Journal of Air Traffic Control. Vol. 44, No. 1, January-March, 2002.

Concept Description and Development Plan for the Surface Management System

Stephen Atkins, NASA Ames Research Center

Christopher Brinton, Metron Inc.

Abstract

NASA Ames Research Center, in cooperation with the FAA, is studying automation for aiding airport surface traffic management. The Surface Management System (SMS) is a decision support tool that will provide information and advisories to help controllers and air carriers collaboratively manage the movements of aircraft on the surface of busy airports, improving capacity, efficiency, and flexibility. This paper describes SMS, which is an element of the FAA's Free Flight Phase 2 (FFP2) program, and outlines the plan for its development. Detailed information about future departure demand on airport resources is not currently available. SMS provides operational specialists at ATC facilities and air carriers with accurate predictions of the future departure demand and how the situation on the airport surface (e.g., the queues and delays at each runway) will evolve in response to that demand. SMS also provides advisories to help manage surface movements and departure operations.

Introduction

A primary function of SMS is to create shared awareness of the current and future departure situation by disseminating information about the expected departure demand and how the surface situation will evolve under that demand. To achieve this, SMS provides information, using either dedicated SMS displays or by adding information to the displays of other systems, to the ATC tower (ATCT) and airline ramp towers. SMS may also provide information to the TRACON and Center Traffic Management Units (TMUs), Airline Operations Centers (AOCs), and ATC System Command Center (ATCSCC). Within the ATCT, SMS may provide information to the Local controllers, Ground controllers, Clearance Delivery/Flight Data controller, and Traffic Management Coordinator (TMC), depending on the result of ongoing research. SMS provides near-term predictions to support tactical control of surface operations and longer time-horizon forecasts to support strategic planning. This capability to predict how future departure demand will play out on the surface is consistent with the RTCA's recommendations for surface automation [RTCA, 2000].

The ability to predict how the state of the airport surface will evolve enables SMS to evaluate the effect of various traffic management decisions in advance of implementing them. SMS uses this capability to advise how to best manage certain aspects of surface operations. For example, SMS advises a departure sequence to the Ground and Local controllers that efficiently satisfies various departure restrictions (e.g., Miles-in-Trail (MIT) and Expected Departure Clearance Times (EDCTs)). Subsequent development efforts will extend SMS to interoperate with arrival and departure traffic management decision support tools (e.g., the Center-TRACON Automation System (CTAS) [Erzberger et al., 1993 and Swenson et al., 1997]) to provide additional benefits.

Departure Situation Prediction Capabilities

SMS will provide both near-term and longer-horizon predictions of the departure situation. Near-term predictions will consist of, for example, the expected queue lengths at each runway for the next 15 to 30 minutes, the predicted takeoff sequence, and the resulting takeoff times and delays for each aircraft. To predict the future state of the surface, SMS will use real-time surface surveillance, air carrier predictions of when each flight will want to push back, and a surface trajectory synthesis algorithm that accurately predicts the movement of aircraft on the surface. To accurately predict the evolution of the surface situation, the algorithm must model how controllers assign departure runways and taxi routes, how they sequence departures, how arrivals affect departures, and inter-departure separation including downstream restrictions.

Developing displays that are useable by controllers and TMCs is a major focus of the research. Although human factors work to identify an appropriate user interface has not been completed, the use of timelines to present SMS-predicted information is being studied. A timeline identifies the times at which aircraft will occupy a resource. Timelines may be referenced to various resources, including runways, hand-off spots, and departure fixes. The information SMS presents depends on the user and what task is being aided. For example, a timeline referenced to the departure runways showing the predicted arrival and resulting departure times and sequence is being studied as a display for the Local controller (Figure 1). Timelines offer several display dimensions to encode additional information. Trend information can be provided "at a glance" through color coding. SMS uses color to distinguish the departure gate to which the flight is filed. Additional information, such as the flight's departure fix, is included in the data block. Furthermore, bars can be added to show the periods of time that the aircraft will occupy the runway. In this way, timelines are capable of depicting the separation between arrival, departure, and crossing operations on a runway.

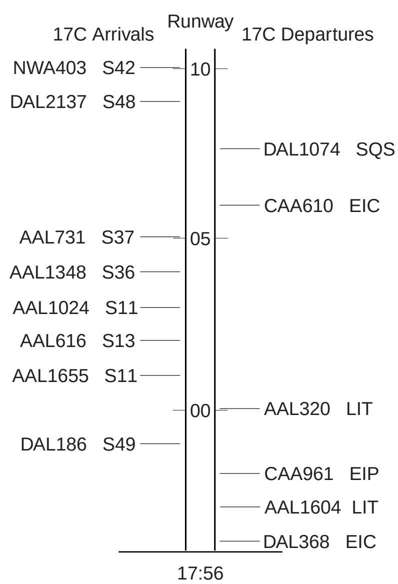

Figure 1. Prototype SMS display showing the times at which aircraft will takeoff.

By providing information that is not currently available, SMS helps controllers to efficiently manage surface traffic and maximize departure throughput. Moreover, common awareness of the near-term departure situation may facilitate the ATCT and air carriers in collaboratively managing surface operations. Information about current and predicted departure queues displayed in the TRACON TMU will allow better coordination of runway use without explicit communication between the ATCT and TRACON. For example, the TRACON will know when a departure queue exists at a runway and can stop sending arrivals to that runway, without the ATCT TMC needing to call the TRACON TMC. Similarly, the TRACON TMC will have information about the delay to cross an arrival runway, and can adjust the arrival spacing to facilitate crossing without the ATCT needing to call. SMS predictions of when departures will take off and when arrivals will land and, given parking gate information, reach their gates will benefit air carrier decision making. SMS will also convey parking gate assignments, which it gets from the airlines, to the ATCT with less workload than is currently required.

SMS will also forecast aggregate demand for each runway, or other constrained resource, over a longer time horizon. To predict departure demand prior to aircraft pushback, SMS uses airline-provided information about when each aircraft will want to push back. By providing common information about the future departure demand, SMS will allow TMCs in the ATCT, TRACON, and Center to coordinate traffic management decisions (e.g., what restrictions to place on departures versus arrivals). SMS-provided information about future departure demand is expected to be most helpful during irregular operations, when controllers cannot use knowledge of daily schedules gained through experience to predict the timing of future demand.

Load graphs are capable of showing both the undelayed demand (i.e., without the effect of capacity constraints) as well as predictions of the number of operations that would be achievable under alternative traffic management strategies, providing a “what if” capability. Load graphs may be referenced to a variety of constrained resources, such as runways or departure fixes, and may graph various measures such as average delay or queue length. For example, SMS displays a load graph of the demand for each departure gate (Figure 2) to the TMC to aid runway balancing decisions, and load graphs of the delay at each runway for the current and alternate departure scenarios.

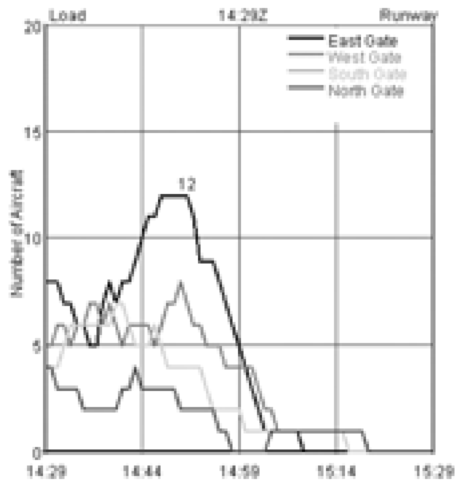

Figure 2. Prototype SMS display showing future departure demand sorted by departure gate.

Departure Planning Concepts

SMS users often do not have the necessary information or time to plan beyond immediate aircraft movements. SMS’s ability to predict the future departure situation enables it to aid users by advising how to manage certain aspects of surface operations now that affect surface efficiency in the future. SMS’s departure planning attempts to increase airport throughput (i.e., peak capacity rate), increase the efficiency of surface operations (i.e., minimize the cost of unavoidable delays and their environmental impact), and improve user flexibility (i.e., minimize the impact of delays on air carrier business objectives), without increasing user workload or reducing safety. SMS will continually update its advisories to react to the current situation and controller actions. Exactly what information or advisories will be displayed to which controllers or air carrier personnel will be determined as part of the research; the following describes the initial focus.

SMS will plan and recommend a departure sequence for each runway that maximizes runway throughput subject to wake vortex and downstream traffic management restrictions (e.g., MIT, APREQs, and EDCTs). Additionally, departure sequencing may incorporate air carrier priorities. At some airports, such as DFW, the taxiway geometry allows the ATCT to construct efficient departure sequences after aircraft enter the active movement area. However, at other airports, the ATCT has limited ability to sequence departures once aircraft have pushed back from their gates. SMS advises how to manage aircraft at available control points to achieve an efficient sequence at the runway. For example, when Philadelphia airport (PHL) operates in an east flow configuration, the ATCT has almost no opportunity to sequence departures off Runway 9L, since the US Airways ramp tower controls taxiway Juliet almost to the departure end of the runway, and the ATCT does not know which flights are in this queue (Figure 3). The ATCT controls parallel taxiway Kilo which also feeds 9L. SMS could help the ramp tower sequence departures on taxiway Juliet, and help the ramp tower and ATCT coordinate which aircraft should queue on taxiway Juliet and which should be handed off to the ATCT to queue on Kilo.

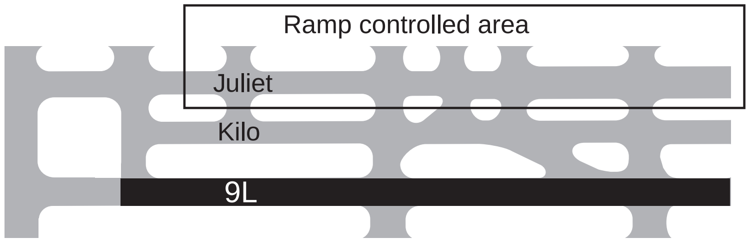

Figure 3. Departure queues for PHL Runway 9L.

Departure Runway Balancing

SMS provides decision support for runway assignment decisions, with the goal of reducing departure delays. Removing a few aircraft from a queue (and reassigning them to a different runway) at the beginning of a departure push can reduce the delays incurred by every subsequent departure. Current procedures assign departures to a runway according to a one-to-one mapping from departure fixes to runways. The purpose of these runway assignment rules is to assure that the airborne trajectories of aircraft that takeoff from different runways do not cross. The different mappings of departure fixes to runways are referred to as *departure scenarios*. The tower TMC selects the departure scenario to balance the demand on each of multiple departure runways.

SMS will evaluate two approaches for aiding departure runway balancing: supporting the selection of the departure scenario schedule and advising runway assignment exceptions for specific flights. SMS supports the TMC's selection of the departure scenario by providing information about the demand, as a function of time, for each of the departure fixes. This information is not currently available. Although currently controllers can scan the flight progress strips for all of the proposed flights to determine the demand for each departure fix, the time at which each flight will want to depart is not known reliably. During normal operations, controllers know approximately when each flight departs from experience. However, during irregular operations, flights will not depart at their typical times. SMS-provided information allows the TMC to select an efficient departure scenario and to plan when to change the scenario. In this way, the departure scenario may be adjusted more frequently, and the timing of changes may better match the time-varying demand. SMS can also calculate and advise an optimal schedule for the departure scenario.

SMS's flight-specific runway advisory function searches to determine whether a small number of runway assignments that are exceptions to the current departure scenario could provide a significant reduction in total departure delays. Since these runway assignments would violate the active departure scenario, which procedurally assures that there will be no airborne conflicts between departures off different runways, the search for beneficial alternate runway assignments is constrained by the requirement that the suggested runway assignments cannot cause airborne conflicts. Airborne departure conflicts would represent a safety concern and create high controller workload. SMS performs a conflict probe to ensure that the advised runways do not result in a conflict in departure airspace. Controllers currently make exceptions to the departure scenario when workload permits. Although the aircraft will be flying to the same departure fix as is in its flight plan, since the aircraft will be departing off a different runway, the Local controller must coordinate with the affected Departure controllers in the TRACON to assure that airborne separation will be maintainable with acceptable workload. By automating the search for feasible and beneficial runway assignment exceptions, and by simplifying the necessary coordination, SMS may allow more frequent use of the technique during busy periods, when it will have the most benefit.

SMS also considers whether changing a flight plan to use a different departure fix and, therefore, a different departure runway without violating the rules of the active departure scenario, would be beneficial. In this case, the aircraft would rejoin its original route to its destination in Center airspace. The purpose of changing the departure runway for a particular flight could be either to help balance the departure runways or to help that particular high-priority flight takeoff earlier. SMS considers the impact on taxi distance and flight time when calculating the benefit of a flight plan amendment. Currently, the tower will occasionally initiate flight plan changes; SMS could automate the search for candidate flights. Due to its affect on fuel requirements or business objectives, the flight's dispatcher/AOC may need to approve a flight plan change. In accordance with the existing Coded Departure Route (CDR) program, which facilitates the communication and coordination of alternate departure routes, the flight's dispatcher will evaluate SMS-recommended CDRs and confirm that the aircraft has the appropriate fuel when initially filing the flight plan. The dispatcher will then inform the pilot which CDRs may be accepted, and SMS will inform the tower which CDRs are available for that flight. SMS will then advise the Clearance Delivery (CD) or Ground controller which flights should be rerouted and which of the available CDRs for those flights should be selected. In addition to advising flight plan changes for particular flights, SMS provides information about the predicted delays for each departure fix to enable the AOC to evaluate which flights to reroute. Based on this information, the AOC may initiate a flight plan change by requesting that a certain CDR be used for a flight.

Arrival-Departure Tradeoffs

At airports where arrival and departure capacities are interdependent, arrival and departure management must be interoperable [Atkins and Hall, 2000]. Shared awareness of the future arrival and departure demands may enable the tower, TRACON, and Center TMCs to coordinate traffic management decisions, such as arrival-departure tradeoffs, with less workload and better use of limited resources. In addition to providing raw information about the demands for arrivals and departures, SMS's trial-planning capability will predict the delays that would result from a traffic management decision that is being considered. SMS can also advise a schedule of coordinated arrival and departure capacities that match the time-varying demands. For example, SMS is able to include considerations such as the potential for surface gridlock if arrivals are favored when departures are late. When arrival gates are not available, SMS would advise favoring departures, since the arrivals will be delayed on the ground anyway.

Queue Length Management

Managing the rate at which aircraft enter the taxiway system has the potential to reduce the environmental and operating costs associated with long departure queues, while maintaining maximum departure throughput. By maintaining shorter runway queues, aircraft are running their engines for less time on the surface. SMS can help the ATCT and ramp tower manage departure queue lengths by advising aircraft pushback or taxi-start times. Pushback management must be done collaboratively with the air carriers so that the solution allows the air carriers to manage their gates, and fairly so that gate-held flights do not lose their place in the virtual departure queue. Eventually, SMS may fairly allocate departure capacity to air carriers, much as the Collaborative Decision Making (CDM) Flight Schedule Monitor (FSM) tool allocates an airport's arrival capacity when ground holds are imposed on departures to that airport. The air carriers are empowered to make decisions about which flight to operate in each slot to best achieve their business objectives. Queue length management also has application during de-icing operations. To determine when to begin de-icing a flight, the departure delay that will be incurred must be estimated. SMS would predict the queue lengths and delays both at the runway and the de-icing operation.

Development Approach

NASA is committed to developing the initial version of SMS (Build 1 SMS), described in this paper, to Technology Readiness Level (TRL) 6 in time for transfer to the FAA's FFP2 program. The Free Flight Program Office is engaged in the development of SMS, and NASA and the FAA will continue to work together throughout the project to transfer SMS technology to the FAA. NASA has awarded Contract Task Order (CTO) 5, under its Air Traffic Management System Development and Integration (ATMSDI) contract, to a team including Raytheon, Metron Aviation, and Booz-Allen & Hamilton, among others, to develop the initial version of SMS.

Human factors research, integral to all aspects of SMS development and testing, will determine display requirements for each user. SMS will be designed so that the information being displayed is suited to the tasks being performed, there are no usability concerns for accessing or interpreting information, and using the information does not adversely increase workload. Experience has shown that involving the eventual users throughout the development process significantly benefits the quality, operational applicability, and usefulness of the final product. Therefore, throughout development, NASA is soliciting feedback on the SMS concept, performance, and interfaces from both ATCT controllers and air carrier representatives. Two real-time, controller-in-the-loop simulations will be conducted using the Future Flight Central (FFC) ATCT simulation facility at NASA Ames Research Center. The first simulation, held in September, 2001, collected feedback on the SMS concept, displays, and algorithms. Simulation results are being used to refine the functionality and user interface, and the second simulation, in January, 2002, will evaluate this next development iteration. To gain additional experience with its performance, SMS will then be deployed to an air carrier ramp tower in the summer of 2002. Controller shadow-mode testing will be conducted in October, 2002 and February, 2003, culminating in an operational use demonstration in the summer of 2003. SMS field testing is expected to be conducted at Memphis airport, to take advantage of the FAA's Safe Flight 21 experience and infrastructure there.

Figure 4 shows the system architecture for SMS; shaded boxes represent elements that will be part of the SMS field testing and outlined boxes represent possible deployment locations. SMS displays will present information and advisories in the ATCT and the air carrier's ramp towers. In addition, SMS information may be provided to the TRACON and Center TMUs, AOCs, and the ATCSCC.

SMS is being designed to use real-time location and identity information about aircraft on the airport surface, although some SMS capabilities will function without this input. The ASDE-X system, currently being developed by the FAA, will combine either an existing ASDE-3 (Airport Surface Detection Equipment) or a new x-band primary radar, an Airport Traffic Information Display System (ATIDS, which is a transponder-based multilateration surveillance system), Automatic Dependent Surveillance – Broadcast (ADS-B) transmissions from aircraft, and Automated Radar Terminal System (ARTS) information to produce a coherent picture of aircraft moving on the airport surface. Some of SMS's functions will require that ASDE-X coverage include the ramp areas, which the FAA has not currently specified as a requirement in the ASDE-X program. NASA will propose to test SMS at Memphis, where the FAA's Safe Flight 21 program has developed a prototype surface surveillance system that is functionally equivalent to ASDE-X and has been enhanced to include coverage of the ramp areas. Where CTAS is available, SMS will use the CTAS arrival time estimates. Otherwise, SMS will use airborne surveillance from ARTS or the Enhanced Traffic Management System (ETMS) to predict landing times.

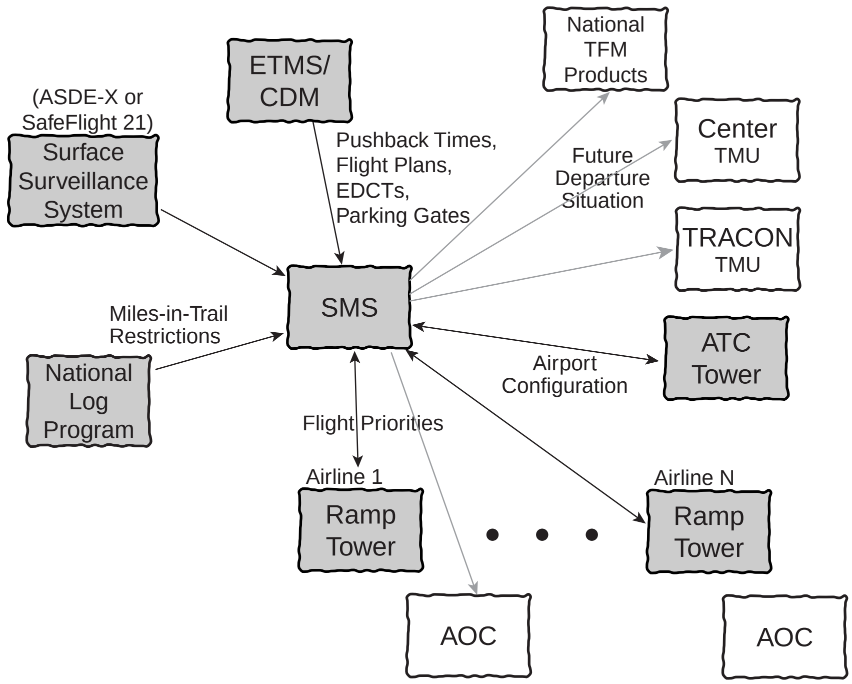

Figure 4. SMS System Architecture

SMS will receive flight plan information, as well as surveillance information for arrivals outside the terminal area, from ETMS. SMS will receive the air carrier's planned departure times for each flight from the Aggregate Demand List (ADL), an element of CDM hosted as part of ETMS. This approach avoids the need to interface to every air carrier's ramp tower automation system. To predict taxi-in times as well as surface conflicts between arrivals and departures, SMS needs to know at what gates the arrivals will be parking. As an interim approach, until this information can be added to the ADL, SMS will get it, along with flight priorities, from the ramp towers, either through manual entries or connections to the air cariers' automation systems. To correctly model inter-departure times and plan efficient sequences, SMS must know what downstream restrictions are in effect. The National Log Program will provide MIT restrictions. EDCTs for aircraft affected by ground holds are available from ETMS. The current airport configuration, planned configuration changes, and APREQ times are the only information that the ATCT will be required to enter.

Future Considerations

The goal of this program is to develop and field test a proof-of-concept SMS, to determine the appropriate functions and interfaces and to validate predicted benefits. Based on lessons learned, the FAA may determine that some re-design of the implementation is required before SMS can be broadly deployed. For example, the human factors need to minimize the number of displays in the ATCT may motivate sharing of displays rather than installing dedicated SMS displays. Consequently, SMS's eventual deployment configuration may incorporate SMS data elements into the displays associated with other systems (e.g., ASDE-X or the STARS ATCT display). In addition, to improve maintainability, the SMS software algorithms could be hosted as part of some other automation system (e.g., ETMS). Integration of SMS with these other systems is beyond the scope of the current task and the time available.

This paper describes the SMS concept at this early point in SMS development. As work continues, additional detail will be identified and elements of the concept may change, especially as a result of user involvement. The current SMS development will not explore every opportunity for surface management automation. As the foundation for subsequent surface automation capabilities, the present work will establish a software design and hardware architecture that is open, modular, flexible, and extensible, so that new functionalities and additional input sources may be added in the future. For example, taxi route planning and runway crossing functionalities are being considered. Furthermore, opportunities exist for automation tools (e.g., CTAS) to interact with SMS to provide additional benefits.

References

Atkins, S. and Hall, W. (2000), “A Case for Integrating the CTAS Traffic Management Advisor and the Surface Management System,” *AIAA Guidance, Navigation, and Control Conference*, Denver, CO.

Erzberger, H., Davis, T., and Green, S. (1993), "Design of Center-TRACON Automation System," *AGARD Meeting on Machine Intelligence in Air Traffic Management*, Berlin, Germany.

RTCA Select Committee for Free Flight Implementation (2000), *National Airspace System Concept of Operations Addendum 4: Free Flight Phase 2*.

Swenson, H., Hoang, T., Engelland, S., Vincent, D., Sanders, T., Sanford, B., and Heere, K. (1997), "Design and Operational Evaluation of the Traffic Management Advisor at the Fort Worth Air Route Traffic Control Center," *1st USA/Europe Air Traffic Management R&D Seminar*, Saclay, France.