System-Oriented Runway Management Concept of Operations

Gary W. Lohr
Langley Research Center, Hampton, Virginia

Stephen Atkins
Mosaic ATM Inc., Leesburg, Virginia

March 2015

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counter-part of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at http://www.sti.nasa.gov

- E-mail your question to help@sti.nasa.gov

- Phone the NASA STI Information Desk at 757-864-9658

- Write to:
  NASA STI Information Desk
  Mail Stop 148
  NASA Langley Research Center
  Hampton, VA 23681-2199

NASA/TM-2015-218699

System-Oriented Runway Management Concept of Operations

Gary W. Lohr
Langley Research Center, Hampton, Virginia

Stephen Atkins
Mosaic ATM Inc., Leesburg, Virginia

March 2015

Table of Contents

List of Figures

List of Tables

Abbreviations and Acronyms

4D CARMA ....Four-Dimensional Cooperative Arrival Management
AAR ....airport acceptance rate
ARMD.......................Aeronautics Research Mission Directorate
AOC ....Airline Operations Center
ARTCC ....air route traffic control center
ARTS ....Automated Radar Terminal System
ASPM........................Aviation System Performance Metrics
ATC...........................air traffic control
ATCSCC ....Air Traffic Control System Command Center
ATCT ....airport traffic control tower
ATIS..........................Automatic Terminal Information System
ATL...........................Hartsfield-Jackson Atlanta International Airport
ATM..........................air traffic management
CADEO.....................Controller Assistance for Departure Optimization
CADM.......................Coordinated Arrival Departure Manager
CADRS ....Combined Arrival/Departure Runway Scheduling
CAIRO ....Complete Airport Optimizer
CIC...........................controller in charge
DLR...........................Deutsches Zentrum für Luft- und Raumfahrt; German Aerospace Center
DST...........................decision support tool
EDCT ....expected departure clearance time
ERAM ....en route automation modernization
ESIS ....Enhanced Status Information System
ETMS........................Enhanced Traffic Management System
FAA...........................Federal Aviation Administration
FCFS ....first-come, first-served
GDTA ....Goal-directed Task Analysis
GI ....general information
GUI ....graphical user interface
IAP............................instrument approach procedure
ILS.............................Instrument Landing System
ITWS.........................Integrated Terminal Weather Service
JPDO.........................Joint Planning and Development Office
KBOS........................Boston Logan International Airport
KDFW.......................Dallas-Fort Worth International Airport
KJFK.........................John F. Kennedy International Airport
KLAX ....Los Angeles International Airport
KLGA ....LaGuardia Airport
KMCO.......................Orlando International Airport

KMEM ....Memphis International Airport
LAHSO ....Land and Hold Short
McTMA ....Multi-center Traffic Management Advisor
MIT ....miles-in-trail
MSE ....Metroplex Simulation Environment
NAS...........................National Airspace System
NASA........................National Aeronautics and Space Administration
NRA ....NASA Research Announcement
NTML ....National Traffic Management Log
NWS..........................National Weather Service
RCM..........................Runway Configuration Management
RNP...........................required navigation performance
SAIE..........................Systems Analysis, Integration & Evaluation
SAOD........................Situation Awareness-oriented Design
SDO...........................Super Density Operations
SESO.........................Safe and Efficient Surface Operations
SOP ....Standard Operating Procedure
SORM ....System-Oriented Runway Management
SRCM ....Strategic Runway Configuration Management
STARS ....Standard Terminal Automation Replacement System
TFDM ....Tower Flight Data Manager
TFM ....traffic flow management
TFMS ....Traffic Flow Management System
TMA..........................Traffic Management Advisor
TMC..........................traffic management coordinator
TMI ....traffic management initiative
TMU..........................Traffic Management Unit
TRACON ....Terminal Radar Approach Control
TRCM ....Tactical Runway Configuration Management

1.0 Introduction

This document describes a concept for runway management that maximizes the overall efficiency of arrival and departure operations at an airport or group of airports. Specifically, by planning airport runway configurations/usage, it focuses on the efficiency with which arrival flights reach their parking gates from their arrival fixes and departure flights exit the terminal airspace from their parking gates. In the future, the concept could be expanded to include the management of other limited airport resources. While most easily described in the context of a single airport, the concept applies equally well to a group of airports that comprise a metroplex (i.e., airports in close proximity that share resources such that operations at the airports are at least partially dependent) by including the coordination of runway usage decisions between the airports. In fact, the potential benefit of the concept is expected to be larger in future metroplex environments due to the increasing need to coordinate the operations at proximate airports to more efficiently share limited airspace resources. This concept, called System-Oriented Runway Management (SORM), is further broken down into a set of airport traffic management functions that share the principle that operational performance must be measured over the complete surface and airborne trajectories of the airport's arrivals and departures. The "system-oriented" term derives from the belief that the traffic management objective must consider the efficiency of operations over a wide range of aircraft movements and National Airspace System (NAS) dynamics. The SORM concept is comprised of three primary elements: strategic airport capacity planning, airport configuration management, and combined arrival/departure runway planning. Some aspects of the SORM concept, such as using airport configuration management[1] as a mechanism for improving aircraft efficiency, are novel. Other elements (e.g., runway scheduling, which is a part of combined arrival/departure runway scheduling) have been well studied, but are included in the concept for completeness and to allow the concept to define the necessary relationship among the elements.

The goal of this document is to describe the overall SORM concept and how it would apply both within the NAS and potential future Next Generation Air Traffic System (NextGen) environments, including research conducted to date. Note that the concept is based on the belief that runways are the primary constraint and the decision point for controlling efficiency, but the efficiency of runway management must be measured over a wide range of space and time. Implementation of the SORM concept is envisioned through a collection of complementary, necessary capabilities collectively focused on ensuring efficient arrival and departure traffic management, where that efficiency is measured not only in terms of runway efficiency but in terms of the overall trajectories between parking gates and transition fixes. For the more original elements of the concept—airport configuration management—this document proposes specific air traffic management (ATM) decision-support automation for realizing the concept.

---

[1] In the development of the SORM concept, it is recognized that effective runway management requires inclusion of factors affecting operations on, and in the immediate vicinity of, the airport. In this regard runway management is a part of airport configuration management.

1.1   Document Organization

The next section provides background and motivation for SORM research, describes current operations that will be affected by SORM, and introduces the elements of the SORM concept. Each of the SORM components is discussed in sections 3.0–1.0; section 1.0 presents information requirements for stakeholders and each of the SORM elements; section 1.0 summarizes the current state of the research and is followed by an overall Summary in section 1.0. Note that as part of this document, historical elements of the concept creation are included for completeness.

2.0 Background

The air traffic system is becoming increasingly complex. New technologies and operational procedures are being considered and deployed to address increase system capacity, reduce delays, improve aircraft efficiency, reduce fuel burn for both operating cost and environmental benefits, increase reliability in poor weather conditions, and improve system safety.

Enhanced surveillance capabilities, such as the use of automatic dependent surveillance and airport surface surveillance, and the proliferation of area navigation approaches and departures signal the need for complementary capabilities to optimize air traffic operations. Many new concepts leveraging new technologies and focusing on increasing safety and efficiency in the NAS are being investigated. Some new concepts strive to increase capacity for operations in enroute airspace, while others focus on terminal airspace operations. Considerable research has been performed to quantify wake hazards in order to determine if reductions to current wake separations are possible. For example, analysis of wake hazards has resulted in a rule change that reduces the required diagonal separation for dependent approaches (ref. 9.1) that may be expanded to additional situations in the future. More recently, "Re-categorization" or "Re-cat" (ref. 2) by aircraft types promises to significantly increase capacity. Changes in required separation standards enable higher traffic rates on runways, stressing the airspace routes to those runways and the taxiway system carrying aircraft away from those runways.

2.1   National Aeronautics and Space Administration (NASA) Airspace Systems Program Research

As studies on concepts focused on efficiency of operations in various air traffic domains continue, the efficient use of runways becomes paramount. Furthermore, runway usage must be efficient with respect to both local airport issues and systemic, NAS-wide goals. An often overlooked "control knob" that significantly affects how efficiently runways are used is the selection of the runway configuration. The SORM concept is envisioned to directly address these needs.

The National Aeronautics and Space Administration's (NASA) Aeronautics Research Mission Directorate (ARMD) is pursuing focused research to help the nation achieve revolutionary advancements in air traffic management. The Joint Planning and Development Office (JPDO)[2] NextGen Concept of Operations (ref. 3) provided direction for ARMD's pursuit of research toward improving the NAS, stating that "during the next two decades, demand will increase." While the magnitude of potential traffic increases has been debated, increased demand, fuel costs, and environmental awareness will all necessitate enhanced air traffic management system capabilities. To address necessary changes in the NAS, NASA developed a research plan under the Airspace Systems Program (ASP). Until recently, the ASP was comprised of two projects: the NextGen Concept & Technology Development Project and the NextGen Systems Analysis, Integration & Evaluation Project (SAIE). As most of the SORM work was conducted under this organizational structure, it will be referenced in this document. Concepts and Technology

---

[2] At the time of the creation of the runway management research effort and during most of the life of the work, the JPDO was the guiding influence for NextGen activities. It has since been replaced, and is included here for historic reference.

Development was composed of research areas that addressed the following: Dynamic Airspace Configuration, Traffic Flow Management, Separation Assurance, Super Density Operations, and Safe and Efficient Surface Operations. System-Oriented Runway Management research is part of the Super Density Operations research area. The SAIE Project was organized into four research areas: Exploratory Analysis, Portfolio Analysis, Interoperability Research, and Integration, Test, and Evaluation.

The most current version of the original plan (ref. 4) cites the impact of effective runway management:

> One of the biggest limiting factors in expanding air traffic capacity lies in airport operations, where a multitude of factors can cause flight delays and other incidents, the effects of which can cascade throughout the NAS. Airport capacity and efficiency is constrained at the individual airport level by surface operations (taxiways, ramps), runways (individually or interacting), and at the metroplex level due to interactions in the flow between nearby airports. Interacting flows between nearby metroplex airports are intricately linked to runway configuration and scheduling at the individual airports and must be treated as a system if system capacities and efficiencies are to be obtained.

Architects of the ASP determined that, among the capabilities being developed to support NextGen, a complimentary runway management capability was needed. The original focus was on runway balancing[3]. It quickly became apparent that this term was limiting in the context of the capability required. The research area was expanded to include a systemic approach to runway management and the inclusion of runway configuration selection. The two milestones from the original research plan were completed at the beginning of this research effort:

- AP.1.C.01 Characterize current runway balance decision-making processes.

- AP.3.C.01 Catalog and assess alternatives for runway balancing and potential benefits.

The first milestone focused on a characterization of current practices for "runway balancing." Results from the work on this milestone determined that the process of runway assignment was fairly rudimentary and that there was minimal coordination between arrival and departure flows at the airport level (ref. 5). Work addressing the second milestone essentially concluded that although alternatives for runway balancing could be defined, specific alternatives were not the solution. Rather, a set of capabilities were required with different weightings appropriate for different situations. This set of required capabilities evolved into the SORM concept. In 2014, the final milestone was completed with the development of an algorithm to address TRCM in a metroplex environment:

- AP.2.C.11 Extend Runway Configuration Management (RCM) and arrival/departure balancing algorithms to multiple airports with multiple runways.

---

[3] The initial term for the area of work which ultimately became SORM was "runway balancing." The area of work was expanded to reflect a systemic approach to runway management and the scope of the decisions that are required to efficiently utilize airport and terminal-area airspace resources.

Planning the airport configuration has the potential to deliver substantial benefits at some airports within current operations and considerably greater benefits in the future as other technologies and procedural changes increase the airport configuration flexibility. However, NASA's current airport traffic management research assumes the runway configuration is known and constant to focus on tactical control of individual flights through runway sequencing, taxi routing, and block-out metering of departures. Research under the SORM concept broadens and complements NASA's portfolio of other airport traffic management research. More recent work under the SORM effort has been focused on a set of algorithmic capabilities to fulfill the SORM objectives. These algorithms were to be developed over a three-year period (2009–2012), addressing increasing levels of operational complexity. The first two years addressed a single airport with single/multiple runways, and in the third year, multiple airports with multiple runways (metroplex).

In May 2009, the SORM research team expanded significantly when NASA awarded a three-year contract under a NASA Research Announcement (NRA) to Mosaic ATM, Inc. to support the continued development of SORM. Exploration of other aspects of the runway management problem has been conducted under contractual efforts and the Small Business Innovation Research Program.

The following three subsections (2.2–2.4) summarize the early work conducted in this area: a description of current practices in runway management operations, an overview of the SORM concept, and other related research.

2.2   Current Air Traffic Operations Related to Runway Management

The SORM concept, as envisioned, relates to the following airport traffic management functions: tactical airport configuration selection, strategic airport capacity planning, and coordinated runway scheduling. Current practices in each of these functional areas are described in the following sections.

2.2.1 Tactical Airport Configuration Selection

At most airports, the airport traffic control tower (ATCT) supervisor or controller-in-charge (CIC) has primary responsibility for selecting which runway configuration should be used and any other procedures for which options are available. The degree to which efficiency can be achieved is a function of many factors including taxiway structure, area availability to absorb traffic overload, and availability of low weather instrument approaches.

As this decision becomes more complex due to traffic flow management issues, traffic management coordinators (TMCs) are becoming more involved. For example, the New York Terminal Radar Approach Control (TRACON) (N90) Traffic Management Unit (TMU) has authority to dictate the runway configurations to be used at New York metroplex airports, due to the need to coordinate the configurations at the airports. References 6 and 7 provide additional information on current procedures for selecting the runway configuration. Some of the considerations for selecting active runways are as follows:

- Surface wind velocity
- Meteorological conditions

- Traffic demand

- Shear/microburst alerts/reports

- Adjacent airport traffic flows

- Severe weather activity

- instrument flight rules departure restrictions

- Environmental factors

- Intersecting arrival/departure runways

- Distance between arrival runways

- Dual purpose runways (shared arrivals and departures)

- land and hold short (LAHSO) utilization

- Availability of high speed taxiways,

- Potential for use of reduced (2.5 nm) separation rule for arrivals

- Airspace limitations/constraints

- Procedural limitations (missed approach protection, noise abatement, etc.)

- **T**axiway layouts

- Terminal flow of traffic

The primary considerations for runway selection are wind direction and speed; thresholds for these values have been established in the interest of safe operations. The FAA Order 8400.9 (ref. 6) defines maximum tailwind and crosswind limits for runway operations, allowing for site-specific exceptions; also in this document is the establishment of runway-use programs, which address the application of noise restrictions. These criteria represent "hard" constraints in the runway selection process. At major airports, pre-defined runway configurations are defined and set forth in facility directives. Runway configurations serve as a basis for a flow of traffic on the airport surface as well as for arrival and departure traffic. Configurations are selected, in large part to accommodate a desired ratio of arrivals and departures. As configurations are selected, the TRACON providing approach control services for the subject airport determines the type of approach in use for each active runway. In general, visual approaches are used when possible, as they usually provide the greatest capacity. Examples of how some of the factors involved in the decision-making process are used are described in Appendix B for two different airports.

2.2.2 Coordinated Runway Scheduling

In current operations, runway assignments are most frequently based on a logical strategy that follows a basic procedure. Departure aircraft are assigned to the runway (from the set of active runways useable by that aircraft type) that is most closely aligned with their initial direction of flight (i.e., toward their departure fix). If a set of parallel runways are used for departures, some aircraft will need to make a turn of about 180 degrees to reach a departure fix in the opposite direction. Sequencing strategies are used to ensure divergent headings between successive departures, which take advantage of rules permitting reduced separations when courses

immediately diverge and requisite weather criteria is met. Significant changes in sequencing are precluded by respecting the first-come, first-served principal and by controller workload, unless traffic flow management restrictions demand otherwise. Other factors that influence departure runway assignment are runway length requirements for larger aircraft, noise restrictions, cross winds, and traffic volume.

Arrivals are generally assigned runways closest to their arrival fixes (usually at the terminal boundary), although parking position is considered, when traffic conditions permit, at some airports in order to reduce taxi distance. Load balancing for both the routes through the terminal area as well as the runways result in exceptions to this rule. Also in today's environment, attempts are sometimes made to sequence aircraft to reduce the impact of the wake vortex separation requirement. Changing the ordering of aircraft for better wake turbulence spacing can result in an overall reduction of the spacing required across an arrival stream and for departures. With the limited TRACON airspace and high workload for approach controllers, this is often not practical when demand is high, although it could be beneficial in reducing arrival delays.

2.2.3 Strategic Airport Capacity Planning

Operations between arrivals and departures are generally not coordinated in today's environment. In the case of dedicated arrival and departure runways, this is not a tactical problem. As the need for higher levels of efficiency for airport operations increases, greater planning and execution of strategies will be required. An example is consideration of airport surface congestion; minimal spacing between arrivals and departures may not permit the number of runway crossings required to facilitate a reasonably efficient surface traffic flow. Hence, sacrifices may be required in terms of capacity and consideration must be given to whether these sacrifices will benefit the system as a whole. A further complicating factor is occasional capacity imbalances at the airport, where trade-offs may be required between arrival and departure loading of the runways. This propagates in the larger context of a metroplex where dependencies extend into the airspace where paths conflict flight and there is competition for shared departure fixes.

Traffic flow management decisions must often be made many hours in advance. For example, if severe weather will reduce the capacity of an airport and result in many flights being delayed, the most efficient place for those flights to incur the necessary delays is on the ground prior to departure, with their engines not yet running. For delayed flights that originate at locations that are several hours flying time from the weather-impacted airport, the traffic flow management (TFM) decision about how to delay them would have to be made before the time they would be departing, which would be several hours in advance of the severe weather impacting the airport. At this long time-horizon, specific decisions about the airport configuration that will be used during the severe weather have not been made and, therefore, are not available to the TFM decision process. However, that TFM decision process must be informed by some estimate of what will happen at the airport.

2.3   System-Oriented Runway Management Concept Overview

The initial SORM concept was comprised of two elements: Runway Configuration Management (RCM) and Combined Arrival/Departure Runway Scheduling (CADRS). Runway Configuration Management is considered to be the process of designating the active runways, monitoring the

active runway configuration for suitability given existing factors, and predicting future configuration changes. Combined Arrival/Departure Runway Scheduling is the process by which arrivals and departures are assigned runways based on local airport and NAS goals through the effective distribution of arrival and departure traffic across active runways in conjunction with effective scheduling of traffic on those runways.

Initial SORM research on current practices necessitated refining the set of capabilities that should be included within the SORM concept and how those capabilities should be organized into components. Based on observed current practices, the refined SORM concepts comprise three functions: strategic airport capacity planning, airport configuration management, and combined arrival/departure runway planning. Strategic airport capacity planning was added to the SORM concept to recognize the need to connect airport planning with traffic flow management decisions over a longer time horizon than the original SORM concept encompassed. RCM was split into two components based on the elements of the SORM concept that existed in present-day operations and elements that would require more significant operational changes. A brief description of the three components currently being developed within SORM: TRCM, SRCM, and CADRS, follows with more detailed descriptions in sections 3.0–1.0.

2.3.1 Strategic Runway Configuration Management

Strategic Runway Configuration Management forecasts the airport configuration over a longer time horizon for the purpose of providing airport capacity forecasts for use in traffic flow management—planning traffic management initiatives (TMIs) several hours in advance. This capability is also seen as beneficial to NAS system users in planning resources. A strategic element of SORM could make an early prediction for the airport arrival and departure capacities. While the output of this function would be a coordinated capacity forecast, underlying this forecast would be determination of the most likely airport configurations and times at which the configuration would change.

2.3.2 Tactical Runway Configuration Management

Tactical Runway Configuration Management plans the airport configuration over a timeframe appropriate for air traffic personnel in the ATCT and TRACON to make runway configuration and operating procedure decisions used to control arrival and departure traffic. Despite the name, which is retained for historical reasons, TRCM goes beyond selecting runway configurations and also selects aggregate policies for the active runways' usage. Note that the FAA uses the term Airport Configuration Management to refer to the TRCM capability.

2.3.3 Combined Arrival/Departure Runway Scheduling

Combined Arrival/Departure Runway Scheduling is more tactical in nature than TRCM; it plans how individual flights should use the available runways and is subject to (or in exception to) the aggregate policies selected by TRCM. The CADRS concept considers runway assignments and aircraft sequencing, airport surface, and TFM factors. The concept does not imply any particular approach to achieving runway operations that are efficient from the perspective of the complete trajectories between parking gates and transition fixes. The envisioned CADRS capability is

intended to efficiently plan the use of the selected runway configurations. This includes consideration of arrival and departure traffic as well as aircraft taxiing across runways.

2.3.4 SORM in the Operational Environment

This organization of functions differs from the initial SORM concept in two significant ways, the most obvious being the addition of the strategic airport capacity forecasting function. In addition, TRCM subsumes the original RCM as well as elements of the original CADRS definition. Under the new concept, CADRS is focused on tactical planning of flight-specific runway usage decisions such as sequencing or scheduling at the runway and runway assignments that are exceptions to the TRCM-defined policies. This reorganization allows the runway configuration and runway usage policy decisions that must be made together to be within the same SORM component. It also separates SORM elements that could readily be deployed within the NAS from those that will require more substantial operational changes.

The SORM concept assumes that automation will be used to provide advisories to air traffic controllers, supervisors, and traffic managers to achieve the SORM vision of efficient runway utilization. Further investigation of the role of the human and automation in the SORM concept is essential. In addition to considering the traffic demand and other factors such as controller staffing and status of navigational aids that affect available runways and procedures, SORM must consider airport surface weather conditions as well as terminal airspace weather such as winds and the presence of convective cells. Current limitations of airport surface weather forecasting capabilities prevent the fully automated planning of runway configurations. Future weather forecast products are expected to provide finer resolution information of when surface winds will change direction, for example, eliminating the need for controllers[4] to interact with SORM to provide sufficient weather forecast information.

The cornerstone of the SORM concept is the consideration of the efficiency of all phases of arrival and departure operations, rather than attempting to optimize only the throughput or delays at the runways. For example, SORM considers how different uses of the runways might cause or avoid taxi congestion or excessive demand for a particular departure fix, which may affect aircraft delays and fuel burn more than the variations that would occur in runway delays if non-runway resources were not constrained. System-Oriented Runway Management avoids situations in which the runway configuration provides a higher departure capacity at the runways when the departure fixes are closed or the departure aircraft cannot reach the runways due to surface gridlock. While the concept encompasses control mechanisms used by many other concepts, such as runway scheduling, SORM is unique in its inclusion of runway configuration and other aspects of airport configuration as key control mechanisms for maximizing overall operational efficiency. The concept provides for the incorporation of inputs from all service providers that are responsible for the administration of air traffic operations, in addition to the system users (airlines and general aviation, among others) and airport operators (those who essentially "own" the airport).

---

[4] The use of the term "controllers" is meant in a global sense; it includes those performing the tactical control of aircraft (including supervisors) as well as traffic flow management personnel.

System-Oriented Runway Management uses runway configuration and other runway usage decisions to improve the efficiency of arrival and departure operations at an airport while considering traffic flow management objectives and restrictions. The longer term vision of SORM is to provide for these capabilities in a metroplex environment, which poses additional challenges due to the need to coordinate runway usage plans between airports. The selection of runway configurations across airports within a given metroplex area requires consideration of the role of each airport in the grander context of NAS efficiency.

The future holds greater complexities based on the promise of future NAS enhancements, e.g., weather products with more accuracy and longer planning horizons, greater accuracy in delivering aircraft to the runway based on required times of arrival, and likely further changes in wake vortex separation standards, among others. The core objective of SORM is to provide a set of capabilities that assimilate information from relevant sources and provide algorithmic solutions for runway management and assignment. It should be noted that SORM is intended to provide recommendations; the human always makes the final decision.

A final note regarding the runway management process that the SORM concept addresses. Although the approach taken with the SORM concept could improve operations at most airports, it is not a simple matter of deploying the tools to any airport without consideration for the operating environment. System-Oriented Runway Management requires a detailed adaptation that is specific to each airport's operating environment, in order to achieve its objectives of optimizing airport operations while considering the different and disparate factors that can affect these operations. There are, in fact, common denominators that define operations across airports; however their uniqueness requires consideration. The sampling of airport configurations shown in Appendix A underscores the significant differences that exist between airports and the need to reflect those differences in crafting effective runway management solutions. Note that those depictions found in the referenced appendix reflect only the geometrical complexities. The fact that each airport has evolved local procedures to handle idiosyncrasies of the geometry, traffic characteristics, surrounding airspace design, controller culture at that facility, etc., creates the uniqueness. The need to provide advisories consistent with local procedures creates the need for complex adaptation.

2.4   Related Research

This section summarizes and provides references to relevant related research. Note that the program structure under which the SORM work was conducted has changed since this work was conducted along with a corresponding change in research focus. Included in this section are the research areas that were in place during the life of this concept development, and that are still relevant to runway management.

Subsections 2.4.1–2.4.3 focus on NASA's research within the ASP discussing how this research affects and is affected/influenced by SORM. The subject research focuses on specific domains and technology related areas. The final subsection (2.3.4) presents relevant non-NASA research which either sets the environment within which SORM must function or which may be leveraged to accelerate SORM research.

2.4.1 *Super Density Operations Research Area*

A ConOps has been developed for Super Density Operations (SDO) (version 1), that serves as a guide for NASA's efforts in researching capacity constraining issues in major terminal areas. The technical challenges cited in the SDO ConOps are worth noting:

> (1) enabling precision trajectories in dense terminal airspace; (2) defining regional resource optimization processes; (3) achieving robustness to varied and chaotic weather conditions; and (4) satisfying environmental considerations while enabling NextGen air traffic density projections.

The JPDO ConOps identifies Super-Density Arrival/Departure Operations as one of eight key capabilities. The concept is multi-faceted and would require extensive description to adequately address it in its entirety. The following discussion will be limited to the framework of the concept and the applicability to the SORM process.

The SDO ConOps identifies "key capabilities" envisioned for NextGen; those which relate to SORM are Aircraft Trajectory-Based Operations, Equivalent Visual Operations, and Super-Density Arrival/Departure Operations. Specific focus of NASA's research in the area of SDO is defined in five core areas: collaboration and coordination of objectives, robust capacity, increased efficiency, reduced environmental impact, and determination of roles and responsibilities. These SDO "core areas" mirror those identified in the JPDO ConOps: Capacity Management, Flow Contingency Management, Trajectory Management, and Separation Management. These are discussed in the context of the SORM work; the short descriptions below of each of these elements are accompanied by brief comments regarding the consideration of a SORM capability.

- Capacity Management assumes balanced capacity/demand (includes incorporation of delay absorption strategies) at the national level which permits SDO at the terminal level. The planning horizon defined is 1–6 hours for the short term and 6+ hours for the long term.

  o Envisioned SORM capabilities respond to short term and long term capacity predictions, as well as forecast weather. The specifics of the planning time horizons are to be determined for SORM.

- Flow Contingency Management is defined as "the process that identifies and resolves congestion or complexity resulting from blocked or constrained airspace." It is assumed that resolutions will impact the management of runways, although it is not known exactly how or to what degree.

  o Coordination with proposed strategies will be necessary if an effective SORM capability is to be achieved.

- Trajectory Management is defined as the "process by which individual aircraft trajectories are managed just before and during the flight to ensure efficient individual aircraft efficiency within a flow."

  o Presumably "flow" has implications which include the airport surface environment; coordination of flows at this level is complex and the SORM vision is for an active role in this process. One of the premises of SORM is that a runway assignment provided several hundred miles from the airport may be

changed for a number of reasons. Although not envisioned to be a common occurrence, this would affect functions envisioned under Trajectory Management, e.g., precision spacing, and continuous descent approaches, among others.

- Separation Management according to the JPDO "ensures that aircraft maintain safe separation from other aircraft, from certain designated airspace, and from hazards (e.g., terrain, weather, or obstructions).

  o The SORM concept assumes that the appropriate separation standards, whether the responsibility of the flight deck or air traffic control, are maintained. As mentioned in a previous sub-section, the future may bring about changes in the separation standards in cases where there are wake considerations, or determined to be the absence of wake vortices. A SORM capability will consider these conditions and plan accordingly.

The SDO research area is considering many capabilities focused on efficiency and safety in airspace and surface operations. One of the significant SORM challenges is to determine when systemic or local interests are best served by providing recommendations that are contrary to operations that are currently planned. An example is an aircraft on a CDA (continuous descent approach), optimized for a specific runway, is when and aircraft is re-assigned to a different runway, a decision based on addressing surface congestion. The same example could hold true for an aircraft on a "precision spacing" clearance.

2.4.2 Safe and Efficient Surface Operations Research Area

The airport surface is arguably the most complex domain of the air traffic control system. Its geographical limitations provide a myriad of problems. Departure traffic is subject to many factors which adversely affect predictable schedules. Other variables include the following: servicing of aircraft, aircraft waiting for delayed passengers, weather, delays at the departure and/or destination airports, and potentially during the enroute phase of flight. Depending on the available space on the surface, many airports have limited capabilities to absorb delays of departing aircraft outside the ramp areas. For these reasons, among others, the surface represents a highly complex traffic management problem and is the focus of efforts at NASA to address surface automation. Currently there is an ephasis on capabilities"to manage traffic on the airport surface (gates, taxiways, and runways) safely and efficiently to enable maximum throughput and capacity in the airport environment" (ref. 4).

The SESO research area is focused on efficiency of surface operations. To support this activity, a ConOps was developed; the remainder of this section addresses features provided in the SESO ConOps. The concept is based on three functionalities: a Spot Release Planner, Runway Scheduler (or Departure Scheduler), and a Taxi Scheduler.

The over-arching model for these functionalities is the Complete Airport Optimizer (CAIRO) which models all operations on the surface. The Spot Release Planner generates a schedule for

"spot[5] release" that is intended to absorb delays at the "spots" rather that at the runway. This function is sub-divided into short term scheduling and long term scheduling, the latter providing for collaborative decision making inputs. The output of the Spot Release Planner is the ground controller. Longer-term usage includes the air route traffic control center which could use the information for metering arrival traffic. The Runway Scheduler manages operations on a single departure runway, this capability includes runway crossings and arrival aircraft in addition to departure aircraft. The Runway Scheduler takes inputs regarding "queue" characteristics, separation criteria, operational constraints on aircraft (ground delay factors, expected departure clearance times (EDCTs)), and others. The Runway Scheduler outputs assignment to departure queues, assignment of take-off times, and active runway crossing times. The Taxi Scheduler is intended to output conflict-free trajectories through use of required times of arrival and estimated departure queue entry times. The Taxi Scheduler integrates the Spot Release Planner and Runway Scheduler to output these solutions. The concept suggests benefits to deviation from the first-come, first-served FCFS paradigm. Alternatives to FCFS are proposed though the CAIRO model.

Significant interaction with the surface automation capabilities is assumed under the SORM concept. Due to the short planning horizon between when an aircraft is known to the system as a viable participant (ready to taxi[6]) in the traffic flow, until it arrives at the runway, there is little discretionary time. It is therefore assumed that the schedule generated by surface automation for departures cannot respond to adjustments.

2.4.3 Dynamic Airspace Configuration Research Area

The notion of dynamic configuration of airspace has been considered for many years. The current system operates on the paradigm of airspace segregation based on aircraft capabilities, services provided, and, in the case of the application of ATC services, the basic premise that a controller is responsible for a piece of airspace defined by horizontal and vertical dimensions ("sectors" in a radar environment).

During periods of reduced traffic volume, one controller may assume responsibility for several sectors. There are formal provisions for "delegating" airspace, which may be required for many reasons. This is handled through intra-facility directives or letters of agreement between facilities. As traffic volume and operational complexity in the NAS increases, it is reasonable to say that greater flexibility in the management of airspace will be required. Research within the Dynamic Airspace Configuration research area focuses on exploring avenues for such flexibility. The objective of this work is to allocate airspace as a resource to meet demand while addressing weather, safety, security, and environmental constraints. In consideration of runway configuration changes, re-allocation of airspace may serve to permit a more "graceful" change to

---

[5] This refers to one of many such locations at large airports, found at the edge of the ramp area prior to entering active taxiways (boundary of the non-movement and movement areas) controlled by air traffic control. These "spots" are used to stage aircraft and control entry onto the active taxiways.

[6] Aircraft usually are in contact with ramp control for the push-back unless the push-back affects the "movement area." The movement area is defined as "the runways, taxiways, and other areas of an airport which are used for taxiing or hover taxiing, air taxiing, takeoff, and landing of aircraft, exclusive of loading ramps and aircraft parking areas" (14 CFR 139.3).

a new configuration and facilitate more efficient operation to that runway. For this reason, information sharing between SORM and the appropriate entities tasked with future airspace allocation will be required. As CADRS capabilities are applied, further coordination may be required as flight paths could be affected.

2.4.4 Traffic Flow Management (TFM)

The systemic aspects of runway management proposed in the SORM concept are heavily dependent upon inputs from TFM on several levels. Greater detail regarding these considerations can be found in Section 5.0. In short, the systems approach proposed by SORM is centered on the notion that airports serve a larger network and that effective runway management is essential in this process. It follows that TFM considerations and constraints are necessary inputs to the runway management process, both in terms of runway selection and how the runways are used. It is envisioned that the use of Traffic Flow Initiatives will be a tool in the conduct of SORM capabilities.

Traffic Flow Management in the NAS is the responsibility of the FAA in the Systems Operations Services Unit of the Air Traffic Organization. Traffic management in the NAS is orchestrated by the Air Traffic Control System Command Center (ATCSCC) in coordination with TMUs located at centers and major TRACON and ATCTs throughout the country. The ATCSCC manages traffic flows on a nationwide basis with the ultimate goal of balancing system demand with capacity. Traffic flow management issues that can be handled by the air route traffic control center (ARTCC) for issues within their airspace are managed at that level assuming there are not implications beyond the center bounds. There are several tools used by traffic flow managers to regulate the flow of traffic. These include Ground Delay Programs, miles-in-trail (MIT) restrictions, re-routes, arrival gate balancing (terminal boundary) for airports, among others. The avenue for providing TFM considerations and constraints, the way they impact runway management, and subsequently how they translate into the ways runways are used, are subjects for investigation.

Details of this work will not be discussed as the SORM concept assumes certain core functionalities for the TFM process. The particular strategies and functions, though interesting, are not necessary for the initial development of SORM capabilities. As future strategies and concepts are further defined, they will be addressed by SORM research.

2.4.5 Other Related Research Activities

The Deutsches Zentrum für Luft- und Raumfahrt (DLR), or German Aerospace Center, developed a concept which also considers both arrivals and departures for dual use runways (used for both arrivals and departures). The concept Coordinated Arrival Departure Management (CADM) combines inputs from the 4-Dimensional Cooperative Arrival Manager (4D CARMA) and the Controller Assistance for Departure Optimization" (CADEO) (ref. 8). Both 4D CARMA and CADEO are separate processes which optimize operations in their respective domains. Under CADM, an algorithm considers the traffic situation on the ground and in the terminal maneuvering area (analogous to the terminal area in the United States). Gaps or arrival-free intervals are identified in the arrival stream for insertion of departing aircraft. Where those gaps do not exist, the required action to create the gaps is calculated and presented to the controller for implementation.

3.0 Tactical Runway Configuration Management (TRCM)

3.1 Introduction to TRCM

This section describes the Tactical Runway Configuration Management tool, an algorithm that plans the runway configuration as well as other aspects of how the runway, airport, and airspace resources are used in aggregate, which we collectively refer to as the airport configuration.

Today, airport configuration decisions are made manually. Air traffic personnel are able to plan runway configuration changes in response to changing weather conditions, as long as the weather is accurately forecast. However, they are less proactive in changing the runway configuration to accommodate traffic demand, because they do not have the requisite information that provides information concerning the benefit, and the additional workload required to affect the change. Without detailed, accurate traffic forecasts, and under high workload conditions, controllers infrequently change the configuration. As a result, the configuration must be adaptable to the variability in conditions that occur over an extended period of time. Significant opportunity exists to use available airport configurations more effectively to improve airport efficiency. Moreover, future technologies and operational concepts will require more complex airport configuration choices. Air traffic personnel will be unable to manually evaluate these choices unaided, further motivating research on automation such as the TRCM tool to support airport configuration management. The uniqueness of airports and the variation in procedures that have evolved from local issues and personalities presents a substantial challenge for airport configuration automation to be deployable and beneficial to any airport. While all airports must select the runway configuration, other aspects of airport configuration vary at different airports. Some airports (e.g., Hartsfield-Jackson International Airport (KATL)) select the departure split (i.e., mapping between runway and departure fix used to assign the departure runway); some airports (e.g., Los Angeles International Airport (KLAX)) choose between runway assignment rules based on either direction of flight or aircraft parking location; John F. Kennedy International Airport (KJFK) has a rigid departure runway assignment policy but must make other decisions related to airspace allocation within the New York metroplex; and many airports must decide how much runway capacity to allocate to arrivals and departures on a mixed-use runway. In many cases where such flexibility exists, a default decision is applied most or all of the time or a traffic manager makes the decision without any quantitative basis (i.e., based only on experience). Optimally planning how the runways within a runway configuration should be used, or how other limited resources should be used, offers substantially larger benefits than optimally selecting only the runway configuration.

The TRCM airport configuration planner provides decision support over the next 90 minutes and is intended for use by personnel in the ATCT, TRACON TMU, and ARTCC TMUs, who are responsible for, or are stakeholders in, airport configuration decisions. Eventually, the traffic managers will interact with TRCM by configuring parameters and objectives. A conceptual TRCM user interface that addresses the information commonly used by air traffic personnel in the runway configuration/usage decision making process has been developed. TRCM respects current air traffic procedures while being extensible to future operational scenarios and is capable of being easily applied to a wide variety of airports. In this way, the TRCM tool is a significant advancement in automation for airport configuration planning that could be implemented within the current NAS, while having increased benefit in NextGen. The TRCM

capability would be implemented as part of an airport automation system, such as the Tower Flight Data Manager (TFDM).

It should be emphasized that TRCM is an advisory tool and does not change the roles or responsibilities of any recipients of the TRCM outputs. The TRCM capability will provide a deterministic output for the airport configuration schedule, although it will explicitly consider uncertainty internally. In a metroplex, TRCM plans coordinated airport configurations for each airport in the metroplex. The set of factors considered in selecting the best configuration schedule will include the traffic demand (which includes direction of flight and parking location), weather (e.g., wind speed, wind direction, ceiling, and visibility), environmental requirements (e.g., mandates that the configuration be rotated at some interval of time), TFM restrictions, and defined configurations and associated procedures. To select the optimal airport configuration, TRCM considers the effect on airport throughput, delay for departures to reach departure fixes and arrivals to reach parking gates, and efficiency (e.g., fuel burn). Note that a number of factors, such as the location of the aircraft's parking gate, is considered implicitly by including the delay and fuel required. Beyond those described in this section, additional capabilities are envisioned for TRCM and the other elements of SORM. National Airspace System user input to the runway management process will eventually be considered in the SORM algorithms. User input, through the collaborative decision making process (ref. 9), has become a mainstay in the conduct of NAS operations. The avenues of such user participation in the SORM concept, and the processes most appropriate for that input, have not yet been studied.

3.1.1 Airport vs. Runway Configuration

Airport configuration planning may be under-studied in air traffic management research for several reasons including a perception that the problem is limited to runway configuration decisions and that controllers currently do a good job of making these decisions with manageable workload. Consequently, the need and potential benefits for providing an airport configuration decision-support tool (DST) has been overlooked. Past studies have shown that, unaided, controllers do not select the best time at which to make runway configuration changes (ref. 10) and that airport delays are highly sensitive to the timing of the configuration change (ref. 11). For example, at the end of an arrival rush and the beginning of a departure push, waiting until runway departure queues have formed to switch to a configuration that favors departure capacity is too late. Controllers tend to use experience to make traffic management decisions. Observing historical operations helps controllers to select the best configuration to use. However, variations from day to day require detailed modeling to select the optimal configuration change time. The potential benefit for a DST to advise the runway configuration change time within current operations is sizeable at some airports.

In addition to runway configuration, aspects of airport configuration such as runway assignment policies must be managed to ensure that airport resources are used efficiently. For example, when Boston's Logan International Airport (KBOS) operates in a runway configuration that lands arrivals on runways 22L and 27 and departs on runways 22L and 22R, the traffic manager must select between the standard operating mode, in which arrivals have priority to runway 22L, and the accelerated departure procedure, in which departures have priority to the mixed-use runway (ref. 12). This decision to balance arrival and departure delays must be made sufficiently in advance so that the arrivals may be managed by the center and TRACON accordingly. Many airports with mixed-use runways always give arrivals priority, when gaps for a certain departure

rate could be coordinated. In NextGen, increased use of mixed-use runways will make selecting the most efficient airport configuration more difficult to do manually.

While air traffic personnel do an excellent job given the information they have available and the other demands on their attention, there are potentially substantial benefits resulting from improvements to the use of less-than-optimal existing procedures. Even when the runway configuration decision appears to be straightforward, other airport configuration decisions must or could be made. Elements of airport configuration beyond runway configuration are often not explicitly controlled or decisions are made infrequently and reactively in response to traffic conditions.

For example, although Dallas-Fort Worth International Airport (KDFW) is a large airport both in terms of the traffic volume and the number of runways, wind and preference are sufficient to select the runway configuration. The preferred runway configuration is South Flow[7]. When winds require, North Flow is used; a few times a year, strong northwest winds require a runway configuration in which runways 31L and 31R are both used for mixed operations. However, how efficiently the airport serves the traffic demand depends strongly on how the aircraft are assigned to the runways. The airport experiences strong directionality to the traffic due to its geographic location and use as a hub. Runways are generally assigned based on direction of flight, and, consequently, delays can occur for one runway while another runway is underutilized. Dallas-Fort Worth has the procedural flexibility to change the set of departure fixes that are assigned to each runway (within constraints that ensure that no airborne crossing or merging can occur), in order to balance the demand for each runway and minimize overall delays. This decision, not the selection of the runway configuration, determines how efficiently the airport will operate and requires an ability to predict departure queues and flight times relative to taxi times. The controllers currently have no automation to aid this decision.

Atlanta Hartsfield International Airport has a simple runway configuration with five parallel runways. Wind and preference are sufficient to determine whether the runways will be used in West Flow or East Flow. Runways 8R/26L and 9L/27R are used for departures and runways 8L/26R and 9R/27L are used for arrivals. Runway 10/28 may be used for departures, arrivals, mixed operations, or not used at all. Consequently, there are four commonly used runway configurations in each flow direction. The taxi distance to/from runway 10/28 is much longer than to/from the other runways. As a result, the decision whether or not to use runway 10/28 must consider both runway delays and taxi distance, which is not easy for a controller to optimize unaided. In addition, KATL uses departure splits to assign departures to the two or three departure runways, to avoid airborne crossing or merging. Figure 1 illustrates the standard departure split when three departure runways are used in West Flow; the departure fixes are shown as waypoint symbols. The departure fixes are shown based on a "north-up" orientation. Aircraft departing over the north and west departure fixes would be assigned runway 8R for departure, aircraft departing over the east fixes, runway 9, and those departing of the south fixes, runway 10. Similar to KDFW, several alternate departure splits, essentially radial lines from the

---

[7] In South Flow, arrivals use runways 17L, 17C, and 18R (13R is also available for arrivals but generally not needed), while departures use runways 17R and 18L. In North Flow, arrivals use runways 36L, 35C, and 35R (arrivals to 31R are also possible but demand generally does not require use of the diagonal runways), while departures use runways 36R and 35L (departures from 31L are also possible).

airport that divide the departure fixes into two or three groups where each group is assigned to one of the runways, have been defined and may be selected to balance the demand on each runway. The departure split is one element of the KATL airport configuration, used to avoid the situation where a departure queue exists at one runway while another runway is underutilized. To use the runways as efficiently as possible for the forecast traffic, the runway configuration and departure split must be planned together.
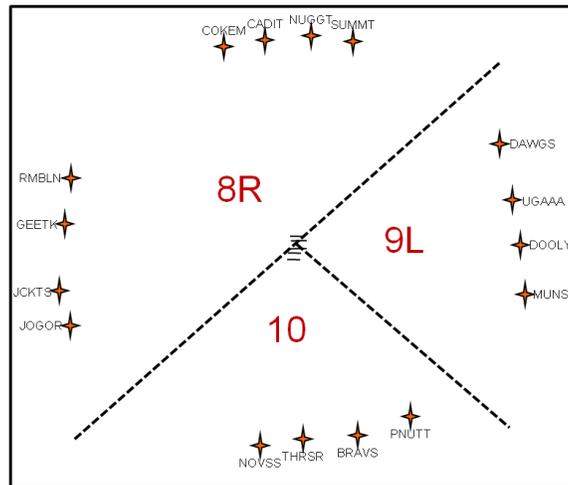

Figure 1. KATL baseline departure runway assignment procedures.

3.1.2 Airport vs. Runway Capacity

Most prior research on runway configuration management has adopted the airport capacity curve model first introduced by Newell (ref. 13) which describes the tradeoffs between arrival and departure capacities using a separate curve for each operating condition. Each runway configuration may operate in different conditions, for example using visual or instrument approaches, resulting in separate curves. Mixed-use runways, crossing or dependent runways, and required taxi crossings are some of the causes for the tradeoff. Gilbo popularized the curves and described a method for drawing the curves by fitting a line around observed traffic counts (ref. 14). The curves may also be drawn based on theoretical maximum rates; the FAA's capacity benchmark provides curves for 35 of the nation's busiest airports.

Numerous people (Frankovich, Weld, Leihong, and Gilbo (refs. 15–18), for example) have built queuing models of the airport employing these capacity curves and then proposed various optimal methods for selecting the sequence of runway configurations and operating points (i.e., feasible combinations of arrival and departure rates) that best serve the forecast demand. While useful for strategic planning of traffic flow management initiatives, this approach is not sufficient for tactical runway usage decisions. Substantial variability exists in the realized capacities observed within a runway configuration, demonstrating that the capability of the airport to handle arrival and departure traffic is much more complex than represented by a single curve for each runway configuration.

Figure 2 plots the arrival and departure capacity pairs that were planned by the TMCs at KJFK at different times when the airport was operating in the same runway configuration, as recorded in

the Aviation System Performance Metrics (ASPM) database. The average arrival and departure capacity matches the airport's standard capacity for this configuration. However, the airport's planned capacity varies substantially from this average, and not only along the standard arrival-departure capacity envelope for the configuration. Note that the data points are not the actual arrival and departure counts, but the capacities that were planned to be used, for the purpose of traffic flow management decisions, when the airport was operating in that configuration. The capacity curve is too simple a model of airport capacity for tactical airport configuration planning. Moreover, ATCT controllers do not explicitly select arrival and departure rates or manage traffic to achieve those rates. For Tactical Runway Configuration Management to be effective, it must communicate the arrival/departure tradeoff in a way that is complementary to current procedures.
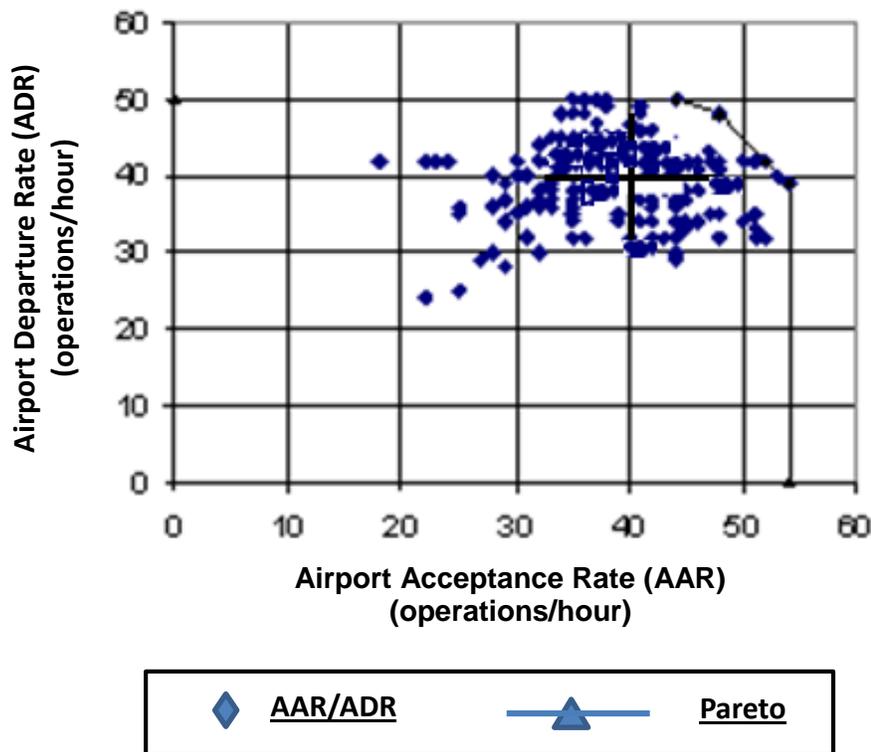
Figure 2.   Planned John F. Kennedy International Airport arrival and departure capacities for different instances of runway configuration 31R/31L in visual meteorological conditions.

Furthermore, the capacity curves for different runway configurations are often not sufficiently distinct so that many different runway configurations appear equally efficient. Runway configuration planning approaches based on capacity curves, consequently, must also use information about local runway configuration preferences. In addition, prior approaches often have used models for the cost to switch between configurations that are too coarse for tactical planning or require data that would be impractical to obtain and maintain for every airport and runway configuration for an operational system. Finally, the operating point, while useful for traffic flow management, does not easily translate into the tactical decisions controllers make.

These approaches also fail to provide a system perspective, such as how a runway configuration and operating point choice might result in taxiway congestion that causes delays not related to the runways.

Many runway configurations involve an operationally important, but often unused, ability to trade-off between arrival and departure capacities. This tradeoff would be part of the airport configuration, specific to the runway configuration which entails specifying the airport operating point—the combination of arrival and departure rates that lie on or within the airport capacity. While this would accomplish the objective of managing the arrival/departure tradeoff and would be applicable at any airport, it would not provide an operationally meaningful advisory to controllers. Controllers would need to convert an output such as 12 arrivals and 17 departures during this 15-minute epoch, for example, into the actual decisions they make, which might be a runway assignment policy at some airports and an inter-arrival spacing policy at others. In TRCM, runway usage policies may be approximate, such as "keep arrivals off runway 18R" or "only arrival overflow to runway 18R," or they can be more precise, such as "10 MIT arrival spacing for departures." Note that TRCM requires a limited number of discrete policies; it will not allow a policy such as "N MIT arrival spacing" and then optimize to find the best value for N. However, since operationally a limited number of options would be efficient (e.g., allow a departure between every arrival pair, allow a departure between every other arrival pair, allow two departures between every arrival pair, etc.), this constraint does not limit the TRCM applicability or achievable benefits.

3.2   TRCM Algorithm

A variety of automation systems have been developed and deployed for individual airports to address specific airport configuration issues; none have been deployed more widely. For example, the Enhanced Preferential Runway Advisory System is used at Boston's Logan International Airport to advise runway configurations to balance environmental impacts on an annual basis by suggesting alternative, lower-capacity configurations when weather conditions and demand permit. The Surface Movement Advisor was a custom solution developed for KATL to aid in the selection of the departure split to balance demand between the two departure runways (ref. 19).

The TRCM tool plans the airport configuration and presents this plan as an advisory to the ATCT and TRACON traffic managers who are responsible for airport configuration decisions. The foundation of the TRCM concept is the assumption that each of the individual decisions that comprise the airport configuration takes the form of a choice between a finite numbers of policies that are known in advance. The runway configuration, for example, is selected as one of a set of predefined runway configurations used at that airport.

The TRCM algorithm efficiently searches the possible airport configurations and the times at which different elements of the configuration may be changed. As part of this search, the algorithm quickly models how aircraft would use the airport resources under possible airport configuration plans to produce metrics for that plan, which are compared to the metrics for other possible plans. Tactical Runway Configuration Management frequently will need to output multiple policy decisions, for example a runway configuration, a departure runway assignment policy applicable under that runway configuration, and an arrival taxi plan (such as whether to cross an active runway or use a longer taxi path that goes around the end of the active runway).

Some of these airport configuration decisions may be independent of others while some are coupled. The requirement to identify the best time to change the configuration creates a computational challenge for the algorithm.

Through planning the airport configuration, TRCM affects flights in aggregate. While an alternative concept would be for automation to individually plan each flight, flight-specific advisories are less likely to be accepted by controllers in the foreseeable future. As a result, TRCM's concept is designed to more closely match how controllers currently do their jobs, simply adding decision support for decisions they currently make.

3.3   TRCM Adaptation

At different airports, the airport configuration determination consists of different decisions. Handling these differences without designing different versions of TRCM for each airport is a common challenge for airport traffic management automation. The fundamental TRCM goal— selecting the airport configuration that will maximize overall efficiency of the runways, airport surface, terminal airspace, and interaction of the airport with the NAS—is consistent at all airports. Elements of the TRCM algorithm and software must also be consistent at all airports.

Some airport configuration decisions and the ways in which controllers express those decisions are common across many airports, while some airports also have configuration decisions that are unique to that airport based on local considerations and constraints. This section describes how TRCM is adaptable to individual issues at different airports to provide a solution that is practical and deployable across airports, using common software.

The runway configurations that may be used at an airport, as well as any unique restrictions on the weather conditions in which each may be used, must be specified as adaptation data. Another common airport configuration decision at many airports is the departure runway assignment policy. This decision affects runway balancing, flight and taxi distances, and whether procedural airborne separation is provided or temporal coordination is required between operations on different runways. How the runway assignment decisions are made varies among airports. The most common approach uses a mapping that assigns each departure fix to one runway. The airport may select between several of these mappings; each mapping must be defined in the adaptation data used by TRCM. The "Runway Assignment Example" section of this paper (section 3.6.2) presents an example.

Another common airport configuration decision is how mixed-use runways (i.e., those that serve both arrivals and departures during the same time period) will be used. This decision, which can significantly affect airport delays, can take different forms at different airports and, currently, is often not explicitly managed, although procedures allow it to be. TRCM could select between policies that achieve different departure capacities by specifying the frequency with which departure slots should be left in the arrival stream. In this case, the adaptation data would simply list policies such as "a departure gap between every arrival pair" and "a departure gap between every other pair of arrivals." The "Runway Usage Example" section of this document (section 3.6.1) presents an example in which the form of the decision is to define a default policy that gives arrivals priority and an alternate policy that defines a dedicated arrival runway as the primary arrival runway and uses the mixed-use runway for overflow arrivals.

While the TRCM approach requires applying local knowledge to define the airport configurations that are used at that airport, the approach allows a common algorithm to be deployed to any airport. In NextGen and metroplexes, the airport configuration will include additional dimensions such as the allocation of Belmont airspace between LaGuardia Airport (KLGA) and KJFK operations in the New York metroplex. The TRCM approach is not only flexible to how different airports and metroplexes currently operate, but adaptable to future changes in procedures and extensible to new aspects of airport configuration that may need to be selected in a NextGen environment.

3.3.1 Airport Configuration Definition

The definition of "airport configuration" will evolve as the TRCM capability matures and other NextGen technologies become available. Initially, airport configuration will consist of the runways that are being used as the default runways and the ways they are being used. Eventually, airport configuration will include other decisions such as the airspace routings being used. Table 1 provides descriptions for airport configuration elements relevant to TRCM.

Table 1. Initial Elements of Airport Configuration

Airport Configuration Element	Description
Default (or primary) arrival runways and default departure runways	Specifies which runways are primarily used for arrivals, which runways are primarily used for departures, and which are "mixed use" runways.
Runway procedures in effect	Defines the rules that apply to operations on a runway, how arrivals and departures may use the runways, such as the required separation between operations on a runway or on dependent runways, whether or not LAHSOs are permitted, and what dependencies exist between parallel, crossing, or converging runways. Also includes runway assignment rules based on arrival/departure fix or parking location.
Planned operating point for airport	Specifies the planned arrival and departure capacities.

Table 2. Future Elements of Airport Configuration

Airport Configuration Element	Description
Planned arrival and departure runway capacities	Specifies the planned arrival and departure capacities for each runway.
Default taxi plan	Describes the primary plan for arrival and departure taxi routing.
Airspace structure	Describes the airspace structure, such as arrival and departure fixes in use, what routes/trajectories are being used, what required navigation performance (RNP) level is required to use a route, and what regions of airspace are primarily used for what flows.
Traffic Management Initiatives at an airport	What TMIs are in effect at the airport, such as approval request requirements or MIT restrictions on departures

3.3.2 Factors that Affect Airport Configuration

This section lists and discusses the factors that affect the airport configuration decision. Several components of weather are central to determining which airport configurations are feasible; these elements are described in

Table **3**.

Table 3. Weather Factors that Affect Airport Configuration

Factor	Description
Wind speed and direction	As noted earlier, FAA Order 8400.9 sets forth limits regarding wind speed/direction and runway assignment. Further, aircraft may not land or takeoff if the cross wind or tail wind exceed certain limits, which are specified by the aircraft manufacturer and flight operator. Therefore, wind speed and direction determine which runways may be used if they exceed permissible thresholds. However, controllers do not know the exact limits for a particular aircraft and a pilot may be more conservative than his/her company allows. Wind also affects the capacity of the

	runway, with stronger headwinds typically resulting in lower capacity.
Visibility and ceiling	Visibility and ceiling affect the procedures that may be used, such as whether visual approaches can be used or if instrument approaches are required. Most frequently, the procedures affect the feasible arrival and departure rates but not the runways in use. At some airports, the highest capacity configuration for instrument approaches is not the same as the configuration with the highest capacity during visual approaches. Some airports only have Instrument Landing Systems (ILS) or precision approach procedures for some runways, reducing the set of feasible airport configurations during low visibility and ceiling conditions. As a result of existing procedures, such as dependencies between closely-spaced parallel runways, the airport configuration may be selected to only use one of the runways. Reduced visibility and ceiling can increase the frequency with which aircraft perform missed approaches, further reducing the realized arrival rate.
Runway condition	Whether the runways are dry or wet (either from rain or snow) affects the average runway occupancy time and, therefore, the feasible arrival rates. Reduced taxi speeds may increase the time required to taxi across active runways. Some procedures, such as LAHSO, may not be available, increasing runway dependencies and consequently reducing the feasible airport arrival and/or departure rates.
Precipitation	Current or recent precipitation itself does not affect the airport configuration; it may however result in longer runways being selected over those with less length since precipitation results in wet runways, may contribute to reduced visibility reduced braking effectiveness, and may be correlated with low ceilings all reducing capacity for each runway configuration.

Table 3. Weather Factors that Affect Airport Configuration Continued

Table 4. Non-weather Factors that Affect Airport Configuration

Factor	Description
Time of day	Whether or not there is daylight or darkness affects the procedures that must be used. For example, controllers may not issue clearance for a departure to taxi into position and hold (now called "line up and wait") at night, which slightly reduces the runway capacity. A second example is variations in the noise mitigation rules may affect what arrival and departure procedures may be used or what runway configurations may be used. For example, the Quiet and Silent procedures used at the San Francisco International Airport and the Metropolitan Oakland International Airport during night and early morning hours creates a dependency between the two airports such that total departure capacity must be shared.
Noise abatement rules and other environmental considerations	Noise abatement rules exist in a variety of different formats at different airports. Procedures at KBOS require the noise exposure on the surrounding communities to be uniformly distributed on an annual basis. Chicago O'Hare International Airport and KJFK procedures require the configuration to be changed at least every so many hours. Some airports have preferred configurations that should be used whenever the weather permits. Some noise abatement rules are effectively requests by the local government with little or no legal obligation by the FAA to comply.
Arrival demand	The number of arrival flights and their earliest possible landing time (which will vary some by runway) must be considered when selecting the airport configuration. Several characteristics of each flight further influence the configuration decision, including the aircraft type, the arrival fix, and the planned parking gate. Aircraft equipage, such as ILS capability, which includes pilot certification, should be considered. In the future, the aircraft's RNP level may affect what routes may be used.
Departure demand	Departure demand based on latest available information times for estimated departure times.

Table 4. Non-weather Factors that Affect Airport Configuration Continued

Factor	Description
Defined runway configurations	Currently, selection of the airport configuration is limited by the set of pre-defined runway configurations. Often, however, the set is large. In the future, even larger numbers of airport configurations may be pre-defined for specific situations. In the development of TRCM, we assume the set of configurations has been defined in advance.
Closures for maintenance, snow/debris removal, mowing near runway	Runways or taxiways may be closed for snow or debris removal, construction (which may be a few hours or several months), or due to mowing near the runway/taxiway. Closed runways may prompt a complete configuration change or may just prevent use of that runway for a period of time without changing any of the other runways in use. Closed taxiways may prompt a runway configuration change if the surface flow would be significantly altered.
Equipment outages	Equipment such as ILS and precision runway monitors occasionally require planned or un-planned maintenance. Equipment outages may reduce the feasible rates or prevent a configuration or runway from being used.

3.4   TRCM System Design

The incorporation of "runway usage policies" is central to the system design. Examples of these include the ways in which runways will be used (arrivals or departures only, mixed use) and restrictions to runway usage, such as MIT for arrivals. These policies can be focused on capacity or driven by other objectives (e.g., to alleviate congestion on areas of the airport). Note the following example of how runway usage policies have to be considered by the TRCM algorithm. Runway configuration A using the default runway usage policy A1 may be more efficient than runway configuration B using its default runway usage policy B1. Runway configuration B with alternate runway usage policy B2 may be superior to runway configuration A under any of its runway usage policies. Consequently, TRCM cannot first select the runway configuration and then select the runway usage policy or any dependent element of airport configuration as a separate step. Rather, TRCM must separately consider each airport configuration—every combination of runway configurations and the other policies defined for that runway configuration. This creates a larger number of configurations that must be evaluated. A large number of distinct runway usage policies for a runway configuration could create a computational problem for the algorithm. In practice, knowledge of the situations for which each policy might be used will allow heuristics to reduce the set of configurations that must be evaluated in detail, although these heuristics may require additional adaptation data based on expert, local knowledge. Furthermore, the runway configuration and runway usage decisions may be changed at different frequencies. While changing runway configurations may be

expensive in terms of lost capacity, there often will be little or no cost to change between runway usage rules. Changing the runway usage policy several times without changing the runway configuration may be efficient. Tactical Runway Configuration Management considers the cost to make the suggested airport configuration change. Different limits on the frequency of various airport configuration changes are also allowed.

Runway configuration and runway usage are also planned at different time horizons. Runway configuration may be planned 45 minutes in advance, while runway usage may not need to be fixed as far into the future. In some cases, the center might need to know whether the arrival rate should be reduced 30 minutes before the landing time of the affected arrivals. To manage arrivals, the TRACON will need to know 15 minutes before arrival runway assignment rule changes are to take effect. Departure runway assignment rules may be changed as aircraft block out from their parking gates. Consequently, TRCM must use different "freeze" horizons[8] for each type of decision since significant changes require more advance notice than minor changes.

Searching for not only the best airport configurations but also the time at which the configuration should change creates a very large search space. To operate in real-time, the TRCM algorithm makes several assumptions that may be relaxed as computational performance is measured and the algorithm matures. First, although the movement of flights is modeled in continuous time, the algorithm considers configuration changes at five minute intervals. This assumption is likely consistent with how TRCM would be used operationally. Second, each iteration of the algorithm searches for a single airport configuration action to add a new configuration change, to remove a previously planned configuration change, or to shift a previous configuration change to a different time. Multiple configuration changes are possible within the TRCM planning horizon through multiple iterations of the algorithm for overlapping time horizons.

The TRCM algorithm operates every five minutes, which is a parameter that will be tuned based on computational loading. Each time the algorithm runs, if a configuration change is recommended, the change produced becomes part of the baseline configuration plan. After multiple passes of the algorithm, a sequence of configuration changes can be planned. This approach helps to incorporate updated information that would not be available if the algorithm ran once every 30 minutes. However, this approach creates some risk that the algorithm could be sensitive to the input data changing slightly for every pass and the results flipping back and forth rather than settling on a stable plan.

To address solution stability under uncertainty, the TRCM algorithm employs an internal Monte Carlo approach. Consider the KLAX situation where departures may be assigned to a runway based on the departure fix mapping (called "taxi right") or to the closest runway (called "taxi easy"). Under the "taxi right" mode, procedures ensure that there will be no airborne conflicts, and departures from the two runways may occur asynchronously without any coordination in time. Under the "taxi easy" mode, some aircraft assigned to the left runway will need to turn right, and some aircraft assigned to the right runway will need to turn left. If there is no departure on the right runway when the right-turning aircraft from the left runway is ready to takeoff, there is no departure delay. However, if there is an aircraft on the right runway, then the two departures must be coordinated in time, requiring one aircraft to be delayed. "Taxi right" is

---

[8] A freeze horizon defines that point beyond which a decision will not change.

always more efficient during heavy traffic. During light traffic, whether "taxi easy" is more or less efficient than "taxi right" depends on the relative timing of flights reaching the two runways, which is uncertain and somewhat random. TRCM will use knowledge of the uncertainty to generate a number of scenarios for the aircraft runway times and will then solve the airport configuration problem for each possible traffic scenario and select the decision that is adaptable to the uncertainty.

3.5 TRCM Problem Description

This section describes the mathematical formulation of the TRCM algorithm. An instance of the TRCM problem is defined by a set of flights, F, representing all arrivals and departures predicted to operate at the airport or metroplex from the current time through a specified modeling horizon. Tactical Runway Configuration Management is defined on a continuous time scale; it is assumed that the current time has been normalized to zero. Parameters h_f and h_p are the freeze and planning horizon, respectively; both are assumed to be greater than zero. No new configuration changes can be scheduled prior to time h_f or after time h_p. In addition, any configuration changes scheduled between the current time and h_f cannot be canceled. In general, h_f and h_p may be different for each airport configuration element, such as runway configuration and runway assignment policy.

Assume that a maximum number, M, of configuration changes are allowed between h_f and h_p. The set of configurations is indexed by $k \in \{1, 2, \dots, K\}$. There are two sets of decision variables defined for each configuration k. For each, $1 \le m \le M$, Δ_{mk} is a binary decision variable equal to 1 if the m'th configuration change is to configuration k and equal to zero otherwise. τ_{mk} is a continuous variable that is equal to the time of the m'th configuration change when $\Delta_{mk} = 1$ and equal to zero otherwise. Define the matrices $\Delta = [\,\Delta_{mk}\,]$, which contains all binary decision variables, and $\tau = [\,\tau_{mk}\,]$, which contains all configuration change time decision variables.

Define π to be the information state of the airport at the current time. The information state includes weather forecasts, scheduled configuration changes up to the freeze horizon, scheduled TMIs, runway and taxiway closures, and any other information affecting the operation of the airport.

$$minimize\ C(F, \pi, \tau) \tag{1}$$
$$s.t. \quad h_f \Delta_{mk} \le \tau_{mk} \le h_p \Delta_{mk} \ \ \forall m, k$$
$$\tau_{m'k'} - \tau_{mk} \ge B_{kk'} - (1 - \Delta_{m'k'}\Delta_{mk})\bar{B} \ \ \forall m, k, m' > m, k' \ne k$$
$$\sum_k \Delta_{mk} \le 1 \ \ \forall m$$
$$\sum_k \Delta_{mk} \ge \sum_k \Delta_{m+1,k} \ \ \forall m$$
$$\Delta_{mk} + \Delta_{m+1,k} \le 1 \ \ \forall m, k$$
$$\tau \in A(\pi)$$
$$\Delta_{mk} \in \{0, 1\} \ \ \forall m, k$$

The objective function $C(F, \pi, \tau)$ is a generalized expected cost function over the set of flights, F, given information state π and configuration change time decision variables τ. Potential cost metrics include flight delays, flight and taxi times, and fuel burn. The first constraint ensures

that each configuration change time is nonzero if and only if the corresponding binary decision variable is set to 1 and any nonzero configuration change time falls between the freeze horizon and the planning horizon. The second constraint requires a separation of $B_{kk'}$ between configuration changes to configuration k and to configuration k'. This allows different configuration pairs to have different restrictions on how frequently changes may be made. For example, the direction in which the runways are used may be changed infrequently, while adding or removing a runway operating in the same direction can be done more frequently. Constant $\bar{B}$ is defined large enough so that this constraint is inactive when either $\Delta_{m'k'}$ or Δ_{mk} is zero. The third constraint ensures that at most one configuration is chosen for each configuration change. The fourth constraint condenses the configuration changes by allowing a $(m+1)$'th configuration change only if an m'th configuration change has been selected. The fifth constraint does not allow consecutive configuration changes to the same configuration. Define $A(\pi)$ as the feasible space for configuration change times based on the current information state. Thus, the sixth constraint allows for airport- and scenario-specific constraints such as noise abatement procedures or resource usage restrictions. The final constraint defines the Δ_{mk} to be binary variables.

The binary variables and the non-linearity of the second constraint in the above formulation imply that the state space is non-convex. In addition, the expected cost function $C(F, \pi, \tau)$ will be difficult or impossible to compute directly due to the complexity of predicting flight operations. Therefore, a solution heuristic that makes a few simplifying assumptions should be defined.

First, replace the cost function $C(F, \pi, \tau)$ with a simplified cost function $\tilde{C}(F, \pi, \tau)$ that can be computed via fast-time simulation. Any such function can be plugged into the solution heuristic. A fast-time simulation model, however, will be dependent on deterministic gate and fix times for arrivals and departures, respectively. In reality, there is a significant amount of error in flight time predictions. This uncertainty can be accounted for by adding a Monte Carlo sampling scheme to the model. Error distributions are defined for the pushback times of departures and the fix crossing time of arrivals. A sample flight list is created by drawing a sample from the appropriate distribution for each flight in flight list F and applying that error to the flight's gate or fix time. Let F_i be the i'th sample flight list. If N samples are drawn, then the objective function in the TRCM problem formulation is replaced with

$$minimize \ \frac{1}{N}\sum_{i=1}^{N} \tilde{C}(F_i, \pi, \tau) \tag{2}$$

The second simplification of the heuristic is a discretization of the state space. Assume that configuration changes can only be scheduled at predetermined times through the planning horizon and assume that configuration changes will only be planned at five-minute intervals. Future work will study removing this restriction, possibly through a second stage of the algorithm. To simplify implementation, also assume that the planning horizon falls on such an interval. Given π, the possible configuration list may be reduced using heuristics. For example, configurations only allowed under visual meteorological conditions do not need to be considered when the weather will be instrument meteorological conditions.

The above simplifications allow for a basic enumerative search to be used to solve the TRCM problem. The TRCM search heuristic is a recursive search algorithm. Each recursive call to the algorithm adds a new configuration change to the end of the list of configuration changes. The

algorithm maintains a single best global solution (Δ^*, τ^*) at all points in the algorithm and at all depths of the recursion. The algorithm is seeded with the solution $\Delta = \tau = [0]$ for all m and k, which corresponds to no new configuration changes, and with the current best objective function value z^* equal to infinity.

> *TRCM_Search($\Delta, \tau, \Delta^*, \tau^*, z^*$)* $\hspace{5cm}$ (3)
>
> > *Evaluate $z = \frac{1}{N} \sum_{i=1}^{N} \tilde{C}(F_i, \pi, \tau)$.*
> >
> > *If $z \leq z^*$ then set $\Delta^* = \Delta$, $\tau^* = \tau$, and $z^* = z$.*
> >
> > *Let m be the smallest value for which $\sum_k \Delta_{mk} = 0$. If no such m exists then return (Δ^*, τ^*, z^*) and exit.*
> >
> > *If $m = 0$ then set $t = h_f$. Else set t to be the first interval time after the $(m-1)^{th}$ configuration change time.*
> >
> > *For each configuration k:*
> >
> > > *Set $\Delta_{mk} = 1$.*
> > >
> > > *For each interval time t' from t to h_p:*
> > >
> > > > *Set $\tau_{mk} = t'$.*
> > > >
> > > > *If τ is a feasible set of configuration change times then recursively call TRCM_Search($\Delta, \tau, \Delta^*, \tau^*, z^*$) and set (Δ^*, τ^*, z^*) to the returned values.*
> > >
> > > *Set $\Delta_{mk} = \tau_{mk} = 0$.*
> >
> > *Return (Δ^*, τ^*, z^*) and exit.*

The above algorithm will return the optimal set of configuration changes over the planning period relative to objective function $\frac{1}{N} \sum_{i=1}^{N} \tilde{C}(F_i, \pi, \tau)$ subject to the constraints of the original TRCM problem over the discretized state space. In operation, the algorithm runs at a periodic rate such that there is significant overlap in the planning windows from one iteration to the next, each iteration beginning with the prior best solution.

3.6 Evaluation

3.6.1 Runway Usage Example

Memphis International Airport (KMEM) frequently operates in one of two equivalent runway configurations: arriving on runways 18R/36L and 18L/36R and departing on runways 18C/36C and 18R/36L. Selection of the North Flow or South Flow configuration depends on the wind and traffic characteristics. KMEM serves both a large cargo operation and a passenger operation with separated ramp areas. Which ramp area the majority of the traffic is taxiing from/to is considered when selecting the runway configuration to reduce taxi distances.

To avoid departures crossing in the air, KMEM uses a rigid departure runway assignment rule based on the flight's departure fix. All flights headed to the west are assigned to runway 18R/36L, while all departures headed to the east are assigned to runway 18L/36R. Most

mornings, between 1300Z and 1500Z, a cluster of flights depart to the west, which requires them to be assigned to runway 18R/36L. This departure push overlaps a period of steady arrivals. The KMEM procedures allow the TRACON to assign arrivals to either arrival runway. Currently, most TRACON controllers do not consider the departure traffic when assigning arrival runways. To minimize flight time and their own workload, controllers assign arrival flights to the runway closest to the flight's arrival fix. Occasionally during light traffic, controllers will consider where the aircraft will park on the airport. During this period of time, many of the arrivals are from the west and are assigned to runway 18R/36L. The arrivals are given priority and the departures form a long queue at 18R/36L waiting for infrequent, random gaps in the arrivals sufficient for a departure, while runways 18L/36R and 18C/36C are underutilized.

When KMEM is in one of these runway configurations, TRCM advises how the arrival runways should be used. Three runway usage policies are defined:

- Assign arrivals to the runway closest to their arrival fixes

- Assign arrivals to the runway that minimizes their combined flight and taxi times

- Use 18R/36L as an overflow arrival runway only after 18L/36R is full

While not explicitly defined in the KMEM Standard Operating Procedures, the third policy is similar to how KJFK operates; KJFK identifies a primary arrival runway and an overflow arrival runway in each of its two-arrival-runway configurations. Note that the second policy requires TRCM to model each flight all the way to its parking gate for each possible runway assignment to determine which runway to select. The third policy requires TRCM to model all of the traffic to know when delays would start to occur on the primary runway such that the overflow runway should begin to be used. The TRCM output specifies which policy should be used and the period of time for which it should be used, the format of which is consistent with current controller decisions; no procedural changes are required.

Tactical Runway Configuration Management was tested using 62 flights that landed or departed during 1400–1530Z on September 9, 2010. Thirty of the 43 departures were departing to the west; 10 of 19 arrivals approached from the west. Airborne and surface surveillance data was used to determine the actual controller policy, which was "assign arrival runway based on direction of flight" for the entire time period. Tactical Runway Configuration Management advised using 18L as the primary arrival runway for the entire time period, sending arrivals to 18R only if 18L was being fully used. The TRCM and actual controller runway usage policies were simulated and the metrics compared. The simulation considered flying time, runway delay, and taxi time. The TRCM-selected policy reduced the total delay for arrivals and departures to 22.6 minutes from 45.0 minutes under the controller's policy. Under the TRCM policy, the arrivals experienced slightly more delay than under the controller's actual policy due to a longer flying distance and slight runway delay. However, departures experienced substantially smaller delays on average. While only for a single traffic sample, this example demonstrates the significant benefit possible with airport configuration management.

3.6.2 Runway Assignment Example

Orlando International Airport KMCO) has four parallel runways oriented north-south. From west to east, they are 36L/18R, 36R/18L, 35L/17R, and 35R/17L. The terminals are between the

36/18 pair and the 35/17 pair and consist of four separate terminal buildings. In south operation, arrivals use the outer runways 36L and 35R, and departures use the inner runways 36R and 35L. In north operation, during "severe clear" weather (basically, few or no clouds and unrestricted visibility), arrivals land on runways 36L and 35R (the outboard runways); runways 36R and 35L are used for departures.

The airport operates in two distinct modes. During heavy traffic, departures are assigned to runways based on direction of flight to avoid airborne conflicts; no coordination is required between the two departure runways. This mode is called "taxi for direction [of flight]." During light traffic, the "taxi for convenience" mode allows departures to be assigned to the departure runway closest to the aircraft's parking gate regardless of the direction of flight. In this mode, the local controllers[9] must coordinate releasing aircraft from the two runways to avoid conflicts in the air, and comply with the wake vortex separation requirements, because the flight paths may cross or merge. The delay at the runway to implement this coordination is small; since traffic is light, departures queues do not accumulate.

The SOPs indicate that the supervisor or controller in charge should select which procedure to use. As traffic level increases, there is a cost to using "taxi for convenience" because the small runway delays required to coordinate the runways begin to also delay subsequent flights as a queue forms. However, controllers often switch to "taxi for direction" well before the true efficiency crossover point. Some controllers prefer "taxi for direction" at all times to reduce workload. Some controllers "taxi for convenience" excessively, causing flights to be delayed more than they would under the "taxi for direction" procedure; TRCM can advise when each runway assignment procedure should be used.

Table 5 shows the taxi distance from each terminal to each departure runway. Assuming a nominal taxi speed of 15 knots, each 1000 ft. of taxi takes about 45 seconds. Therefore, runway 35L is more than seven minutes farther than runway 36R from terminal 1. The difference in flight distance is relatively small in terms of time. The departure runways are separated by 8500 ft, which is only about 30 seconds of flying time.

Table 5. Approximate Taxi Distances from Ramps to Departure Runways

	Runway 36R	**Runway 35L**
Ramp 1 (north–west)	8300 ft	18,200 ft
Ramp 2 (north–east)	14,600 ft	10,200 ft
Ramp 3 (south–west)	4500 ft	12,100 ft
Ramp 4 (south–east)	9500 ft	7100 ft

Thirty-eight departures from 1055Z to 1155Z on October 13, 2010 were studied (taken from

---

[9] The "local" controller is responsible for traffic using the runways and in the immediate vicinity of the airport.

actual traffic data). Eleven of 17 flights from the west terminals and 10 of 21 flights from the east terminals departed to the east. The airport operated in the North Flow configuration with departures using runways 36R and 35L. Based on analysis of airport surface surveillance data, the actual operations were "taxi for direction" throughout the time period. Tactical Runway Configuration Management considered the two runway assignment policies, including the possibility of changing the policy during the time period. The TRCM algorithm advised that "taxi for convenience" should be used for the entire hour. The policies used historically and advised by TRCM were simulated and metrics compared.

Table 6 summarizes the simulation results. "Taxi for convenience" results in slightly longer runway delays because of the need to wait for traffic on the other runway that will cross or require merging. However, "taxi for convenience" produces a significantly smaller delay overall. This delay reduction comes primarily from shorter taxi times; the flight time to the fix from each runway is nearly the same. This example illustrates the potential of TRCM to provide significant benefit within existing procedures as well as the importance of measuring all phases of aircraft movement between parking gates and departure/arrival fixes. Future work will expand TRCM to consider fuel burn, workload considerations due to required coordination, and other metrics in addition to aircraft transit time.

Table 6. Tactical Runway Configuration Management Results at Orlando International Airport

	Taxi for Direction (Actual Controller Decision)	Taxi for Convenience (TRCM Output)
Total delay	41.4 min	16.5 min
Average runway delay (per flight)	24 sec	26 sec

3.6.3 Runway Configuration Examples

Tactical Runway Configuration Management is also capable of planning the runway configuration and when to change it. To illustrate, a one-hour period of traffic from KJFK on March 19, 2009 was studied. Forty departures and 24 arrivals operated during the time period from 2:30 to 3:30 PM local time, which contained a wind shift at 3:00 PM that exceeded the tailwind threshold for runways 22L and 22R.

The actual runway configuration changed from runway 13L, 22L | 13R to 4R | 4L, 31L at 3:00 PM.[10] The TRCM algorithm selected the same initial and second runway configurations and advised the change to be made at 2:51 PM. This example supports that controllers are currently able to select runway configurations and TRCM is able to replicate these selections. In addition, TRCM planned which flights would be the last to use the first configuration and first to use the new configuration.

---

[10] The data source used to provide the actual runway configuration was limited to 15-minute resolution.

Tactical Runway Configuration Management does not always select the same runway configurations as were historically used. On June 24, 2009, according to ASPM data, KJFK changed from runway configuration 22L, 22R | 22R to 22L | 22R, 31L at 3:00 PM as demand shifted from heavier arrivals to heavier departures. For this traffic scenario, TRCM was seeded with the actual initial configuration. The TRCM algorithm advised changing the configuration to 13L, 22L | 13R immediately and then to 4R | 4L, 31L at 3:37 PM. Both runway configuration schedules were simulated for 79 flights between 3:00 and 4:00 PM and the metrics compared. The TRCM configuration plan achieved 245 minutes of total delay, as opposed to 360 minutes of delay for the runway configurations actually used. TRCM's initial configuration change provides independent arrival and departure runways, rather than a mixed-use runway. The later change to a configuration that favors departures reduced arrival delays before departure queues started to form. This example, while suggesting that planning runway configurations and change times may provide benefit, suggests that shadow-mode testing is needed to discuss with controllers why they would make certain decisions, possibly leading to enhancement to TRCM to ensure operational acceptance.

3.7   TRCM Benefit Mechanisms

In addition to the examples already described, the TRCM concept provides or enables a large number of operational improvements compared to current operations, as summarized in Table 7.

Table 7. Tactical Runway Configuration Management Benefit Mechanisms

Current Operations	Impact of TRCM
Controllers currently change airport configuration reactively (e.g., after observing a departure queue form).	Airport configuration changes are planned in advance, considering both traffic demand and weather forecasts. Scheduling multiple future configuration changes supports other traffic management systems.
Controllers sometimes have difficulty planning the last aircraft on the old configuration and the first aircraft on the new configuration. Errors result in either aircraft needing to be rerouted to a different runway or runways being idle longer than necessary.	TRCM uses accurate estimated time of arrival predictions to plan which aircraft will be the last to use each runway in the old configuration and the first to use the new configuration.
Airport configurations are changed infrequently due to high manual workload and lost capacity during the change.	Automation helps to plan and coordinate configuration changes, enabling more frequent changes. TRCM considers the cost (i.e., lost capacity) of changing the configuration.
Airport configurations must handle a wide range of conditions.	New airport configurations may be defined for specific situations and applied tactically for short periods of time.

Table 7. Tactical Runway Configuration Management Benefit Mechanisms Continued

Current Operations	Impact of TRCM
Runway configuration is the primary decision.	Airport configuration encompasses runway configuration and other decisions about how the airport operates, such as standard taxi plan, airspace configuration, and runway assignment procedures.
Manual coordination of resources shared within a metroplex required. Procedures used to decouple airports.	TRCM plans metroplex configuration including airport configuration for each airport. Resources are dynamically assigned to different airports to match capacity with demand and provide highest efficiency for highest demand at that time.
Rigid procedures result in a long departure queue at one runway while another runway is underutilized (and holding at one arrival fix while other fixes are underutilized). Flexibility available in current procedures is not fully used.	TRCM selects between procedures currently allowed at that airport to balance runways and avoid surface congestion and other sources of inefficiency.
Lack of information and DSTs result in controllers making airport configuration decisions based on a single or limited objective(s) (e.g., arrival capacity).	Multi-objective optimization considers the effect of airport configuration on runway delays as well as surface congestion and airspace efficiency.
Operating point (i.e., combination of arrival and departure rates) is not coordinated between the TRACON and ATCT. TRACON gives priority to arrivals with limited awareness of departure delays or surface congestion. ATCT departs aircraft opportunistically with poor predictability of departure rate.	TRCM communicates optimal arrival/departure tradeoff. Frequent operating point changes allow airport resources to be dynamically matched to time-varying demands.
Controllers perceive additional flight time as making an additional taxi time to a runway with a shorter queue not beneficial.	Automation determines the runway assignment policy that optimizes over all of the factors that influence airport and individual flight efficiency.

3.8   Summary of the TRCM Concept and Algorithm Development

NASA's TRCM research to date has succeeded in advancing the recognition within the research community that the problem of efficiently scheduling the airport configuration is broader than planning the runway configuration, and that the near-term potential benefit for airport configuration planning is substantial, and the future need is even larger. An algorithm that implements the TRCM concept producing optimal airport configuration schedules has been developed and tested through fast-time simulations. An in-situ evaluation of this algorithm (site adapted) has been conducted at KMEM by the FAA in early 2014. The data from this evaluation is currently being analyzed. To complement the decision support tool, a conceptual interface has been developed.

The TRCM concept calls for automation to plan runway configuration at an airport as well as other airport configuration decisions, such as runway assignment policies, runway usage procedures, and airspace allocation within a metroplex, depending on the decisions that must be made at the particular airport. The algorithmic approach uses common software with local adaptation data to accommodate existing variations between airports while being flexible to support new decisions as required under NextGen concepts. Moreover, the approach outputs operationally meaningful advisories; controllers do not need to translate the outputs into the actual decisions to be made.

The algorithm selects the elements of airport configuration by first considering forecasts for weather and other conditions to determine feasible choices. The algorithm then uses fast-time modeling to predict how the forecast demand would be served by the runways and other limited resources under each possible configuration schedule to identify which configuration schedule will maximize the airport and terminal area efficiency. The output includes the sequence of airport configurations and the times at which the configuration should be changed. Different elements of airport configuration are allowed to change at different maximum frequencies. The algorithm's objective function currently considers overall delays for arrivals to reach their parking gates and departures to reach enroute airspace, not just runway delays. The cost for changing the configuration is modeled through reduced capacity during the change and varies for different configuration changes. Preferences for certain runway configurations that capture aspects of the decision not currently modeled, such as the noise footprint of resulting flight paths, can also be considered by the algorithm. Future enhancements will allow the objective function to consider additional factors such as fuel efficiency, environmental impact, and operator preference in addition to delays. The algorithm simultaneously optimizes runway configuration and the other airport configuration decisions since selecting the runway configuration first, assuming the default runway usage policy, could result in an overall solution that is sub-optimal. The algorithm currently runs on a standard laptop computer sufficiently fast to be used within a real-time decision-support system and does not require any expensive software licenses to solve the optimization problem. Heuristic techniques are used to reduce computation time, which could be relaxed with more powerful computational resources.

Results from evaluations using real-world examples and data have shown that significant benefits are possible by using current procedures more efficiently. Examples using several airports demonstrated that the proposed automation could have achieved valuable delay reductions as compared to actual historical operations. Allowing changes to current procedures, for instance at airports that currently do not provide runway balancing control through runway assignment policies by reducing workload concerns through decision support, would deliver larger benefits. In addition, many other automation systems require the airport configuration that will be used as input data; the described algorithm could be used to provide that information.

Continued research is focusing on extending the airport configuration planning concept and algorithm to metroplex and NextGen environments. The dependencies between airports within a metroplex create a requirement to simultaneously consider the airport configurations at each interdependent airport in order to minimize airport interactions and allocate resources between the airports to best achieve efficiency across the entire metroplex. Tactical Runway Configuration Management will be able to advise what airport and airspace configuration would be more optimal to use.

Additional areas of study include TRCM operating in possible NextGen environments; identifying new airport configuration decisions that would need to be made, and how effectively TRCM can advise these decisions; and the additional benefit possible if procedures related to airport configuration decisions currently available at some airports were made available at additional airports.

NASA has transferred the developed software to the FAA's Surface Trajectory-Based Operations project, which is developing and field-testing various advanced airport automation concepts for integration into current and future ATM systems.

4.0 Strategic Runway Configuration Management (SRCM)

4.1 SRCM Overview

At the beginning of the SORM research effort, SRCM was an entirely un-studied area—the interaction between TFM and airport traffic management. Since that time, NASA has begun other research efforts in this area. The TFM process currently only considers airport arrival capacities when planning TMIs and does not consider the interaction between capacities at different airports (outside of metroplexes).

Although controllers and traffic managers at and near an airport only need to plan the schedule of airport configurations 90 minutes or less into the future, traffic management specialists in the ATCSCC and traffic management coordinators in the ARTCC require predictions of the airport capacity several hours in advance. At this time interval, these traffic management decision makers do not need to know the actual airport configuration. The essential information is the resulting capacities (for the combined terminal environment and airport surface, not just runway capacities) for use in planning strategic TMIs.[11] Further, system users, in particular the airlines, would benefit significantly from a capability that would reliably predict runway configurations in the planning of resources.

Strategic Runway Configuration Management will be a piece of automation (i.e., software implementing a set of algorithms) residing within some larger ATM system. The SRCM capability could be implemented with TRCM in an airport-based system such as TFDM or within a TFM System (TFMS). Strategic Runway Configuration Management will receive a variety of information from other automation systems such as forecast traffic demand, forecast weather at the airport, descriptions of the airport's available configurations, and planned TMIs. This is expected to be the same data used by TRCM. These inputs may be stochastic.

The outputs of SRCM will be displayed to traffic management specialists in the ATCSCC through the displays of their existing TFM automation systems. In addition, SRCM outputs may be displayed to traffic management coordinators in ARTCC TMUs as well as the TRACON and tower. The role of the traffic management specialists and TMCs will not change as a result of SRCM. Each user will continue to make traffic management decisions to balance demand with airport arrival capacity.

At single airports, a separate SRCM instance would operate independently for each airport, planning the configuration schedule and converting this plan to a capacity schedule. In a metroplex, a single SRCM would provide a coordinated plan for the capacities at each airport. For example, if an airport in a metroplex environment has experienced significant delays due to weather, consideration would be given to this airport to maximize capacity, possibly at the expense of other airports in close proximity. For both metroplexes and single airports, NAS priorities would be considered in determining configurations and capacities for each airport.

---

[11] At one hour in advance, knowledge of the specific configuration may be used to select the specific TMIs, with consideration for the operational challenges associated with each configuration. For example, some configurations may be more adaptable to weather uncertainty and, therefore, more reliably provide the forecast capacity. These factors are included in the TMI decision making process, albeit in a qualitative manner.

Strategic Runway Configuration Management is distinct from TRCM due to the different characteristics of the input data quality and the requirements on the outputs. Strategic Runway Configuration Management must be capable of operating with traffic demand and weather forecasts that include considerably more uncertainty than that which TRCM uses. Strategic Runway Configuration Management operates independently of both TRCM and CADRS due to the time horizons involved.

The algorithmic approach used for SRCM will compare aggregate demand and capacity, within the constraints imposed by weather and other external factors. In contrast, TRCM models individual flights. Consequently, SRCM may employ a more robust algorithmic approach, explicitly considering the possible outcomes due to the uncertainty in the input data.

The available weather forecasts in the near-term may limit the resolution with which SRCM may plan the configuration schedule. For example, if wind forecasts are only available at 15-minute intervals, then SRCM will have no information on which to base configuration change times other than at those intervals for which the wind is forecast. It is anticipated that higher time resolution in forecasts will be available in the future.

If stochastic weather and traffic demand forecasts are available, SRCM will use these. In addition to stochastic inputs, the SRCM outputs will be stochastic and then a method for converting to a deterministic capacity prediction will be provided to support TFM uses that are not ready to consider uncertainty information.

4.2   SRCM Algorithm

The algorithm developed for the SRCM capability is less mature than that developed for TRCM. This is because of the uncertainties involved with longer term planning. The current version of the SRCM algorithm considers forecast demand and forecast weather, as well as known air traffic management constraints such as navigation aids that are out of service, and evaluates the predicted capacity for each possible airport configuration. This capability produces a forecast for the airport capacity (both arrival and departure) that is balanced to match the demand. Due to the time horizon over which SRCM must operate, SRCM must consider the uncertainty in the demand and weather forecasts.

The SRCM algorithm is a "queuing model" in that it applies airport capacity models and tracks the number of aircraft entering the arrival and departure queues and being served by the airport in 15-minute epochs. The algorithm does not model the continuous, four-dimensional movement of each aircraft. The current configuration is assumed to be known.

5.0 Combined Arrival/Departure Runway Scheduling (CADRS)

5.1 CADRS Overview

Significant research on planning how groups of flights should be managed through runway assignment and sequencing to use runways efficiently is ongoing at NASA, from both an airspace perspective and an airport surface perspective. Capabilities under CADRS are not envisioned as a competing system but rather a set of requirements for the integration of airborne and surface runway planning. The intent is to ensure runway usage optimizes efficiency from a broader perspective than just the arrivals, departures, or runway delays.

Combined Arrival/Departure Runway Scheduling is the SORM concept element that is intended to efficiently manage ground traffic, increasing throughput while meeting arrival and departure schedules. Runway assignment is a key output of CADRS. This capability balances local airport goals such as demand for runways and minimizing taxi distance with traffic flow management goals such as complying with imposed restrictions. It also applies automation to coordinate runway usage more effectively than can be done manually by controllers in today's environment.

Combined Arrival/Departure Runway Scheduling is a concept to enable efficient tactical planning of runway operations for individual flights. This element is a key component of the overall SORM concept. However, numerous other past and current research initiatives have studied the problem of planning individual aircraft operations on runways. Therefore, the SORM NRA project only studied more novel aspects of the CADRS requirements, primarily how airborne planning (typically arrival) and surface planning (typically departure) may be integrated and how to expand the scope over which runway operations are optimized, from considering only runway-based metrics to considering the efficiency of flights along their full trajectories between transition fixes and parking gates.

The objective of CADRS is to both ensure separate arrival and departure schedulers produce coordinated schedules and enable communication of constraints and efficiencies so that the arrival and departure solutions are globally optimal. As such, CADRS is not necessarily a system itself, but rather a set of requirements on the runway schedulers that are included within the CADRS grouping. Combined Arrival/Departure Runway Scheduling assigns individual flights to runways and sequences (or schedules) flights on each runway to maximize the efficiency of the airport or metroplex, in a way that is resilient to uncertainty. As a result, an optimized schedule will be presented to the tower and TRACON controllers. Note that the schedule will be a recommendation to controllers and traffic flow managers.

Combined Arrival/Departure Runway Scheduling is a tactical tool, determining the runway assignments and sequence or schedule for individual flights over a time horizon of less than one hour. Tactical Runway Configuration Management provides tactical airport configuration planning over a time horizon slightly longer than the CADRS time horizon, while SRCM predicts airport capacity over a longer, strategic time scale.

The simplest approach for TRCM and CADRS interaction is for CADRS to use TRCM's airport configuration schedule; no information is provided from CADRS to TRCM. In this way, TRCM and CADRS may operate together, and each may operate independently. Tactical Runway Configuration Management may plan the airport configuration without CADRS being

responsible for runway scheduling. Similarly, CADRS requires knowledge of the airport configuration to manage runway schedules, but the airport configurations may be planned manually as done in current operations rather than TRCM.

An important design question is whether CADRS is limited to solving the runway scheduling problem within the constraint of the airport configuration schedule specified by TRCM. Current operations allow for runway assignments that are exceptions to the stated runway configuration to improve efficiency or respond to un-common and real-time situations. To ensure the airport (or metroplex) operates as efficiently with CADRS as under current procedures, the CADRS algorithm will need to search for and allow some exceptions to the TRCM-selected policies.

5.2   CADRS Algorithm

Despite sharing the runways and other resources, automation that plans arrival runway operations (i.e., assigns runways to arrivals, sequences arrivals, and spaces consecutive arrivals) and automation that plans departure runway operations are expected to be separate systems for the foreseeable future. Therefore, CADRS can be described as adding an arbitrator between the departure planner that produces a runway schedule that is optimal from the perspective of the airport surface and the arrival planner that produces a runway schedule that is optimal from the terminal-area perspective. In addition, TFM produces schedule constraints that must be considered, although they should already have been considered by the individual arrival and departure planners. Three possible CADRS approaches are global optimization, arbitration, and allocation.

The global optimization approach is to merge the separate arrival and departure planner formulations for the runway scheduling problem into a single, combined formulation and solve the new, larger problem. This approach is essentially a "one time" arbitration between the individual systems, as cost function elements are assigned relative weights in the combined formulation. The merging could occur in the problem formulation or with a solution method that finds the solution that optimizes a weighted combination of the two separate problems.

A second algorithmic approach is to build an arbitrator that interacts with separate arrival and departure planners. The arbitrator would receive proposed runway plans from each planner and then send some information to one of the planners to provide a new schedule (and possibly some supporting information like a cost-sensitivity) that satisfies some constraints; the arbitrator repeats this process with the other planner and iterates until the separate, myopic arrival and departure solutions have converged or, at least, are compatible.

The third approach is to build an allocation system that interacts with separate arrival and departure planners. Allocation may be considered to be a sub-class of arbitration. An allocation system assigns the shared resources to the two separate planners so as to decouple those systems. Decoupled from one another, whatever independent solutions the two runway schedulers determine within the bounds specified by the allocation system will be compatible with each other. In this situation, the allocation would need to be for both the runways and flights. For example, all arrivals could be assigned to the airborne planner and all departures to the surface planner and then runways or runway capacities assigned to each planner for periods of time.

Each approach has advantages and disadvantages. A primary weakness of the global optimization approach is that once merged, future changes to the arrival and departure planning

logic may require re-merging and, therefore, this approach reduces future flexibility. This drawback is somewhat reduced by merging at the solution rather than at the problem formulation, but this itself reduces the flexibility in merging the problems.

One disadvantage of the arbitration approach is that convergence is not likely to be guaranteed and, therefore, some executive would be required to make a final decision. In addition, the arbitration method could depend on details of the separate runway scheduling systems, again reducing future flexibility. The allocation method seems feasible when the runway plans are used to manage traffic, but controllers provide final de-confliction between flights. Trajectory-based application of this approach would be highly susceptible to uncertainty. In terms of performance, the global optimization approach would have the highest performance. Allocation is likely to be the lowest performance approach.

A variety of different arbitration techniques are feasible. For example, the "loosely coupled scheduler" approach employed by Multi-center Traffic Management Advisor (McTMA) motivates a "flight type" arbitrator approach. In McTMA, all flights are treated as interchangeable, and rate profiles are passed between schedulers responsible for different points through the metering geometry. The separate airborne and surface schedulers might pass schedules of slots back and forth. Each scheduler in McTMA calculates a schedule of flights, but then converts that to a "rate profile" (basically an allocation of slots) that is passed to the next up-stream scheduler, which is free to assign any flights into those slots (not necessarily the same as the downstream scheduler had predicted). The surface would calculate a runway schedule and pass the "abstracted" arrival slots to the airborne scheduler, as well as any flight specific restrictions on arrivals. The arrival scheduler, in turn, would calculate a runway schedule using the received restrictions on arrival capacity and estimates of departure demand, and provide abstracted departure slots to the surface scheduler, as well as any flight-specific departure restrictions. The surface scheduler would re-calculate a runway schedule using the received departure capacity and estimates of arrival demand. Similar to McTMA, the solutions are expected to converge (and adjust as new information becomes available) through iteration.

As the number of different types of flights increases, the approach of abstracting them into slots rapidly breaks down since the availability of a flight of the correct aircraft type may be limited. Unfortunately, the runway schedulers will likely need to consider at least some flights as unique. For example, two Boeing 757 arrivals that will cross the same corner post and land on the same runway at a given airport may be equivalent from an airborne scheduling perspective. However, one of these flights may have an occupied arrival gate while the other is late and a priority for the flight operator. From the perspective of the surface scheduler, there is a clear preference for the order of these flights such that they may not be able to be treated as equivalent.

5.2.1 Factors that Affect Runway Assignment and Sequencing/Scheduling

This section lists and discusses the factors that affect the runway scheduling decision, which includes runway assignment, sequencing, and possibly specific scheduling of individual aircraft.

Table 8. Factors that Affect Runway Usage

Factor	Description
Wind	*Runway assignment:* Wind generally does not affect runway assignment.
	Runway sequence: Wind may affect the sequence of two flights if they are merging from different directions such that the wind slows the ground speed of one aircraft while increasing the ground speed of the other aircraft.
	Runway time (spacing): Wind can affect runway times for arrivals by increasing the average inter-aircraft spacing. When the aircraft on the final approach leg gain or lose ground speed relative to aircraft on the downwind or base legs, aircraft may exhibit increased compression or increasing spacing. Controller uncertainty about aircraft ground speed due to variability between aircraft requires additional "buffer" to ensure necessary separation is maintained. Wind gusts can have a similar effect.
Visibility and ceiling	*Runway assignment:* Based on weather minimums for different instrument approach procedures (IAPs), runway availability may be limited.
	Runway sequence: N/A
	Runway time (spacing): Ceiling and visibility dictates whether or not visual approach procedures may be used[12], affecting the feasible arrival rate and, therefore, runway scheduling (i.e., times). All of the factors that affect arrival/departure rates affect runway times (but not necessarily sequence or runway assignments).

---

[12] Weather minima required for the issuance of a visual approach is 1000' ceiling and 3 miles visibility. In practice visual approaches are not used unless the ceiling and visibility is significantly in excess of the allowable minima.

Table 8. Factors that Affect Runway Usage Continued

Factor	Description
Airport configuration	*Runway assignment:* The runway configuration (i.e., the set of runways designated to be the primary runways to be used) affects runway assignment. The default runway assignment rules, which may be part of the airport configuration, affect runway assignment. *Runway sequence:* N/A *Runway time (spacing):* Established procedures affect the required spacing between flights.
Noise mitigation rules	*Runway assignment:* Noise mitigation rules affect runway assignment, such as precluding jet aircraft from certain runways during certain designated periods. *Runway sequence:* N/A *Runway time (spacing):* N/A
Traffic demand level	*Runway assignment:* When the number of arrivals and departures is low, aircraft will often be assigned to the runway with the shortest taxi time. When the demand is high, runway assignment will be based on direction of flight to avoid crossing flight paths. Automation to plan conflict-free airborne trajectories and precisely plan/control arrival time at the runways for departures have significant potential to increase the ability to use non-default runways to better balance runways and reduce taxi times. *Runway sequence:* The runway sequence will typically be close to FCFS when demand is lower and may be optimized (non-FCFS) to maximize capacity when demand is high. *Runway time (spacing):* Controllers will often expend additional effort to fully use runway capacity when demand is high.

Table 8. Factors that Affect Runway Usage Continued

Factor	Description
Aircraft type	*Runway assignment:* Aircraft type affects which runways are feasible of use; some runways may not have adequate length for some aircraft; some runways may not be available due to noise restrictions for jet aircraft. *Runway sequence:* Aircraft type affects sequencing flights on a runway. Aircraft of similar weight category will be grouped, to the extent possible, to maximize runway capacity. *Runway time (spacing):* The weight category of adjacent flights on a runway affects the necessary spacing between those flights; this is the case for not only a single runway but also closely spaced parallel runways and intersecting runways
Aircraft capabilities	*Runway assignment:* Aircraft capabilities, such as ILS or RNP level, affect which runways may be assigned. *Runway sequence:* N/A *Runway time (spacing):* Aircraft capability, such as the ability to self-separate from a leading aircraft, may affect spacing at the runway.
Arrival / departure fixes	*Runway assignment:* The direction from which arrivals approach the airport, or initial direction of flight for departures, affects runway assignment. *Runway sequence:* The initial direction of flight for departures affects sequence for consecutive departing aircraft since less separation is required if divergent headings (15 deg) will be flown immediately after departure. *Runway time (spacing):* Spacing for consecutive departing aircraft cannot be reduced (as in the divergent heading case) if aircraft are flying the same lateral path and altitude separation cannot be applied.
TFM restrictions	Runway assignment: N/A *Runway sequence:* The presence of a TFM restriction, such as MIT on all departures to a destination airport, may affect sequencing to ensure consecutive flights subject to the restriction are sufficiently separated. *Runway time (spacing):* The TFM restriction affects the spacing of flights on a runway and, possibly, on different runways.

Table 8. Factors that Affect Runway Usage Continued

Factor	Description
Route	*Runway assignment:* N/A *Runway sequence:* Flights on same route (air or surface) will remain in the same order. Flights that must merge may be re-ordered relative to their un-impeded order on the first common segment. *Runway time (Spacing):* Spacing for consecutive departing aircraft cannot be reduced (as in the divergent heading case) if aircraft are flying the same lateral path and altitude separation cannot be applied.
Earliest time at runway	*Runway assignment:* When a flight enters the terminal area or is ready to taxi or may affect runway assignment. This requires known flying time between fix and each runway for arrivals and taxi time between gate and each runway for departures. *Runway sequence:* When each flight will be ready to use a runway affects the runway sequence. *Runway time (spacing):* N/A
Flying time between fix and each feasible runway	*Runway assignment:* The flying time (after takeoff) between each runway and the departure fix affects runway assignment for departures. *Runway sequence:* N/A *Runway time (spacing):* N/A
Taxi time between parking gate and each feasible runway	*Runway assignment:* The taxi time (after landing) between each runway and the parking gate can affect runway assignment for arrivals. *Runway sequence:* N/A *Runway time (spacing):* N/A
Ease with which flight may be delayed	*Runway assignment:* N/A *Runway sequence:* How easily a flight may be delayed (e.g., measured in terms of a cost metric) may affect the runway sequence. *Runway time (spacing):* N/A

6.0 Information Requirements

This section discusses the information input to and output from SORM. As part of identifying the information exchange, the information providers and users of SORM information are defined.

6.1   SORM Stakeholders

Table 9 lists the SORM stakeholders, the ATC positions or automation systems that are currently involved in making or acting on SORM decisions, or will be in the future, and describes the stakeholder's role in interacting with the SORM decisions. The SORM information stakeholders —the positions or automation systems that will provide and/or receive information to/from SORM—and what information they receive or provide are described in the following subsections.

Table 9. System-Oriented Runway Management Stakeholders

Stakeholder	RCM	CADRS
ATCSCC TFM Specialist	*Current:* Uses airport configuration prediction to forecast airport arrival capacity, which is an input to TFM decisions. *Future:* In addition to current use, will use planned airport configuration schedule to forecast airport departure capacity. RCM may output capacity forecast directly rather than configuration schedule; capacity forecast may be stochastic. Airport configuration will be planned in coordination with configurations at other airports/metroplexes and TFM decisions.	*Current:* None (i.e., in the current environment, does not use runway assignments or planned flight sequence/times on the runways). *Future:* None (i.e., in the SORM / NextGen environment, uses runway assignments or planned flight sequence/times on the runways).
ATCSCC Automation	*Current:* TFMS (formerly ETMS) requires airport arrival capacity estimates. *Future:* TFMS will be required to support the future role described above for the ATCSCC Specialist	*Current:* None *Future:* None

Table 9. System-Oriented Runway Management Stakeholders Continued

Stakeholder	RCM	CADRS
ARTCC TMC	*Current:* Uses airport configuration prediction to forecast airport arrival capacity, which is an input to regional TFM decisions. Shorter time horizon than ATCSCC Specialist. *Future:* No change as current. May also consider departure capacity when selecting departure TMIs.	*Current:* Initiates formal "delay" procedures including "ground stops" and assignment of departure release times for individual flights EDCTs. *Future:* ASDO/CADRS departure release times will comply with TFM restriction, which will continue to be manually selected by the TMC. Necessary TMIs will be incorporated into 4D trajectories such that the TMC will no longer need to manually apply TFM restrictions on individual flights.
ARTCC TMU Automation	*Current:* TFMS requires configuration to predict capacity and flying times within the terminal airspace. Configuration changes can also require automation changes and affect Standard Terminal Arrival Route assignments in adjacent ARTCCs. *Future:* Handle stochastic capacity forecasts.	*Current:* Uses current automation to help make TFM decisions that affect runway schedule; TMA used to meter arrivals. *Future:* Automation such as TMA/TBFM or DFM may select departure release times automatically. TFMS could use departure schedule to improve sector entry time predictions.
ARTCC Area Supervisor	*Current:* Uses planned configuration changes for staffing decisions. *Future:* Same.	*Current:* None *Future:* None

48

Table 9. System-Oriented Runway Management Stakeholders Continued

Stakeholder	RCM	CADRS
ARTCC Sector Controller	*Current:* En route automation modernization (ERAM, formerly Host) requires configuration to configure controller's scopes and process flight plans properly. Configuration may be required to plan arrival aircraft altitude to enter TRACON at correct altitude ("short" side vs. "long" side). Need to know last arrival prior to a configuration change to plan delay absorption strategy. *Future:* Same	*Current:* None *Future:* None
TRACON TMC	*Current:* None *Future:* RCM would be available for TMC.	*Current:* None *Future:* ASDO would plan arrival runway assignments and sequence/schedule.
TRACON Supervisor	*Current:* Use configuration changes to make staffing decisions. *Future:* Same	*Current:* None *Future:* None
TRACON Arrival Controller	*Current:* Configuration used to manually make runway assignments and other ATC decisions. Need to know the last arrival for the prior configuration from each fix. *Future:* More frequent configuration changes may require CADRS to maintain acceptable workload.	*Current:* Manually make runway assignment and sequence decisions. *Future:* CADRS provides runway assignment and sequence/schedule.

Table 9. System-Oriented Runway Management Stakeholders Continued

Stakeholder	RCM	CADRS
TRACON Arrival Controller's Automation	*Current:* Standard Terminal Automation Replacement System (STARS) and Automated Radar Terminal System (ARTS) require airport configuration to configure controller's displays properly. *Future:* Same	*Current:* Runway assignment manually entered. *Future:* Runway assignment received from CADRS. Sequence/schedule at runway or merge points may be received from CADRS.
TRACON Departure Controller	*Current:* Uses knowledge of configuration to configure automation and know what to expect. *Future:* CADRS will provide advanced knowledge of departures; configuration may not be required.	*Current:* No responsibility for runway assignment or scheduling. Uses some information about departure sequence for planning. *Future:* Will use CADRS departure runway assignment and sequence/schedule for planning.
TRACON Departure Controller's Automation	*Current:* STARS and ARTS require airport configuration to configure controller's scopes properly. *Future:* Same	*Current:* None *Future:* CADRS departure list will be available through STARS/ARTS.
ATCT TMC	*Current:* Makes or is involved in selecting the airport configuration. *Future:* Same as current.	*Current:* May manually recommend runway assignments or sequences. *Future:* When CADRS is being used, no role.
ATCT TMC's Automation	*Current:* Automation, such as TMA, is used to visualize traffic demand; weather data is obtained from various sources. *Future:* TFDM will provide the RCM-planned configuration schedule.	*Current:* Paper flight strips are used to visualize demand for various resources from which suggestions for exceptions from default rules are made to improve efficiency. *Future:* SESO/CADRS will provide runway assignments and sequences/schedules for departures.

Table 9. System-Oriented Runway Management Stakeholders Continued

Stakeholder	RCM	CADRS
ATCT Supervisor / Controller-in-Charge (CIC)	*Current:* Uses planned configuration change times for staffing decisions and to respond to airport authority maintenance requests. *Future:* Same as current.	*Current:* None *Future:* None
ATCT ATC Coordinator (coordinates between control/non-control positions in the tower)	*Current:* Same as local and ground controllers. *Future:* Same as local and ground controllers.	*Current:* Same as local and ground controllers. *Future:* Same as local and ground controllers.
ATCT Clearance Delivery / Flight Data Controller	*Current:* Uses airport configuration to verify flight plan validity. *Future:* Same as current operations. Access RCM-planned configuration from TFDM. More frequent configuration changes may require automation to assist.	*Current:* None *Future:* Issue expected runway assignment or taxi route from SESO/CADRS.
ATCT Ground Controller	*Current:* Uses airport configuration to assign departure runways and sequence aircraft as well as assign taxi routes. Uses planned configuration changes to plan runway assignments and taxi routes. Uses configuration to assign arrival taxi routes. *Future:* Configuration will not be required; CADRS will provide runway assignments and SESO will provide taxi route decisions.	*Current:* Manually assigns departure runways and sequence. *Future:* CADRS selects departure runway and sequence.

Table 9. System-Oriented Runway Management Stakeholders Continued

Stakeholder	RCM	CADRS
ATCT Local Controller	*Current:* Uses knowledge of airport configuration (including procedures) to apply separation between departures on a runway and between operations on interacting runways. Uses airport configuration to select taxi route for arrival aircraft. *Future:* CADRS provides sequence; configuration will be required for controller(s) to apply correct separation. CADRS makes runway schedule decisions; controller no longer needs to know configuration for aircraft separation.	*Current:* Select departure sequence; selects when to taxi aircraft across active runways. *Future:* CADRS may specify sequence; controller must apply separation manually. When CADRS provides schedule and runway crossings, controller no longer needs to make these decisions. CADRS output provided via TFDM.
ATCT Controller Automation	*Current:* ATIS updated with new configuration. Enhanced Status Information System or a similar system used to display current configuration. Manual entries to change configuration. *Future:* TFDM will host SESO and CADRS.	*Current:* Paper flight strips. Departure Spacing Program or bar-coded flight strips in a few airports. *Future:* SESO and CADRS via TFDM.
Flight Operator's Ramp Tower / Station	*Current:* At airports where the taxi direction from the gate depends on the assigned runway, uses airport configuration to determine direction to taxi in the ramp. *Future:* Taxi route provided to Flight Operator such that configuration is not required.	*Current:* None *Future:* CADRS runway assignment and sequence used to predict ON and OFF times; SESO predicts IN times and controls OUT or spot times; improved predictability for operator.

Table 9. System-Oriented Runway Management Stakeholders Continued

Stakeholder	RCM	CADRS
Flight Operator's (AOC)	*Current:* Use configuration for general planning and expected airport delays. Get configuration from staff on-site at airport or predictions based on weather forecasts. *Future:* Receive planned configuration schedule from RCM. Provide preferences for the airport configuration.	*Current:* None *Future:* Improved predictability for flight operator.
Airport Authority	*Current:* Use configuration to plan snow removal and maintenance. Observe configuration or call ATCT for configuration. *Future:* Receive planned configuration schedule from RCM. Participate in planning process as appropriate when there is discretion regarding the use of resources, e.g. anticipated maintenance.	*Current:* None *Future:* None

6.2   Strategic Runway Configuration Management

6.2.1 Information Required by SRCM

SRCM will require forecasts for each of the required input data over a time horizon at least as long as SRCM computes outputs. SRCM inputs may be grouped into three types: traffic demand, weather, and airport information. Traffic demand data describes the following:

- Flights that are expected to use the airport, including status as an arrival or departure

- When the flight plans to use the airport

- The flight's route of flight or direction of flight relative to the airport

- The aircraft type

All of this information affects the airport resources required to serve the flight. The traffic demand data will likely be provided by TFMS. The data is required at least as frequently as SRCM will run to produce updated outputs. Weather data consists of the elements of weather considered by SRCM to determine the airport configuration. Weather may include wind speed and direction, ceiling and visibility, and precipitation at the airport, as well as runway visual range, terminal area winds, and convective weather in the terminal area that would block routes.

The lack of availability of weather forecasts for certain weather elements may delay SRCM from including those elements until new information becomes available. The update rate of weather forecasts may be less frequent than SRCM re-computes outputs. However, the traffic demand input data will be updated more frequently than required.

Airport information includes the description of the defined airport configurations and the weather and other conditions under which each configuration may be used. This data is generally static for many days, with occasional changes resulting from construction or procedure changes, for example. This data is expected to be manually generated as part of adapting SRCM to an airport or metroplex.

6.2.2 Information Provided by SRCM

SRCM will provide a forecast of airport capacity as a function of time for the time period beginning at the present time and extending six hours into the future. The forecast will specify the maximum arrival capacity for each quarter hour. SRCM will provide a new forecast every 15 minutes, on the quarter-hour. In addition, SRCM will provide forecasts of departure capacity and airport configuration. The forecast arrival and departure capacities consider the demand at the airport and required tradeoff associated with allocating resources to either arrivals or departures. The configuration will allow the information recipient to consider alternative tradeoffs that may provide a higher or lower arrival capacity. The SRCM forecasts may be stochastic, presenting the uncertainty known to exist due to uncertainty in input data and control decisions external to SRCM.

6.2.3 Entities that Interact with SRCM

Table **10** summarizes the stakeholders for the SRCM functionality and what information they either provide to or receive from SRCM.

Table 10. Strategic Runway Configuration Management Stakeholders and Information Exchanged

Stakeholder	Information Received or Provided
ATCSCC Specialist ARTCC TMC	Receives airport configuration and capacity forecast for use in TFM decisions.
TFM Automation	Receives airport configuration and capacity forecast for use in forecasting traffic situation and advising TMIs. Provides forecast traffic demand.
Flight Operator's Airline Operations Center	Receives airport configuration and capacity forecast for planning resources. Provides configuration preference.

Table 10. Strategic Runway Configuration Management Stakeholders and Information Exchanged Continued

Stakeholder	Information Received or Provided
Airport Operator	Receives airport configuration and capacity forecast for planning resources. Provides plans for use of airport resources.
Weather Automation	Provides weather forecast.

6.3 Tactical Runway Configuration Management

6.3.1 Information Required by TRCM

TRCM requires the same basic information as SRCM—weather forecast, traffic demand forecast, and airport (or metroplex) information— over a shorter time horizon. In addition to receiving traffic demand data from TFMS, more accurate arrival time predictions may be received from TMA. If insufficient weather data is available from other systems, then the system hosting TRCM functionality may allow for manual entries such as whether or not the runways are wet.

6.3.2 Information Provided by TRCM

Tactical Runway Configuration Management will provide a schedule of planned airport configurations over the next hour. The information associated with each planned change may include identification of the last aircraft for the prior configuration.

6.3.3 Entities that Interact with TRCM

Table 11 summarizes the stakeholders for the TRCM functionality and what information they either provide to or receive from TRCM.

Table 11. Tactical Runway Configuration Management Stakeholders and Information Exchanged

Stakeholder	Information Received or Provided
TRACON TMC TRACON Supervisor ATCT TMC ATCT Supervisor / CIC	Receives planned airport configurations (over next hour) for implementing and making local traffic management decisions.

Table 11. Tactical Runway Configuration Management Stakeholders and Information Exchanged Continued

Stakeholder	Information Received or Provided
TRACON Arrival Controller TRACON Departure Controller ATCT Ground Controller ATCT Local Controller ATCT Flight Data / Clearance Delivery positions	Receives current and planned airport configuration changes (over next 15–30 minutes) to control aircraft.
TFM Automation	Provides forecast traffic demand.
Flight Operator's Airline Operations Center	Receives airport configuration and capacity forecast for planning resources. Provides configuration preference.
Airport Operator	Receives airport configuration and capacity forecast for planning resources. Provides plans for use of airport resources.
Weather Automation	Provides weather forecast.

6.4   Combined Arrival Departure Runway Scheduling

6.4.1 Information Required by CADRS

Combined Arrival Departure Runway Scheduling will receive information from terminal area arrival management and airport surface departure management automation systems. Details on this information exchange will be identified as the CADRS concept and algorithm are studied further.

6.4.2 Information Provided by CADRS

Combined Arrival Departure Runway Scheduling provides a coordinated plan for how arrivals and departures will use the runways: runway assignments and either sequence (near-term) or schedule (under 4D trajectory-based operations). This runway plan will initially cover the next 30 minutes and eventually the next 60 minutes. The runway plan for the next few minutes may be updated every few seconds based on new surveillance data indicating compliance deviations from the prior plan. The plan for times further from the current time may be updated less frequently.

6.4.3 Entities that Interact with CADRS

Table 12 summarizes the stakeholders for the CADRS functionality and what information they either provide to or receive from CADRS.

Table 12. Combined Arrival Departure Runway Scheduling Stakeholders and Information Exchanged

Stakeholder	Information Received or Provided
TRACON Arrival Controller TRACON Departure Controller ATCT Ground Controller ATCT Local Controller ATCT Flight Data / Clearance Delivery Controller positions	Receives runway assignments and sequence/schedule
ASDO Automation SESO Automation	Provides runway assignments and sequence/schedule.

7.0 SORM Research and Development Status

This section briefly summarizes the current status of SORM development.

Runway management research under the SORM effort has been ongoing over the past five years. Much of the work described in this document has focused on the development of SORM over the initial three years. For that period, research was conducted as three one-year spirals to develop basic capabilities for a single airport in the first year, more complex SORM capabilities for a single airport in the second year, and SORM capabilities for a metroplex environment in the third year. The first year of SORM research focused on concept engineering, such as identifying SORM-use cases and information requirements for potential SORM users. Initial algorithm exploration was also conducted in addition to preliminary investigation of SRCM. The second year of SORM research saw the development and testing of TRCM and CADRS prototypes applicable to a single airport as well as continued work on SRCM. The third year of SORM research focused on developing a prototype of TRCM that is applicable to metroplex environments.

This research program has proven laboratory prototypes for some elements of the SORM concept. Additional research is required to develop field prototypes including user interfaces, to conduct field tests of the technology, to address issues necessary to ensure compatibility with FAA systems, and to ensure the full variety of airport and metroplex characteristics are handled. In addition, further research on less-studied aspects of the SORM concept is needed.

Two types of software have been developed during SORM research and development. Initial work to evaluate concepts and design algorithms has been performed in Matlab, to take advantage of the flexibility and integration of software development and analysis. Subsequently, SORM algorithms selected for further study have been coded in Java. The Java software development consists of implementing SORM algorithms and enhancing the Metroplex Simulation Environment (MSE).

The MSE is used as a platform for the SORM software, providing the necessary input data, such as weather and traffic forecasts and static adaptation data describing the airport and defined airport configurations. The MSE is also used to run fast-time simulations, either implementing the airport configurations suggested by SORM or using scripted baseline airport configurations obtained from historical data. The simulations produce a variety of metrics which are then used to measure the performance of SORM relative to the baseline simulation. Figure 3 provides a high-level architecture of the implementation of the TRCM algorithm within MSE.

A user interface was developed in the course of the SORM research effort that is conceptual in nature. The philosophy underlying the design reflects the FAA's move toward fewer displays in the tower and the ready availability of the pertinent information required by air traffic personnel to make runway management decisions. A description and depiction of the interface can be found in Appendix A.

Analysis work has been conducted in the past year to assess benefits of the TRCM capability. The work focused on capacity, efficiency, and impact on delay. The publications are in the final review process (refs. 20 and 21).

Figure 3. Tactical Runway Configuration Management in MSE.

Over the course of the SORM research and development, several airports have been used for SORM testing. John F. Kennedy International Airport was selected as the focus airport for single-airport SORM testing. However, for a variety of reasons related to the complexity of operations in the New York metroplex, KJFK does not make many airport configuration decisions; the TRACON usually makes these decision. To study the importance of dimensions of airport configuration in addition to runway configuration, the application of SORM was also studied at KMEM, KMCO, and KATL. Studying four different airports ensured the system design is flexible and the concept is readily adaptable to different airports, which each possess unique characteristics.

The application of SORM to a metroplex environment was tested in the context of the New York metroplex, which was defined as consisting of primarily KJFK, KLGA, Newark Liberty International Airport, and Teterboro Airport.

8.0 Summary

Significant inefficiencies exist at airports throughout the NAS with respect to arrival and departure operations. The effective management of runways is central to addressing these inefficiencies. The airport runway sits at the crossroads of the airport surface and the airspace environment. Although technically part of the airport surface, the runway and management of this resource can be thought of as a process separate from other surface automation capabilities. The two capabilities, surface and runway management would ultimately have to be coordinated, however. This document defines a concept, System-Oriented Runway Management that addresses effective runway management through the determination of optimal runway configurations and subsequent runway assignment policies. The development of SORM capabilities assumes that consideration of the broader landscape of operational factors on the airport surface and in the airspace is required for effective and viable solutions. Further, SORM was developed with the understanding that any effective runway management capability must be complementary to the broader challenge of Airport Configuration Management. In addition to the airport and related surface operations, the effects of runway configurations/usage are cross-cutting in terms of their effect on other elements/ processes of the air traffic system. Airspace operations, TFM, and airline operations, among others, are all affected by runway management decisions. This effect will be amplified for concepts and technologies under investigation for the future. Dynamic reconfiguration of the airspace, potential changes in wake separation standards, and migration to a fixed-path environment coupled with the use of required times of arrival are but a few examples.

System-Oriented Runway Management is composed of three elements: Strategic Runway Configuration Management, Tactical Runway Configuration Management, and Combined Arrival Departure Scheduling. Strategic Runway Configuration Management forecasts the airport configuration over a longer time horizon for the purpose of providing airport capacity forecasts for use in traffic flow management—planning TMIs several hours in advance. Tactical Runway Configuration Management plans the airport configuration over a timeframe appropriate for air traffic personnel in the ATCT and TRACON to make runway configuration and operating procedure decisions used to control arrival and departure traffic. Combined Arrival/Departure Runway Scheduling is more tactical in nature than TRCM; it plans how individual flights should use the available runways and is subject to (or in exception to) the aggregate policies selected by TRCM.

Algorithms have been developed that address each of the three SORM capabilities. Emphasis has been placed on algorithm development for TRCM addressing both the single airport and metroplex environments, with the former currently at a higher level of maturity. Single airport TRCM considers overall delay (not just delay at the runway), costs due to reduced capacity during this period, among other factors. Compute power to run the algorithms are well within capabilities that exist today. Future envisioned capabilities for the TRCM will incorporate inputs from system users and airport operators. For metroplex TRCM, algorithms will be further developed to incorporate the dependencies between flight paths as well as airspace. Capabilities that address prioritization of resources will be an integral part of future functionalities; e.g., priority of operations at one airport over another may be required in the interest of NAS performance. This may drive runway configuration selection.

In support of the SORM research effort four airports (for the single runway cases) have been modeled: KJFK, KMEM, KMCO and KATL. Limited simulation and evaluation of SORM tools in these environments has been conducted and positive results have been observed in all cases. Note that with runway configuration management tools, trade-offs are an inherent part of the selection process so there will be negative benefit value in some cases; however it is the overall benefit that is the focus of runway management optimization. For the multiple airport case, the New York Metroplex was modeled, the four major airports- KJFK, KLGA, KEWR, and Teterboro. Extensive benefits analysis for both of the single airport and the metroplex capabilities have recently been completed and will be published in the near future.

The single airport TRCM was transferred to the FAA in April, 2012 through a technology transfer agreement; the multiple airport version of TRCM will be transferred in March 2015. Further development of both SRCM and CADRS capabilities are planned. Plans are in place for integration of SORM capabilities with other work areas within NASA's Airspace Systems Program. There is also a collaboration agreement between NASA and the German Aerospace Center (DLR) focused on the integration of DLRs arrival/departure and surface capabilities and the TRCM algorithm. The collaboration agreement has been in place for one year, and a proposal is under consideration that would extend the work for two additional years.

9.0 Bibliography

9.1 Works Cited

1. Federal Aviation Administration, "1.5-Nautical Mile Dependent Approaches to Parallel Runways Spaced Less than 2,500 Feet Apart," JO 7110.308, Federal Aviation Administration, Washington, D.C., November 5, 2008.

2. Federal Aviation Administration, "Wake Turbulence Recatagorization," JO 7110.659A, Change 3, June 1, 2014.

3. Joint Project Development Office, "Concept of Operations for the Next Generation Air Transportation System (NextGen)," Version 3.2, September 30, 2010.

4. National Aeronautics and Space Administration, "Next Generation Air Transportation System NextGen-Airportal Project Plan," December 2008, http://www.aeronautics.nasa.gov/pdf/airportal_508.pdf

5. Lohr, G., D. Williams, "Current Practices in Runway Configuration Management (RCM) and Arrival/Departure Runway Balancing (ADRB)," NASA/TM-2008-215557, December 2008.

6. Federal Aviation Administration, "National Safety and Operational Criteria for Runway Use Programs," JO 8400.9, Washington, D.C., November, 1981, 2009.

7. Federal Aviation Administration, "Air Traffic Control," JO 7110.65U, February 9, 2012, Washington, D.C.

8. Bohme, D., R. Brucherseifer and L. Christoffels, "Coordinated Arrival Departure Management," German Aerospace Center (DLR), 7th USA/Europe Air Traffic Management R & D Seminar, Napoli, Italy, June 2000.

9. Keyes, J. "Collaborative Decision Making," Presentation, 2000.

10. Brinton, Chris, S. Atkins, L. Cook, S. Lent, and T. Prevost, "Ration by Schedule for Airport Arrival and Departure Planning and Scheduling," 2010 ICNS Conference, 11–3 May 2010.

11. Atkins, S. and W. Hall, "A Case for Integrating the CTAS Traffic Management Advisor and the Surface Management System," Proceedings of the AIAA-2000-4471, Guidance Navigation, and Control Conference, Denver, CO.

12. Idris, H., "Diagnosis and Empirical Analysis of Departure Operations at a Major Airport," Ph.D. Thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, MA, September 2000.

13. Newell, G. "Airport Capacity and Delays," Transportation Science, Volume 13, Number 3, August 1979.

14. Gilbo, E.P., "Airport Capacity: Representation, Estimation, and Optimization." IEEE Trans. Control System Technology, Vol. 1, No.3, Sept. 1993.

15. Frankovich, M., "Air Traffic Flow Management at Airports: Unified Optimization Approach," Massachusetts Institute of Technology, Cambridge, MA, 2012.

16. Weld, C., M. Duarte, and R. Kincaid, "A Runway Configuration Management Model with Marginally Decreasing Transition Capacities," Advances in Operations Research, Volume 2010, Article ID 436765, 2010.

17. Leihong, L., J.P. Clark, "Airport Configuration Planning with Uncertain Weather and Noise Abatement Procedures," Digital Avionics Systems Conference (DASC), Salt Lake City, Utah, 2010.

18. Gilbo, E., "Arrival/Departure Capacity Tradeoff Optimization: a Case Study at the St. Louis Lambert International Airport (STL)," 5th USA/Europe Air Traffic Management R&D Seminar, Budapest, Hungary, 2003.

19. Glass, B, "Automated Data Exchange and Fusion for Airport Surface Traffic Management," AIAA Paper 97-3679, 1997.

20. Phojanamongkolkij, N., R. Oseguera-Lohr, G. Lohr, S. Robbins, and J. Fenbert, "Benefit Assessment for Metroplex Tactical Runway Configuration Management," NASA TM/0000-000000 (in publication), 2014

21. Oseguera-Lohr, R., G. Lohr, N. Phojanamongkolkij, "Benefits Assessment for Tactical Runway Configuration Management Tool," NASA TM/0000-000000 (in publication), 2014.

22. Jones, Debra, M. Lenox, and E. Onal, (2012). *System-oriented runway management (SORM) decision support tools and user interface support.* Internal report to Stinger Ghaffarian Technologies, element 5.2, deliverable #2; under NASA LITES Task A099.

9.2   Guide to Further Reading

23. Provan, Chris, "Optimization Models for Strategic Runway Configuration Management," 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Fort Worth, TX, 13–15 September, 2010.

24. Weld, C., M. Duarte, R. Kincaid, "A Runway Configuration Management (RCM) Model with Marginally Decreasing Transition Capacities," 2010 IEEE Systems and Information Engineering Design Symposium (SIEDS), Charlottesville, VA, 23 April, 2010.

25. Kincaid, R., R. Zhang, M. Haines, and J. Thorne, "Optimization Models for Runway Configuration Management," 12th INFORMS Computing Society Conference, Monterey, CA, 9–11 January 2011.

26. Provan, C. and S. Atkins, "Tactical Airport Configuration Management," IEEE/AIAA Integrated Communications Navigation and Surveillance (ICNS) Conference, Herndon, VA, 10–12 May 2011.

27. Lohr, G., S. Brown, H. P. Stough, S. Eisenhawer, S. Atkins, and D. Long, "System Oriented Runway Management: A Research Update," USA/Europe Air Traffic Management Research and Development Seminar, Berlin, Germany, 14–17 June 2011.

28. Lohr, G., S. Brown, S. Atkins, S. Eisenhawer, T. Bott, D. Long, S. Hasan, "Progress Toward Future Runway Management," 11th AIAA-ATIO Conference, Virginia Beach, VA, 20–22 September 2011.

29. Zhang R. and R. Kincaid, "Robust Optimization for Runway Configuration Management," 11th AIAA-ATIO Conference, Virginia Beach, VA, 20–22 September 2011.

30. Thorne J. and R. Kincaid, "Tabu Search for Tactical Runway Configuration Management,"12th AIAA-ATIO Conference, Indianapolis, IN, 17–19 September 2012.

Appendix A. Examples of Airport Geometries

This appendix is composed of eight airport diagrams. The diagrams in Figure A-1 – Figure A-8 are intended to illustrate differing airport surface geometries. Coupled with these differences are the unique procedural requirements that are inevitably part of different local operational environments.
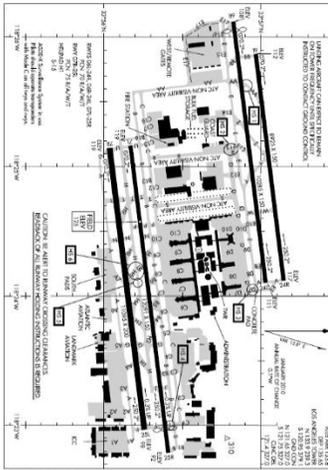
Figure A-1. Los Angeles International Airport.
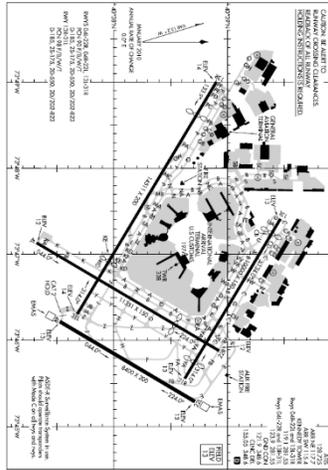
Figure A-2. John F. Kennedy International Airport.
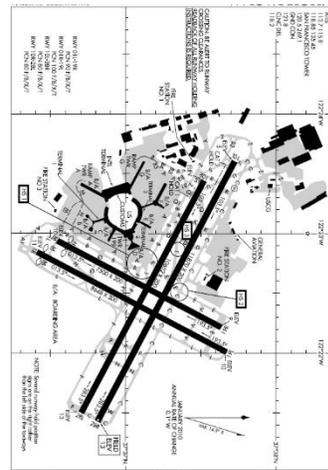
Figure A-3. San Francisco International Airport.
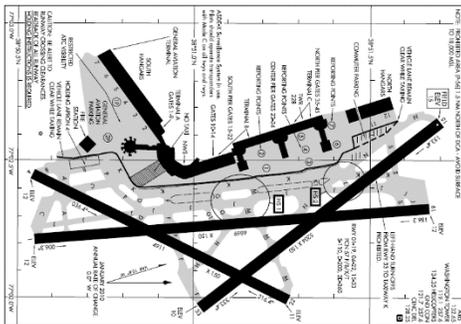
Figure A-4. Ronald Reagan Washington International Airport.
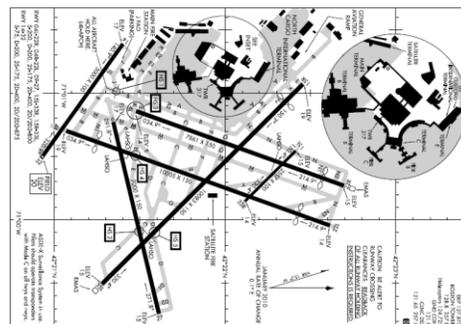
Figure A-5. General Edward Lawrence International Airport.
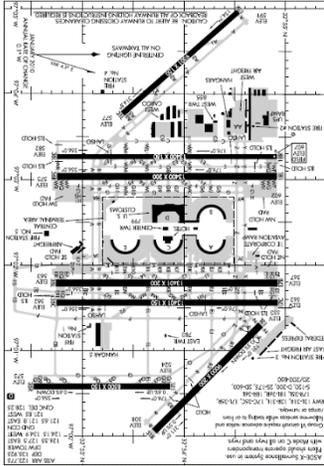
Figure A-6. San Diego International Airport.
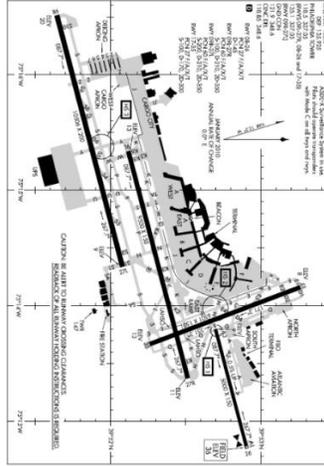
Figure A-7. Philadelphia International Airport.
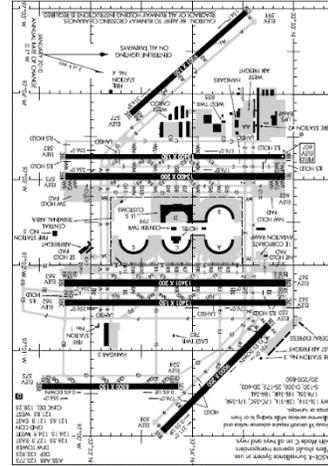
Figure A-8. Dallas-Fort Worth International Airport.

Appendix B. Descriptions of Decision Making process for Runway Configuration Selection at Two Select Airports

This appendix provides an overview of the decision-making process with respect to runway management for two large airports: Dallas-Fort Worth International Airport (KDFW) and Memphis International Airport (KMEM). Note that there are common considerations such as those identified in sub-section 2.2.1; a few of the more common considerations include the following:

- Wind direction and speed

- Convective weather activity in the TRACON airspace: if thunderstorms would affect traffic flow on the final approach courses for one configuration, but not affect the final approach courses for another runway configuration

- Equipment outages, for example components of the Instrument Landing System (ILS), e.g., the glide slope or localizer

- Runway or taxiway closures

- Procedures affecting the departure capacity

- Configuration changes which must be negotiated at high density TRACONs with several busy airports. Wind forecasts are critical in these instances.

- Noise abatement procedures—certain configurations are required during "quiet time" operations

B.1. Dallas-Fort Worth International Airport Example

At KDFW, the TRACON TMU selects the configuration change time and the ATCT typically accepts the recommendation. A TRACON TMC looks at the forecast weather, primarily wind direction and speed, and at the arrival demand using the traffic management advisor (TMA). The TMC wants to set the change time at least 20 minutes in advance, 40 minutes is preferred, with a possible refinement of the time at 30 minutes in advance.

The TMC chooses the last arrival across each arrival fix, using the TMA estimated time of arrival at the fix and runway. They look for coincident gaps (adjusted for flying time to the runway) between arrivals at each of the arrival fixes. All arrivals after the designated last flight for each fix go into holding. The change time represents the time the airport surface changes configurations, which effectively is the time the last of the arrivals for the old configuration lands.

All departures in the old configuration must be airborne three minutes before the change time. This same requirement applies to both Dallas Love Field and KDFW. Sometimes, the TRACON TMU will require the last departure to be airborne five minutes prior to the change time. Departures may resume in the new configuration immediately after the change time.

Arrivals from the "long flight time" side can resume for the new configuration five minutes before the change time. Arrivals from the short side can resume three minutes before the change time. The goal is for the last four arrivals in the old configuration to land just before the change

time. These flights cross the arrival fixes about 15 minutes before the change time. Therefore, there is about a 10- minute period when no arrivals are crossing the arrival fixes and, equivalently, for the first 10 minutes in the new configuration there are no arrivals landing on the runways.

If a change is required during a busy traffic period, the TRACON TMU may stop all traffic to and from the satellite airports during the entire period the airport and airspace are flushing the traffic in the old configuration and establishing the new flows to reduce traffic complexity.

Planning a configuration change involves not only selecting a time at which the airport surface switches configurations but times at which arrivals and departures stop for the old configuration and start for the new configuration and, further, identifying the last/first aircraft. Dallas-Fort Worth currently uses rules-of-thumb that experience has shown avoids airborne conflicts.

B.2.   Memphis International Airport Example

The current winds dictate the runway configuration most of the time. The FAA Order 7110.65, section 3-5-1 requires the use of the runway most nearly aligned with the wind when five knots or more, and the "calm wind" runway when less than five knots. The calm wind runway is specified in the local Standard Operating Procedures; not all airports have specified a calm wind runway or configuration. When the wind is calm, or nearly calm, other factors are considered.

At KMEM the tower cab supervisor or CIC determines the configuration. Normally, the CIC will select the configuration that results in the highest airport acceptance rate.

At KMEM, for instance, runway 27 crossover procedures make it desirable to not use runway 27 frequently if the departure volume is mostly FedEx. At Newark International Airport, if a ship is docked at a particular pier, their most popular airport configuration is unavailable until that ship departs, because its height conflicts with the missed approach procedure for that runway. Another consideration is arrivals versus departures and their taxi distance. Passenger aircraft are based roughly in the middle of the airport. Since taxi distance is not a critical factor for them, they rarely comment on, or request a particular configuration. FedEx, on the other hand, is very interested in configuration because of their ramp location. FedEx's operations personnel frequently call the Memphis TRACON to request a particular configuration at KMEM.

For operations at night, the configuration is decided in a conference call with Memphis Center-TMU, the TRACON, and the tower. The terminal forecast is used. The TMU supervisor also discusses the forecast with the center's meteorologist prior to conferencing with the tower or FedEx. These conferences are held about four hours prior to the start of the FedEx arrivals. FedEx needs this information well in advance for fueling considerations and planning arrival parking gates. However, the situation can, and often does, change at the last minute.

At KMEM, FedEx prefers to land to the north and depart to the south to minimize taxi distance. The KMEM airport layout is shown in Figure B-1. However, FedEx has discovered that if they land with a tailwind component up to 10 knots, more of their planes get on the ground faster and the resulting savings outweighs those resulting from shorter taxi times to the parking gates. Analysis of actual operations has revealed that the aircraft on final approach have less inter-arrival spacing, and groundspeeds are higher with a modest tailwind. This is an example of the

importance of considering the effect of runway configuration on both airborne trajectories and surface trajectories and selecting the option with the highest overall efficiency.
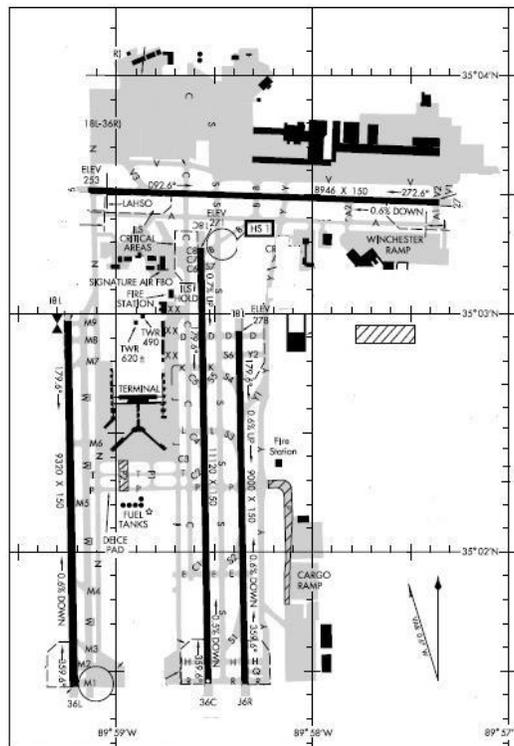

Figure B-1. Memphis International Airport.

In normal daytime operations, if the supervisor foresees a configuration change, he/she will decide to execute the change in time to have the aircraft positioned correctly when the actual change takes place; this is usually no more than 20 minutes in advance.

The terminal weather forecast from the National Weather Service is used for longer term planning. It is issued every six hours. Observing wind reports from stations close to the airport to the west, like West Memphis, Jonesboro, or Walnut Ridge, gives the supervisor an idea of what the trend is and when he/she can expect to see a change. These are usually updated hourly. The Integrated Terminal Weather Service (ITWS) weather system is also valuable, since it shows gust fronts and wind data near the outer fixes; ITWS is continuously updated. The tower supervisor may also use visual cues in determining wind changes. At KMEM, they will often check the direction smoke is blowing from smoke stacks west of the airport, as an indicator of a change in wind direction or magnitude.

Traffic demand information is primarily based on historical knowledge and experience rather than any data source. The traffic patterns at KMEM and most airports are regular and predictable. Traffic Flow Management System /Traffic Situation Display and flight strips may be used if traffic is not expected to be similar to most days.

When the configuration will be changed, the tower supervisor/CIC calls the TRACON supervisor and advises of the new configuration and change time. The TRACON supervisor

69

advises the arrival and departure controllers of the plan for the configuration change. Communicating a configuration change also requires recording a new Automatic Terminal Information System (ATIS) broadcast[13] and calling the overlying ARTCC TMU. The TMU will then enter the change in the National Traffic Management Log (NTML), unless the TRACON has TMU and NTML access. The center TMU will also inform its operational sectors that require the information, either by phone, the Enhanced Status Information System (ESIS), general information (GI) message, or hand-held radio. Depending upon their working relationship, the TRACON or TMU supervisor may call one or more major users either during the decision-making process, or to inform them when the decision has been made.

The ESIS display is a function of the NTML. When a restriction comes through the NTML, the receiver can edit it and display it on a screen so that it is available to everyone. At ZME there is an ESIS display in the TMU and in each of the six operational areas. The display has different sections that show restrictions, airport information, and military activity. The ESIS display will automatically update information (e.g., if times or altitudes change) based on changes in NTML. Restrictions change color close to the expiration time and then disappear after expiration. Not every facility uses ESIS, and some use it differently, but it has become the primary source for current restrictions in the center.

A GI message is the old way of disseminating information at a center. This is entered into an en route automation modernization terminal and prints out on the flight strip printer at each sector. This method is still used to issue some operational information and a lot of non-operational information in the center.

At KMEM, specified procedures like those described for KDFW to identify when the last arrivals/departures in the old configuration must be across the fix/airborne and when the arrivals/departures for the new configuration may cross the fix/take off do not exist. For arrivals, the TRACON supervisor will advise the tower which arrival will be the last one for the old configuration. For departures, the tower supervisor will advise the TRACON supervisor which departure will be the last one for the old configuration. The supervisors will always coordinate with the controllers before making the decision.

In addition to the runways in use, the configuration must specify some procedures such as whether IAPs or visual approaches may be used. A visual approach cannot be issued if the reported weather at the airport is at or below basic visual meteorological conditions minima (1000' cloud ceiling and 3 miles visibility). Note that in practice, visual approaches are not used unless the weather is significantly better than the required minima. Visual approaches are, however, used whenever possible, but must also be accepted by the pilot.

---

[13] Clearance delivery or the flight data position is responsible for the ATIS broadcast. At many locations, the ATIS is now digitized and the controller simply selects the information to include.

Appendix C.   An Airport Runway Management User Interface and Decision Support Toolset

To achieve the objectives of this project, SA Technologies, Inc. utilized the innovative Situation Awareness-Oriented Design (SAOD) approach. The SAOD process is a user-centered approach that covers all aspects of system design from requirements analysis, to design development, to evaluation of the resultant designs. This approach has been effectively utilized and validated across a variety of domains and results in validated, user-accepted graphical user interface (GUI) designs. SAOD is comprised of three main stages: requirements analysis, GUI design, and measurement (Figure C-1).
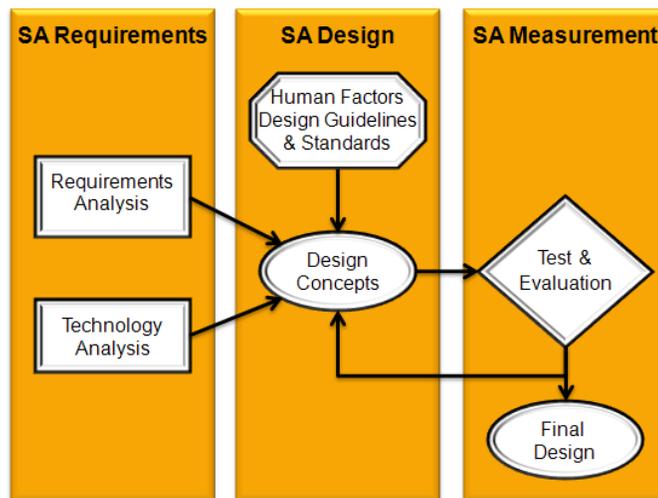
Figure C-1. SAOD Process.

The first phase of the SAOD process focused on understanding requirements, both from a user perspective and from a technology perspective. To understand the users' requirements, SAOD utilizes a form of cognitive task analysis called a Goal-Directed Task Analysis (GDTA) to understand the goals, the decisions that must be made to achieve those goals, and the information required to make the decisions. This analysis not only defines the goals associated with traffic management, it also identifies the type of information that needs to be easily accessible on the GUI to support traffic management activities and provides clear guidance about how that information needs to be combined to support optimal decision making. In addition to the GDTA, the SAOD process includes a traditional function analysis to define the functions and tasks that must be accomplished. To understand the technology perspective, a work domain analysis was conducted to model the functional constraints of the SORM systems. The users' requirements and the technology insight were integrated to create a set of information requirements essential for the success of the SORM DST. The artifacts resulting from this phase of the project include (1) the work domain analysis, (2) the GDTA, (3) the functional analysis and (4) the resultant information requirements.

The second phase of the SAOD process combines the results of the analysis phase with SAOD principles as well as human factors design guidelines and standards to create common, intuitive, goal-based GUI designs. Each design is based on a goal drawn from the GDTA, thereby

providing designs that are goal-centric, support the decisions that need to be made relative to that goal, and provide the relevant information to support decision making, all in a single view. The results of this design are detailed GUI schematics that provide the functionality needed to support traffic management activities.

The third phase of the SAOD process entails systematically evaluating the GUI to ensure the designs support those involved in traffic management activities. A full evaluation involves a variety of metrics that when combined, provide a robust picture of the ease with which the user can develop and maintain an appropriately high level of situation awareness, workload associated with using the GUI, and performance obtained with the new designs. For this project, the measurement phase was limited to two informal GUI evaluation sessions. However, in order to provide a path forward for future evaluations of the SORM DST, additional information pertaining to low-fidelity cognitive walkthroughs, part task testing, and high-fidelity simulation experiments was identified.

The SORM DST concepts developed during this effort included four designed views (current ops, demand, configuration, and balance traffic) and two configurable tile panes (one on each side of the display). Full descriptions can be found in the Preliminary GUI Functionality Description (ref. 22). Figure C-2 shows a view of the GUI with these tiles presented.
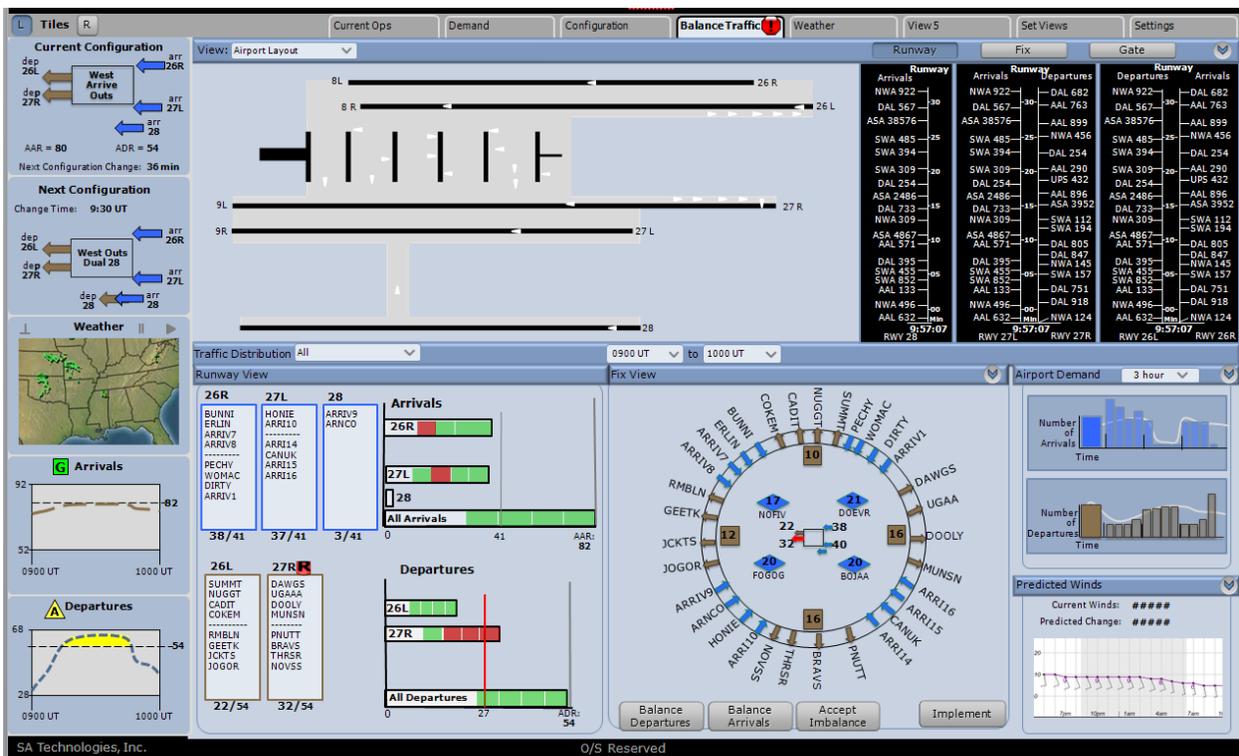

Figure C-2. Preliminary GUI design.

REPORT DOCUMENTATION PAGE

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01-03-2015	Technical Memorandum	

4. TITLE AND SUBTITLE

System-Oriented Runway Management Concept of Operations

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Lohr, Gary W.; Atkins, Stephen

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

411931.02.61.07.01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER

L-20135

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)

NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

NASA-TM-2015-218699

12. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 03
Availability: NASA STI Program (757) 864-9658

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The goal of this document is to describe the overall SORM concept and how it would apply both within the NAS and potential future Next Generation Air Traffic System (NextGen) environments, including research conducted to date. Note that the concept is based on the belief that runways are the primary constraint and the decision point for controlling efficiency, but the efficiency of runway management must be measured over a wide range of space and time. Implementation of the SORM concept is envisioned through a collection of complementary, necessary capabilities collectively focused on ensuring efficient arrival and departure traffic management, where that efficiency is measured not only in terms of runway efficiency but in terms of the overall trajectories between parking gates and transition fixes. For the more original elements of the concept-airport configuration management-this document proposes specific air traffic management (ATM) decision-support automation for realizing the concept.

15. SUBJECT TERMS

Air traffic system; Arrivals; Departures; Runway

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
U	U	U	UU	81	19b. TELEPHONE NUMBER *(Include area code)* (443) 757-5802