System Oriented Runway Management: A Research Update

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Abstract— **The runway configuration used by an airport has significant implications with respect to its capacity and ability to effectively manage surface and airborne traffic. Aircraft operators rely on runway configuration information, as it can significantly affect an airline's operations. Current practices in runway management are limited by a relatively short time horizon for reliable weather information and little assistance from automation. Wind velocity is the primary consideration when selecting a runway configuration, however when winds are below a defined threshold, discretion may be used to determine the configuration. Other considerations relevant to runway configuration selection include airport operator constraints, weather conditions (other than winds) traffic demand, user preferences, surface congestion, and navigational system outages. The future offers an increasingly complex landscape for the runway management process. Concepts and technologies that hold the potential for capacity and efficiency increases for both operations on the airport surface and in terminal and enroute airspace are currently under investigation. Complementary advances in runway management are required if capacity and efficiency increases in those areas are to be realized. The System Oriented Runway Management (SORM) concept has been developed to address this critical part of the traffic flow process. The SORM concept was developed to address all aspects of runway management for airports of varying sizes and which accommodates a myriad of traffic mixes. SORM, to date addresses the single airport environment; however, the longer term vision is to incorporate capabilities for multiple airport (Metroplex) operations as well as accommodating advances in capabilities resulting from ongoing research.**

I. INTRODUCTION

The runway is a limited resource used for arrivals and departures, and as a taxiway; effective management of this resource must be viewed from this perspective. It follows that runway configuration[1] selection is a critical element to the air traffic flow process. The Concept of Operations for the Next Generation Air Transportation System (NextGen) states, "runway capacity at the busiest airports is the primary limiting factor in National Airspace System (NAS) operations today…"[1]. Similar comments can be found in Reference 2. The runway, although technically part of the airport surface, the runway is the gateway between airport surface and airspace environment, each having its own challenges to efficient operations. The airport surface is particularly challenging and is arguably the most complex element in the NAS, in terms of the number of factors can adversely affect operations. Traffic congestion, weather related considerations (e.g. de-icing operations, snow removal) delay programs based on airspace and destination airport constraints, gate availability, among others, present significant challenges to the movement of aircraft on the airport surface and ultimately, to efficient runway management. Many research efforts are underway to address surface congestion through the regulation of traffic; Reference 3 provides one such concept. In the airspace congestion remains a problem as well. Streams of inbound traffic converge on Terminal Radar Approach Control (TRACON) airspace which has minimal room for delay absorption if demand significantly exceeds capacity at the airport. The many challenges for both of these domains provide a complicated and complex landscape for developing effective runway management strategies and capabilities and the future promises greater complexities based on the promise of future NAS enhancements. In response to the need for more effective runway management, the System Oriented Runway Management (SORM) concept was

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[1] In this document, runway configuration refers to a set of runways included as part of a runway configuration plan; runway management refers to how runways are used.

created under National Aeronautics and Space Administration's (NASA) Airspace Systems Programs (ASP). This concept focuses on the process of effectively managing runways by providing recommendations to air traffic control personnel that address the myriad of factors coupled with provisions for advances in NAS capabilities. SORM is comprised of two basic capabilities: Runway Configuration Management (RCM), which is further sub-divided into Strategical RCM (SRCM) and Tactical RCM (TRCM), and Combined Arrival/Departure Runway Scheduling (CADRS). Runway Configuration Management is the process of designating 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 the NAS goals through the effective distribution of arrival and departure traffic across active runways in conjunction with effective scheduling of traffic on those runways. Included in the suite of envisioned SORM capabilities are strategic and tactical runway configuration evaluation and the output of recommendations for runway configuration as well as runway assignment. The evaluation of configuration options is systemically driven, i.e. based on overall needs of the NAS.

This paper provides a brief overview of the SORM concept with emphasis on TRCM as it is more mature than SRCM or CADRS. Progress in the area of algorithm development, systems analysis studies, and benefits analysis are also included.

II. Overview of Runway Configuration Selection and Planning

Today, the runway configuration selection process is generally reactive in nature, applied based on experience and rules of thumb, and with limited automation assistance [4]. When weather forces a runway configuration change, controllers are able to plan runway configuration changes to the extent the weather is accurately forecast. However, controllers are less proactive in changing the configuration to accommodate traffic demand. As a result, the configuration must be robust to the uncertainty and 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, which can affect how airspace will be allocated. Air traffic personnel will be unable to manually evaluate these choices due to the complexities of the factors involved, further motivating research on automation to support airport configuration management.

There are several parties involved in the runway configuration selection process. Ultimate responsibility for determining the runway configuration rests with the Airport Traffic Control Tower (ATCT), specifically, the Supervisor or Controller-in-Charge [5]. However, the ultimate configuration selection may include inputs to the TRACON, the Air Traffic Control System Command Center (ATCSCC), the airport operator and the system users. Since the incorporation of Collaborative Decision Making (CDM) in 1998 [6], system users have been an integral part of the decision making process regarding NAS operations.

There are many considerations factored into determination of the runway configuration; these factors can be thought of as falling into two basic categories: those which serve as constraints and those for which discretion can be applied in the determination process. Examples of constraints include winds beyond permitted thresholds, restricted runway operations based on environmental considerations, i.e. noise and runway/taxiway closures imposed by the aircraft operator. Wind velocity is the primary driver when selecting a runway configuration. When maximum tailwind limits [7, 8] are exceeded a runway cannot be assigned. Assuming that no constraining factors exist, other considerations can be used in determining the configuration. The runway configuration with the highest capacity is normally selected. Absent sufficient demand to necessitate a high-capacity configuration, alternative configurations can be selected that will provide other benefits, e.g. reduce taxi time, accommodate user preferences or reduce controller workload. As a result of the selected runway configuration, weather conditions as well as other factors will be considered and an Airport Acceptance Rate (AAR) determined. This rate has been established for most runway configurations; however, it can be adjusted as conditions dictate. Planning to the AAR occurs at all levels of the TFM process including the ATCSCC, Air Route Traffic Control Centers (ARTCCs), TRACONs, and of course the ATCT. Bi-hourly telecoms are conduct by the ATCSCC with Traffic Management Units (TMU) throughout the System to receive inputs regarding the state of NAS resources and determine if actions are required to ensure the smooth flow of traffic. As the air traffic system moves forward into an era when there is greater dependency between airports, (i.e. Metroplexes), the challenge of managing runways becomes significantly more complicated. 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, as well as user preferences where possible. Many factors demand consideration in arriving at runway configurations that collectively best serve the System as a whole. Within the Metroplex, significant inefficiencies can arise when configurations are selected at given airports that yield traffic flows inconsistent with the terminal flow of traffic.

III. Overview of the SORM concept and research

A. Brief overview of the SORM concept

A brief overview of the SORM concept follows; greater detail can be found in Reference 9. There are several

objectives of the SORM concept, two of which are critical to effective runway management in the future. First, a "systems" approach which serves to promote efficiency for the NAS, and second, automation to provide assistance to air traffic personnel in the runway management decision making process. A partnership between the decision makers and automation is required.

SORM provides three necessary capabilities in the area of runway management: SRCM, TRCM, and CADRS. Runway Configuration Management is presented as two separate capabilities because they are used in substantially different ways and at unequal levels by those involved in the traffic flow process, and they involve operations at different time scales. Traffic Flow Management requires an estimate of airport capacity that may be used in planning traffic management initiatives (TMI) several hours in advance. However, since the TMIs depend on the capacities, SRCM will plan airport capacities in concert with TFM planning the TMIs. Controllers and traffic managers at and near the airport require an airport configuration plan over the next hour or less. The significant difference in the uncertainty characteristics on these time scales is expected to result in different algorithms being used, further warranting the separation. TRCM will plan the airport configuration to best satisfy demand over the next hour. In the far-term, as uncertainty is reduced through other technologies, strategic and tactical RCM may merge. CADRS is a concept and algorithmic approach for coordinating runway planning – runway assignments and sequencing or scheduling – so that all of the relevant factors are considered, including airborne, airport surface, and TFM. A concept of operations (conops) has been developed for SORM and an updated version is planned for publication by mid-year 2011.

B. Phased approach to SORM development

SORM research involves a two-phased approach based on complexity of the operational environment. Phase I addresses the single airport, multiple runway case; Phase two focuses on the Metroplex case. The far term vision of SORM is to provide for these capabilities in a Metroplex environment. The Metroplex environment poses considerable challenges to RCM. 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, as well as user preferences where possible. A myriad of factors require consideration in arriving at runway configurations that collectively best serve the System as a whole.

C. SORM Connectivity with relevant research areas

To accomplish the objectives of the SORM concept, integration with other air traffic entities/processes is required. As previously stated, the broader air traffic system's (airport and ultimately, Metroplex) objectives can be achieved through the incorporation of TFM inputs. Current and future

TFM capabilities will, as appropriate, be incorporated in to SORM. As the results of research yields changes to procedures on the surface and in the airspace domains, appropriate complimentary modifications will be made. Situated at the crossroads of the of airport surface and the airspace, SORM will be tightly coupled with these domains in terms of exchanging schedule information and information exchange. SORM will also provide information useful to future envisioned functions such as Dynamic Airspace Configuration (DAC). Dynamic Airspace Configuration is intended to provide flexibility to airspace management through alternatives to the current static airspace structure. Information provided by SORM would permit informed decision regarding the allocation of airspace. If, for example, the traffic for an airport over a given period of time is 75% arrivals and 25% departures, this could influence how airspace is configured in a DAC environment.

D. Research Transition of SORM

The Federal Aviation Administration (FAA) has established four Research Transition Teams (RTTs) jointly lead by the FAA and NASA to identify concepts for transition to the FAA. Under the Integrated Arrival/Departure/Surface (IADS) Research Transition Team, RCM has been identified as a Research Transition Product for both the single airport as well as the Metroplex RCM capability.

IV.   AIRPORT CONFIGURATION MANAGEMENT

The increasing presence of airport surface surveillance technologies has spawned a strong interest in airport surface traffic management research; the vast majority has assumed that the airport's runway configuration is known and is constant. This section addresses the issue of planning the airport configuration by presenting the TRCM concept. A laboratory prototype of TRCM that selects optimal airport configuration schedules has been implemented and studied within a simulation environment. This section presents simulation results for several airports, under various weather and traffic conditions. TRCM could be implemented and provide benefits at any airport within the NAS, being adaptable to the uniqueness of airports, while having increasing value in NextGen. Plans are underway for field trials during 2011 in which the algorithm will be evaluated by controllers in shadow-mode. Future research will extend the concept and algorithm to provide coordinated plans for Metroplex airports.

It is generally understood that selection of the runway configuration alone is insufficient to manage runway usage efficiently. Other decisions, such as runway assignment policies, have significant effects on airport efficiency and exist even at airports where the runway configuration selection appears trivial. Dallas-Fort Worth International Airport (DFW) and Atlanta Hartsfield International Airport (ATL) are both large airports at which wind and preference are sufficient to select the runway configuration. However, how efficiently the airport serves the traffic demand depends

strongly on how the aircraft are assigned to runways. Selecting between pre-defined "departure split" procedures is the critical airport configuration decision at these airports, and requires an ability to predict departure queues relative to taxi times.

The uniqueness of airports presents a substantial challenge for airport configuration automation to be deployable to and beneficial at any airport. While all airports must select the runway configuration, other aspects of airport configuration vary at different airports. The TRCM algorithm and software are the same for any airport. Just as the runway configurations used at an airport must be provided as input data to the algorithm, the other procedures that may be selected are specified as input data. In this way, TRCM is able to output operationally meaningful advisories, rather than a value, such as operating point, that controllers would need to translate into the actual decisions to be made.

The TRCM algorithm selects the elements of airport configuration defined at that airport, including runway 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 objective function. 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 frequencies. The objective function considers overall delays for arrivals to reach their parking gates and departure to reach enroute airspace, not just runway delays. 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 to the objective function will consider 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 standard operating procedures 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. Some techniques are used to reduce computation time, such as searching for a single change to the current airport configuration schedule each time the algorithm runs.

A. Runway Usage Example

The TRCM algorithm and software are designed to operate at any airport. However, local knowledge is required to define the airport configuration questions that must be decided at that airport. Memphis International Airport (MEM) frequently operates in a runway configuration in which arrivals land on runways 18R and 18L and departures takeoff from runways 18C and 18R. A similar situation occurs in the equivalent north-flow runway configuration.

MEM uses rigid departure runway assignment rules based on the flight's departure fix to avoid departures crossing in the air. Most mornings, between 1300Z and 1500Z, there is a cluster of west-bound departures which are assigned to runway 18R. This departure push overlaps a period of steady arrivals. MEM procedures allow the TRACON to assign arrivals to either arrival runway. TRACON controllers, not aware of the impact on the overall operation, choose to minimize flight time and controller workload by assigning arrivals to the runway closest to their arrival fix. During this period of time, many of the arrivals are from the West and are assigned to runway 18R. The arrivals are given priority and the departures form a long queue at 18R waiting for infrequent, random gaps in the arrivals sufficient to fit a departure, while runways18L and 18C are under-utilized. TRCM will recommend that the arrivals be assigned to 18L and only overflow arrivals be assigned to 18R. This is similar to JFK which identifies a primary arrival runway and an overflow arrival runway. When runway 18R is not needed for departures, TRCM will advise that the closest arrival runway be used or, in light traffic, that the arrival runway that will minimize the combination of flight and taxi time (or cost) be used. No procedural changes are required; however, knowledge of the decisions that can be made at a given airport is required to adapt TRCM for the airport.

Tactical RCM was tested using the 62 flights that landed or departed during 1400Z-1530Z on September 9, 2010 at MEM. Thirty of the 43 departures were headed west; 10 of 19 arrivals approached from the west. Airborne and surface surveillance data were used to determine that the actual controller policy was to assign flights based on direction of flight for the entire time period. TRCM 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 metrics compared. The simulation considered flying time, runway delay, and taxi time. The TRCM-selected policy reduced the total delay for arrivals and departures from 45.0 minutes under the controller's policy to 22.6 minutes. 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.

B. Runway Assignment Example

Although John F. Kennedy International Airport (JFK) has a single rule for assigning departure runways based on departure fix, many airports have more flexibility. Atlanta Hartsfield International Airport (ATL) has several "departure splits" that describe different mappings between departure fixes and runways. Tactical Runway Configuration Management advises the departure split to balance the demand across the runways and minimize overall delay.

Orlando International Airport (MCO) has four parallel runways oriented north-south. From west to east, they are

36L/18R[2], 36R/18L, 35L/17R, 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, arrivals land on runways 36L and 35R; departures take off from 36R and 35L.

Orlando International 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 must coordinate the release of aircraft from the two runways to avoid conflicts in the air because the flight paths may cross or merge. The delay at the runway to implement this coordination is small and since traffic is light, departures queues do not accumulate. Los Angeles International Airport (LAX) similarly uses two modes, referred to as "taxi right" (assign runway based on departure fix) and "taxi simple" (assign closest runway).

The standard operating procedures (SOP) indicate 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 their workload. Some controllers taxi for convenience excessively causing flights to be delayed more than they would under the taxi for direction procedure. Tactial Runway Configuration Management can advise when each runway assignment procedure should be used.

Thirty-eight departures at MCO from 1055Z to 1155Z on October 13, 2010 were studied. Eleven of 17 flights from the west terminals, and 10 of 21 flights from the east terminals, departed to the west. Orlando International Airport operated in the North-flow configuration with departures on 36R and 35L. 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 policy during the time period. Tactical Runway Configuration Management selected "taxi for convenience" be used for the entire hour. The policies used historically and advised by TRCM were simulated and metrics compared.

Table 1 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

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[2] Normal convention for referring to runway configurations is Arrivals/Departures.

from Ramp 1 than runway 36R. 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 I.   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.

Table 2 summarizes the simulation results. Taxi for convenience results in slightly longer runway delays due to the need wait for traffic on the other runway that will cross and require merging. However, taxi for convenience produces a significantly smaller delay overall. This delay reduction, approximately 60% comes primarily from shorter taxi times, since 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.

TABLE II.   TRCM RESULTS AT MCO

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

C. Runway Configuration Examples

Tactical Runway Configuration Management is also capable of planning the runway configuration. To illustrate, a one-hour period of traffic from JFK on March 19, 2009 was studied. Forty departures and 24 arrivals operated during the time period from 1930Z to 2030Z, which contained a wind shift at 2000Z that exceeded the tailwind threshold for runways 22L and 22R.

The actual runway configurations were 13L,22L|13R prior to 2000Z and 4R|4L,31L after 2000Z. The TRCM algorithm selected the same initial and second runway configurations and advised the change to be made at 1951Z. The data source used to provide the actual runway configuration was limited to 15-minute resolution. This example shows that the configuration chosen by the controller is replicated by TRCM. In addition, TRCM planned which flights would be the last to use the first configuration and first to use the new configuration.

Tactical RCM does not always select the same runway configurations as were historically used. On June 24, 2009, according to Aviation System Performance Metrics (ASPM) data, JFK changed from runway configuration 22L,22R | 22R to 22L | 22R,31L at 1900Z as demand shifted from heavier arrival loading to heavier departure loading. For this traffic scenario, TRCM was seeded with the actual initial configuration. Tactical Runway Configuration Management

advised changing the configuration to 13L,22L | 13R immediately and then to 4R | 4L,31L at 1937Z. Both runway configuration schedules were simulated and metrics compared for 79 flights between 1900Z and 2000Z. 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 a departure queue started to form. This example, while planning runway configurations and change times may provide benefit, suggests 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.

V. System Analysis Studies for Metroplex RCM

System analysis studies have been performed for both RCM [10] and CADRS [11]. Chicago O'Hare International Airport (ORD) was modeled for the single airport RCM study. This airport is of particular interest because of the complexity of operations, the presence of dependent runways where arrival and departure procedures must be coordinated, a large number of available Runway Configuration Plans (RCP) and the Land and Hold Short Operations (LAHSO) on multiple runways. Modifications to the model were made to extend the analysis to the Chicago Metroplex by adding a second airport-level model for Chicago Midway International Airport (MDW) and a simple interaction module to account for the effect of MDW arrivals on ORD departures for specific pairs of RCPs. However it was clear that a more realistic model would be needed to model a Metroplex where the number of interacting airports was greater and the complexity of the interactions were stronger. A follow-on analysis of RCM in a Metroplex environment began in 2010.

A. RCM in a Metroplex Environment

There are a number of metrics available for identifying and characterizing a Metroplex (MP) [12]. The complexity of the airspace near closely spaced airports introduces effects that must be accounted for by a RCM Decision Support Tool (DST). The objective of the Metroplex RCM (MP-RCM) study is to understand what additional input variables are needed for MP-RCM, how an Airport-level RCM (AP-RCM) should be modified and extended to account for these inputs at dependent airports and what form the output of a MP-RCM DST should take.

The granularity of the airspace interactions among MP airports can be quite fine and occurs at the runway level. That is, operations on runway end Rwy_{A1} at Airport A, directly impacts those on Rwy_{B3} at Airport B. In the worst case, simultaneous operations on Rwy_{A1} and Rwy_{B3} may not be practical. More frequently the capacities on one or both runway ends will be reduced for any combination of RCPs at the two airports where this runway pair appears.

Additional Metroplex effects arise from the fact that forecast dynamic conditions (wind direction and speed,

visibility and ceiling, runway condition etc.) and operational state (arrival or departure bank, LAHSO, ground stops in effect etc.) cannot be assumed to change simultaneously nor in an identical way at the dependent airports. The visibility and ceiling at proximate airports can be significantly different and improve or degrade at different times and rates. The relative importance of these factors is expected to be strongly dependent on the Metroplex under consideration. To address this concern an MP-RCM system analysis study was conducted for the New York Metroplex.

B. Analysis Approach

Airports in a Metroplex can be weakly or strongly coupled. For the case where the coupling is weak, an AP-RCM analysis using the methodology developed for ORD is appropriate. For the strongly coupled case the procedure shown in Fig. 1 was developed. The AP-level model is used in the first iteration to rank order the RCPs at each airport assuming the airports are independent. These rankings are based on an aggregate RCP attractiveness metric and are used to downselect RCPs for further consideration. The down selected plans are combined into a set of n-tuples where *n* is the number of airports for which RCP changes are under consideration. The runway capacities for each RCP in the n-tuple are adjusted for Metroplex effects and the AP-level aggregate metric is re-computed with updated inputs. Finally the set of n-tuples with the updated attractiveness metrics for each RCP are input to a second ranking model to generate a MP-level attractiveness metric for each n-tuple. The rank ordering of the RCP n-tuples is one of the two primary outputs of a RCM DST. The second output is a schedule of times for the RCP changes, which may be different for each airport in an n-tuple. Schedules for two n-tuples may also be different.

C. Single Airport-level Calculation

The AP -level model consists of two modules. The first module computes a set of performance metrics for the set of available RCPs for forecast dynamic conditions and Operational State. The primary metrics are the arrival and departure capacity-demand ratios (CDRs) and the estimation Of aircraft delays resulting from an RCP change. In addition, There are qualitative metrics associated with the RCP change
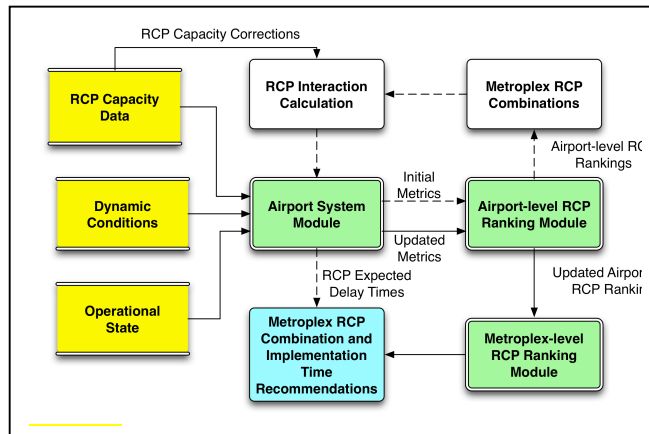

Figure 1.   System Model Block Diagram.

and any difference in ATC and aircrew workload between the current and future RCP. These metrics are input to the ranking model.

1) RCP Ranking Considerations

The ranking module is a conceptual representation of the decision process component of the RCM DST. It is not a final RCM decision support algorithm, but rather is designed as a mechanism to explore possible DST concepts and to evaluate how air traffic and runway configuration metrics can be combined to produce a useful DST. Air Traffic Control personnel using expert judgment do RCM currently and a successful RCM DST should at a minimum be capable of emulating this expert judgment. An inferential module uses an Approximate Reasoning (AR) algorithm well suited to emulating expert judgment using a combination of quantitative and qualitative input variables [13] [14].

2) AP-level Results for ORD

A series of use cases spanning a wide range of dynamic conditions, operational states and forecast capability were analyzed using the AP-RCM model. Fig. 2 shows the ranking of the five most common ORD RCPs for a set of representative use cases. These results showed that an AP-RCM DST could provide useful guidance to ATC TFM in planning and scheduling RCP changes at an independent airport.

D. New York Metroplex Model

Based on available Metroplex studies, four airports were modeled: John F. Kennedy International (JFK), Newark Liberty International (EWR), La Guardia (LGA) and Teterboro (TEB). A set of RCPs was selected from the FAA OIS website [15] for each airport. The number of RCPs varies from 21 (JFK) to 5 (TEB). Initial Airport Acceptance Rate (AAR) and Airport Departure Rate (ADR) estimates for a RCP as a function of meteorological conditions were also taken from the website and later verified with New York TRACON (N90) personnel. An
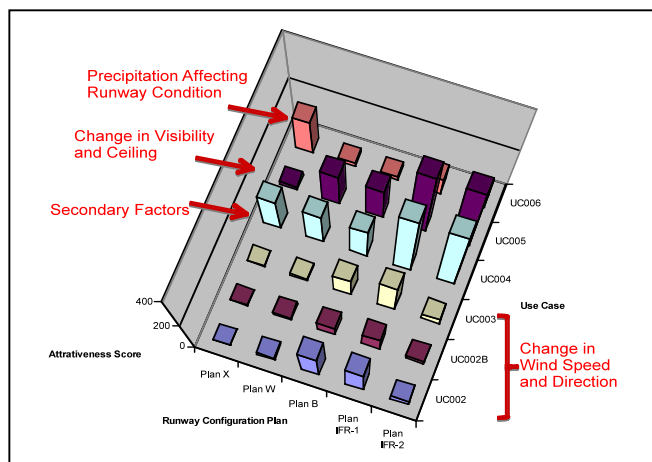

Figure 2.   Representative use case results for ORD analysis

analysis was performed to convert RCP-level data to individual runway capacities taking into account intra-airport dependencies; corrections for LAHSO operations were also estimated. This is similar to the ORD analysis except that all of the capacity data are at the runway- rather than RCP-level in anticipation of MP dependence.

Demand data as a function of time of day and aircraft weight class for visual meteorological conditions (VMC) were generated using Airspace Concept Evaluation System (ACES) calculations [16]. Reductions in demand as a function of meteorological conditions were also computed. John F. Kennedy International Airport and EWR handle a significant number of international operations with characteristic demand peaks at specific hours that are also tracked. Residual demand resulting from earlier inadequate capacity can also be input. All of the capacity and demand data are stored in a database that is queried by the system module to calculate the CDRs. In a functional RCM DST a database architecture would provide an interface with other TFM DSTs.

E. Metroplex-level Calculations

MP-RCM leads to the selection of an RCP for each airport. The number of possible RCP n-tuples can be very large. For the New York airports there are over 10,000. Evaluation of each quadruple for capacity dependencies was judged impractical. Capacity corrections are performed for pair-wise combinations of airport RCPs where a runway interaction occurs. The first step in the MP -level calculation is to select a subset of RCPs, S at each airport using the AP-level attractiveness metric ranking. The total number of quadruples, Q to be considered is S^4. Analysis showed that examination of only the top two ($S = 2$) or three ($S = 3$) ranked plans is sufficient. Based upon discussions with N90 personnel, a secondary ranking step was added to give greater consideration to the most commonly used RCPs.

Iteration is performed over the set Q. Each RCP in a quadruple is tested to determine whether it has an interaction with another RCP. If the interaction results in the loss of an active runway then the quadruple is dropped. Runway capacities are updated for interacting RCPs and the airport-level ranking model is called to update the attractiveness metric. The revised RCP attractiveness metrics are input to a second ranking module that computes an overall attractiveness for the quadruple. This module also uses the relative importance of the airports in the rank ordering.

1) Illustrative Results

Fig. 3 shows the output of the MP-level inferential model for a test use case with N = 2. Each bar is the attractiveness metric for the quadruple with the RCP identified by the first letter of the airport designator and a numeric key. For this test case the overall capacity at LGA for one of the two down selected RCPs is insufficient. Examination of the rankings shows that the variation is explained by the difference in CDRs for the two LGA RCPs. A set of use cases similar to the New York MP-RCM model is currently being analyzed
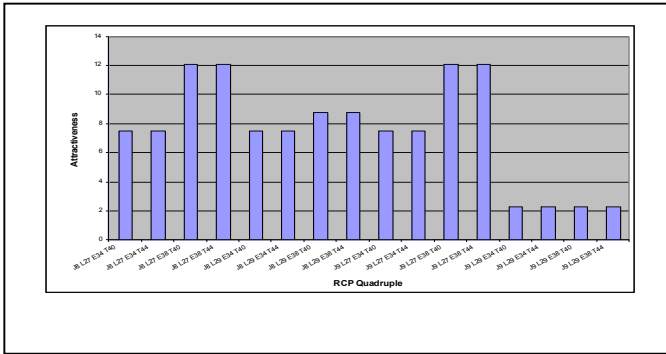
Figure 3. Rankings for RCP quadruples for NY Metroplex

with emphasis on dynamic conditions and operations states that lead to strong airport interactions.

2) Future Work

Several areas for future research have been identified.

- Evaluate the level of effort to adapt the model to a specific Metroplex. To this end, models for the Northern and Southern California Metroplexes are under development.

- Provide the ability to drill down into the DST output and to generate what-if scenarios for RCM.

- Extend the expected delay time model for a single airport as the basis for MP-RCM scheduling.

VI. INITIAL SORM BENEFITS ASSESSMENT

System Oriented Runway Management's expected benefits include supporting traffic growth, cost reduction as a result of system efficiency, NAS optimization from Metroplex operations, fairness in aircraft operations, and rational decision-making. SORM's two primary elements, RCM and CADRS, are distinct technologies that individually will enhance airport performance, but they will perform best in unison.

A. SORM Airport Capacity Benefits

The analysis of SORM's airport capacity benefits is important not only for its own sake, it is also the starting point for the subsequent throughput and flight time saving estimations. Of the two SORM components, our analysis only covers the airport capacity enhancement provided by CADRS. By definition, RCM chooses between configurations so, as a result of RCM, an airport might operate in a configuration that has a higher capacity than the baseline configuration chosen by controllers and the airport would benefit from this. However, RCM cannot change a given configuration's capacity, it can only choose between configurations to find the one best suited to the demand and weather conditions. RCM's airport capacity benefit depends on the dynamics of the demand pattern and the weather and our measure is gauged against the runway configuration used in the baseline year (2009). Accordingly, while RCM does

have capacity benefits, they have not been captured in our current modeling effort.

We used an analytical runway capacity model for the estimation of CADRS capacity benefit. The binding constraints of the capacity models are the miles-in-trail (MIT) separation and the single occupancy rule on the active runway with due consideration of the traffic mix, the length of the final common path, the delivery inefficiency at the TRACON fixes, and the uncertainties of the position, speed, and wind. The CADRS capacity benefits stem from sequencing the aircraft for reduced separation, balancing of the runways, and reduced separation due to wake vortex avoidance by taking advantage of crosswinds. This initial benefits analysis took an encompassing view of SORM benefits but the allocation of particular functional benefits – such as wake vortex avoidance – is subject to further refinement before reaching any investment analysis decisions. Thus while the actual wake vortex avoidance algorithms and concept of operations is outside the scope of SORM, we envision CADRS receiving such data and advisories as input and then making a systematic assessment of how to take advantage of that information with the additional system-wide perspective of arrival and departure scheduling that CADRS provides.

The capacity increases were estimated during each 15-minute window during the year 2009 for each of the 77 airports in the FAA's Aviation System Performance Metrics (ASPM) database, depending on the runway configuration used at the time. Out of this massive data collection and analysis, a simple measure of the capacity benefit is the change in the average airport capacities, measured by Airport Arrival Rate (AAR) and Airport Departure Rate (ADR). Results show that the average AAR and ADR increased from 47.9 to 53.3 (11.3%) and from 45.7 to 46.6 (1.9%), respectively.

B. SORM System-wide Throughput Benefits

The throughput benefit estimate follows a well-developed methodology that has been used for many NASA and Joint Planning and Development Office (JPDO) benefit studies [17]. In this methodology, the throughput benefit is defined as the difference between the number of scheduled flights with and without SORM. Since airlines start the flight scheduling process several months ahead of the operating time, it is impossible to foresee the weather and thus impossible to take advantage of the possible enhanced airport capacity offered by RCM, thus our estimation of SORM throughput benefits is based on CADRS only.

The methodology is based on the premise that because of the traffic growth in the future, an airport may not be able to support the unconstrained demand for operations predicted from socio-economic factors; i.e., some of the flight operations must be trimmed from the future schedule to fit the airport capacity constraints. Following the capacity benefit estimate, the capacities used for the throughput

benefit estimates are the 90th percentiles of AAR and ADR as in the baseline and under SORM [18]. Using eight sample days, the unconstrained annualized airport operations at ASPM 77 airports in 2018 and 2025 are 23.52 and 27.16 million, respectively. Without SORM, the projected throughput in 2018 and 2025 is 22.27 and 24.64 million operations, respectively. With SORM, the projected throughput in 2018 and 2025 is 22.44 and 24.90 million operations, respectively. In other words, SORM would enable an extra 170,000 and 270,000 annual operations in 2018 and 2025, representing roughly 0.7% and 1% of the unconstrained operations in those years, respectively.

C. SORM Flight Time Savings Benefits

We built an abstract queuing model to estimate the flight timesavings benefits of CADRS, RCM, and their combination as SORM, relative to the baseline. The model is built in Arena. The model's scope is limited to the area within the TRACON and also does not consider the inner gate area. The model was used to study 10 airports, five in the New York City area: JFK, EWR, La Guardia Airport (LGA), Westchester County Airport (HPN), and Teterboro Airport (TEB), and five in the Los Angeles area: LAX, Long Beach Airport (LGB), Ontario International Airport (ONT), Bob Hope Airport (BUR), and John Wayne-Orange County Airport (SNA).

Combined Arrival/Departure Runway Scheduling was modeled as a runway processing capacity enhancement. RCM is modeled with an approximation of the real world algorithm. This approximation chooses configurations that will minimize unmet demand over a 90-minute time horizon while taking taxi distance, flight path distance, and the direction of aircraft flows into account. SORM was modeled as RCM and CADRS working together. We compared the time required to move through the system under different demand and technology scenarios to calculate the potential flight delay reduction benefit.
Fig. 4 depicts the results for the benefits of SORM in reducing time-in-system for arrivals and departures for the 10 airports we modeled, for 2025 demand.
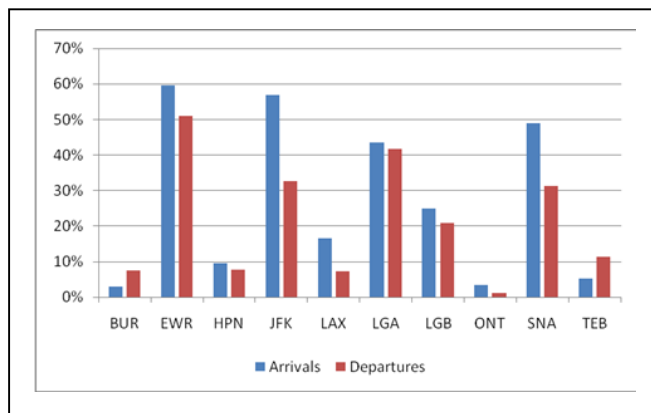

Figure 4. Percent reduction in annualized average time-in-system by airport, 2025 demand

The initial analysis indicated that RCM, CADRS, and their combination can significantly reduce average flight time and ground time for operations within the TRACON, in some cases by as much as 60%. Such large benefits should be taken with caution as these results follow from situations where our model has the airport operating very near its baseline airport capacity and thus the baseline time in system is very high; even a small level of capacity increase engendered by SORM then produces a large reduction in time in system and thus a high reduction percentage. The primary New York airports (EWR, JFK, and LGA) exhibit such results. To refine these initial benefits estimates, our further analysis needs to more realistically constrain the level of projected traffic at airports like these; indeed, these are airports that already operate under FAA slot controls. Once the traffic projections are more realistic, our benefits analysis of SORM will be correspondingly more realistic.

For brevity, only the results of the combined RCM and CADRS benefits are shown but note that, in general, CADRS has a greater impact than RCM, and the combination of CADRS and RCM provides only modest improvement over CADRS alone.

D. Remaining SORM Benefits Work

The benefits analysis results presented in this paper are the initial results of ongoing analysis work. The most significant gap in the current work is the lack of treatment of Metroplex benefits. Given its envisioned capabilities to optimize runway configuration selection and balancing not just within a given airport but across the runways at proximate airports, SORM's benefits in improving Metroplex operations is expected to be significant. Additionally, while the capacity and throughput benefits estimation has been done at 77 airports and can thus be reasonably described as system-wide, the flight time savings estimates should be extended to more than 10 airports. Furthermore, each of the performance benefits should be translated into economic terms; i.e., into monetary benefits. That monetization process should only be done once the modeling and analysis of performance benefits has been refined in the ways indicated. Finally, a cost analysis should be conducted to allow for a complete cost-benefit assessment to support a traditional investment analysis.

VII. SUMMARY

The airport runway is a constraining factor in the NAS and effective management of this limited resource is required if NAS efficiency gains are to be realized. The SORM concept has been developed to assist with the task of runway management. This includes runway configuration selection, time for configuration changes and runway assignment for both the single airport case as well as multiple airport, or Metroplex) and providing recommendations to air traffic personnel. Progress to date has included development of a concept of operations, algorithms to support runway configuration selection, modeling work focused on the single

airport and metroplex, and benefits analysis work. It seems clear however, that SORM would provide clear benefit in terms of runway configuration management and runway assignment. Further, due to the complexity of the factors affecting runway management, continuing analysis will be required as capabilities are developed. The RCM function of SORM has been identified as a product for eventual transition to the FAA through the IADS Research Transition Team for both the Single Airport and Metroplex. The FAA has already requested the initial version of the SORM TRCM algorithms.

VIII. FUTURE RESEARCH ACTIVITIES

Basic runway management capabilities have been incorporated into the SORM algorithms based on the initial concept of operations. Significant work lies ahead in a number of areas. Refinement of the core function configuration management functions will continue and additional capabilities will be added (e.g. airport operator constraints, user preferences, environmental considerations, among others). Emphasis to date has been on the TRCM capability, which will continue to be developed in concert with further progress planned for SRCM and CADRS in the coming year. As progress is made in other research areas such as surface and airspace operations and TFM, SORM will continue to adapt its capabilities to ensure maximum effectiveness of intended functions. Integration of enhanced TFM functions is particularly critical to SORM as the NAS moves forward to more integration oriented solutions. SORM will also leverage on longer term, more accurate weather forecasts. As the air traffic system realizes greater precision through the use of Required Time of Arrival (RTAs), benefits of SORM may increase significantly. Potential changes in wake vortex separation standards require added functions to the SORM logic to permit the assessment of capacity changes and provide recommendations accordingly. A prototype user interface is currently under development; an expanded effort is anticipated in this area over the next year. Finally, SORM capabilities will continue to be developed using the New York Metroplex as the operational environment. Other airports will be considered as resources permit.

ACKNOWLEDGEMENTS

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