelenka, R. E., “ATC / Air Carrier Collaborative Arrival Planning,” *2nd USA/Europe Air Traffic Management R&D Seminar,* Orlando, FL, December 1-4, 1998.

[8]Metron Aviation, “Surface Management System Adaptation Procedures Manual,” December 2004.

[9]Hoang, T., Farley, T., Foster, J., Davis, T., “*The Multi-Center TMA System Architecture and its Impact on Inter-Facility Collaboration*,” Second AIAA Aircraft Technology, Integration, and Operations Forum, Los Angeles, California, October 2002.