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A Concept of Operations for Far-Term Surface Trajectory-Based Operations (STBO)

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June 2014

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Contents

Figures and Tables

Acronyms

2D	two dimensional
4D	four dimensional
ADS-B	Automatic Dependent Surveillance-Broadcast
AMA	airport movement area
ANSP	air navigation service provider
AOC	airline operational control
ATC	air traffic control
ATCo	air traffic controller
CD&R	conflict detection and resolution
CDM	Collaborative Decision Making
ConOps	Concept of Operations
CSPO	Closely Spaced Parallel Operations
DataComm	Data Communications
DFW	Dallas Fort Worth International Airport
DR	Departure Routing
DRM	Departure Reservoir Management
DST	Decision Support Tool
EFB	electronic flight bag
ETA	estimated time of arrival
FAA	Federal Aviation Administration
FARGO	Flightdeck Automation for Reliable Ground Operation
FD	flight deck
FMS	flight management system
GBAS	Ground-Based Augmentation Sstem
GC	Ground Controller
GPS	global positioning system
HITL	human-in-the-loop
IADS	Integrated Arrival, Departure, and Stystems
kts	knots; nautical miles per hour
LC	Local Controller
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASEA	National Airspace System Enterprise Architecture
NextGen	Next Generation Air Transportation System
nmi	nautical miles

PDRC	Precision Departure Release Capability
PDT	Proposed Departure Time
PFD	primary flight display
RCM	Runway Configuration Management
RNAV	Area Navigation
RNP	Required Navigation Performance
RTA	required time of arrival
SORM	System Oriented Runway Management
STBO	Surface Trajectory-based Operations
SWIM	System-wide Information Management
TAPSS	Terminal Area Precision Scheduling System
TBO	Trajectory-Based Operations
TFDM	Terminal Flight Data Manager
TFM	traffic flow management
TMAT	Target Movement Entry Time
TMI	Traffic Management Initiative
TND	Taxi Navigation Display
WP	work package
WTMD	Wake Turbulence Mitigations for Departures

Definitions

4D trajectory: *x-y* position assigned for each time, *t.* (Referred to as a 4D trajectory even though altitude is fixed on surface.)

Airport movement area: Taxiways and runways under control of Air Traffic Control (generally does not include ramp).

Conflict-free route: Routes on which two or more aircraft will not intersect, assuming a nominal range of safe speeds.

Contingency hold: Contingency hold procedures are implemented as a fail-safe procedure at active runways and traffic flow constraint points. Pilots are expected to hold unless cleared by ATCo. Ideally, if RTAs and sequencing constraints are met, the aircraft is cleared before the pilot initiates slowing.

Departure queue: The number of aircraft waiting for departure.

Departure queue area: The paved holding area where aircraft in departure queue wait for clearance onto the departing runway.

Departure schedule: Specific timing required to accomplish sequencing and integrate with arrival/ departure schedule.

Departure sequence: The order of aircraft as they takeoff from the departure runway.

Expect taxi clearance: Expect taxi clearances (also referred to as pre-clearances in Cheng, Yeh & Foyle, 2003) are issued at gate, or on approach, and are intended to allow pilots to better manage workload and increase situation awareness by providing sufficient time to review and load clearances in advance. They are not a clearance to taxi from ATC. Actual clearances may be different than the expected clearance if a replan is required.

Required time of arrival (RTA) window: A time window within which an aircraft must arrive at a traffic flow constraint point, runway, or gate.

Runway occupancy time: The amount of time that an aircraft occupies a runway.

Runway occupancy time window: The window of time allocated for an aircraft to cross a runway.

Runway entry time: The instant in time at which an aircraft enters the runway.

Safety monitor automation: A category of NextGen STBO automation capabilities that is responsible for surveillance, conformance monitoring, conflict detection and resolution.

Scheduling and sequencing automation: A category of NextGen STBO automation capabilities that is responsible for scheduling departure runways, runway crossings, and spot release.

Spot reference: A point on the ramp where aircraft enter the movement area and are controlled by ATC. (Not all airports have spots.)

Surface Trajectory-Based Operations (STBO): Surface Trajectory-Based Operations is a concept for managing flows and resources on the airport surface. STBO envisions delivering a specific aircraft to a specific place on the airport (e.g., runway) at a specific time to meet a specific event (e.g., takeoff) in the most efficient manner possible (Ashley, et al., 2011).

Taxi manager automation: A category of NextGen STBO automation capabilities that is responsible for generating taxi routes and runway clearances, traffic sequencing, and taxi route replanning.

Traffic flow constraint point: A known location on the airport surface used for traffic sequencing.

A Concept of Operations for Far-Term Surface Trajectory-Based Operations (STBO)

Becky L. Hooey[1], Victor H.L. Cheng[2], and David C. Foyle[3]

ABSTRACT

This document provides a high-level overview of a far-term NextGen Surface Trajectory-Based Operations (STBO) Concept of Operations (ConOps).

The goal of this far-term STBO ConOps is to increase the efficiency and predictability of airport surface operations, and reduce the environmental impact, by incorporating a time-based component to surface operations. In the far-term NextGen timeframe, airport surface operations will transition from current-day first-come, first-served operations, to strategically scheduled operations in which pilots are recruited as active participants in meeting the precise time-based goals of NextGen surface operations.

The far-term STBO concept includes two-phases. Phase 1 introduces time-based traffic flow constraint points, which divide the taxi route into segments with an assigned required time of arrival (RTA). This Phase 1 approach provides temporal certainty only near the traffic flow constraint points, but not in between. Minimal augmentations to the flight deck are required to support RTA management.

Phase 2 further increases precision and efficiency by introducing full four-dimensional (4D) trajectories, with an x-y location for all times t. This phase assumes adoption of advanced flight deck equipage enabling higher temporal precision sufficient to support aircraft conformance to 4D trajectories. This allows more precision and less temporal uncertainty at all times along the route.

Given the far-term nature of this concept, one of the main purposes of this document is to identify the research issues and gaps to provide guidance for the research required to accomplish this vision. It is also intended as a necessary first-step towards system studies, which will be required to quantify expected benefits and costs in the NextGen environment.

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[1] San Jose State University.

[2] Optimal Synthesis Inc.

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1. Introduction

1.1 Identification

This document summarizes a far-term NextGen Concept of Operations (ConOps) for Surface Trajectory-based Operations (STBO). STBO is a NextGen concept that envisions delivering a specific aircraft to a specific place on the airport (e.g., runway) at a specific time to meet a specific event (e.g., takeoff) in the most efficient manner possible (Ashley, et al., 2011).

1.2 Scope

The purpose of this ConOps document is to capture the far-term vision for surface operations to guide NASA's research program. It is intended as a logical follow-on to the FAA mid-term ConOps (Ashley, et al., 2011) and supports the incremental deployment toward full surface trajectory-based operations, with a transition path from current equipage to far-term equipage.

This ConOps includes airport surface operations between the airport movement area (AMA) and runway. It is not intended to specify gate management, airport configuration, or runway management concepts (these are addressed under other Surface Collaborative Decision Making (CDM) concepts and Integrated Arrival, Departure, and System (IADS) concepts). Ground vehicles (e.g., fuel trucks, baggage carts, catering trucks) and airline-controlled ramp operations are beyond the scope of this ConOps.

Given the far-term nature of this concept, one of the main purposes of this document is to identify the research issues and gaps to provide guidance for the research required to accomplish this vision. It is also intended as a necessary first-step towards system studies, which will be required to quantify expected benefits and costs in the NextGen environment.

2. Background

This far-term STBO concept builds on two previously established and related efforts: 1) The FAA mid-term STBO concept; and, 2) the Terminal Flight Data Manager automation system[4]. These efforts serve as the starting point for the far-term concept, and thus are described next, before the far-term concept is introduced.

2.1 FAA Mid-Term STBO Concept Overview

The FAA mid-term NextGen STBO concept aims to reduce taxi times and congestion, resulting in reduced fuel burn, lower carbon emissions, less noise, and enhanced surface safety (FAA, 2009a). STBO operational concepts are expected to increase airport surface efficiencies through shared situation awareness and local collaboration, and to support better decision making through local information sharing and Decision Support Tools (DSTs; Prevost, 2009). The FAA's mid-term STBO ConOps includes capabilities that support the following high-level surface operations (Morgan & Burr, 2009):

- providing recommendations to improve utilization of airport surface resources without overly constraining operators
- maximizing runway throughput by appropriately spacing and sequencing departure aircraft and by managing queues for departing and arriving flights when demand for airport surface resources exceeds capacity

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[4] The FAA mid-term STBO concept and the TFDM are currently under development and as such their specifications are evolving. The information presented is based on the documents available at the time of writing (August 2012).

- exchanging operational surface data among stakeholders
- facilitating collaboration between air traffic management (ATM) and flight operators to develop a surface schedule that meets traffic flow management (TFM), arrival and departure constraints as well as surface constraints
- generating taxi routes and surface conformance

The STBO concept functional capabilities that are expected in the FAA mid-term timeframe can be classified into three concept areas:

- Surface Operational Data Exchange
  - Robust data exchanges necessary for shared situation awareness provided using authorized and secured access.
- Planning and Scheduling of Airport Resources
  - DST capabilities that use multiple characteristics such as airport status, National Airspace System (NAS) status, airspace configuration, flight arrival and departure demand information, current assigned runway, and the predicted departure schedule to support tower controllers and traffic managers in the generation of a surface plan. It includes a sequence of flights on taxiways for the departure runway and the automation support to improving airport throughput and provides impact analysis of user preferences.
- Managing Taxi Operations
  - Includes the generation, modeling, monitoring, and optimization of taxi routes. It also includes the integration and coordination of the taxi routes during airport planning and scheduling events (e.g., a runway configuration change).

2.2 Terminal Flight Data Manager

Terminal Flight Data Manager (TFDM) is planned as a highly integrated tower automation system that consolidates a number of tower automation systems and displays used in current-day tower operations (Nene, Morgan, & Colavito, 2010). It is expected to provide electronic processing and distribution of flight data to different control positions in the tower and to other domains, surface surveillance information including associated alerts and alarms indicating potentially unsafe conditions, and a suite of integrated tools to assist the controllers in performing their tasks and reducing workload.

TFDM assumes electronic processing of flight data to enhance data exchange between the en route, TFM and terminal domains. TFDM will consist of a set of tactical and strategic tools (see Table 1) to support scheduling and sequencing aircraft, managing surface movement, and other tasks. Strategic tools will support Traffic Management Initiatives (TMIs) related to weather and traffic flow constraints.

It is anticipated that TFDM capabilities will be implemented in incremental work packages (WPs) with the first work package being the foundational or “core” work package and Work Packages 1 and 2 representing the NextGen mid-term concept (FAA, 2011). The Core Work Package provides basic infrastructure to support NextGen tower automation functions identified in the NAS Enterprise Architecture (NASEA), begins the consolidation of legacy tower equipment, and lays the foundation for additional functionalities in later work packages. Core capabilities include electronic flight data, surface surveillance data, traffic management, aeronautical information, weather data, data link communications to pilots, early system-wide information management (SWIM) interfaces, and limited DST capabilities. Work Packages 1 and 2 will refine and improve the Core DST capabilities and introduce new DST capabilities for Departure Routing (DR). These future work packages will also introduce expanded data exchange between the tower and airport entities, additional SWIM interfaces, and additional consolidation of legacy equipment (FAA, 2011). Adapted from the FAA STBO Mid-Term ConOps v2 (Ashley, 2011), Table 1 represents the surface capabilities that are expected to be developed and implemented in the NextGen mid-term timeframe.

Table 1. TFDM Functional Capabilities

Function	*Capabilities*
Airport Configuration Management	Core: - Analyze, implement, and disseminate airport configuration change. WP1 added functionality; includes Core functionality: - Recommend configuration change and time.
Scheduling and Sequencing	Core: - Generate runway schedule. - Display flight-specific TFM times/constraints and indicators. - Generate flight state data. WP1 added functionality; includes Core functionality: - Recommend departure runway sequence. - Generate flight-specific surface event times. - Process flight-specific information from flight operators and ramp towers. - Monitor surface schedule compliance. - Integrate Wake Turbulence Mitigations for Departures (WTMD) into surface departure schedule. - Process deicing information and surface schedule impacts. - Manage departure queue collaboratively with flight operators. - Manage the surface departure schedule collaboratively with flight operators. - Analyze alternatives for surface management.
Runway Assignment	Core: - Assign departure runway based on pre-defined rules. - Provide real-time runway assignment rule management and use. WP1 added functionality; includes Core functionality: - Analyze manually entered runway assignment. - Balance departure loads on runway. - Process flight-specific departure runway assignment information from flight ops. - Integrate WTMD into runway assignment.
Taxi Routing	Core: - Manage and display real-time state of runways and taxiways. - Provide queue location and/or intersection departure. WP2 added functionality; includes Core functionality: - Manually assign pre-defined taxi route to a flight. - Manually enter and assign ad hoc taxi route to a flight. - Recommend pre-defined two-dimensional taxi route. - Recommend non-standard two-dimensional taxi route. - Monitor conformance to two-dimensional taxi route. - Monitor aircraft compliance with control instructions.
Departure Routing Tool	Core: - None. WP1 added functionality; includes Core functionality: - Display flight-specific departure route indicator.

2.3 Mid-Term Concept Assumptions

The following operational and technical assumptions are expected to be fulfilled throughout the timeframe of the FAA mid-term work packages 1 and 2. As such, these are fundamental building blocks for the far-term concept.

2.3.1 Operational Assumptions

Based on (FAA, 2010), the following operational conditions are assumed:

- Traffic demand may be as much as 1.5 to 2.0 times current-day level.
- There will be no major changes to airport infrastructure (e.g., runways, taxiways) at most airports.
- Aircraft will be able to fly Required Navigational Performance (RNP)/Area Navigation (RNAV) routes into and out of the airport.
- Air carriers and other aircraft operators will have better information about the status of their surface operations than they do today; they will share this information with Air Navigation Service Provider (ANSP) personnel and systems.
- Weather observations will be more frequent and predictions will be more accurate. All weather information will be broadly distributed in a net-centric way. Improved weather information and distribution are expected to result in less restrictive Traffic Management Initiatives (TMIs).
- Expected TMIs will be shared with all stakeholders in a net-centric way.
- Inter-domain exchange of flight data will be significantly expanded to include elements of the future Flight Object[5].

2.3.2 Technical Assumptions

Based on the FAA mid-term ConOps, the following technologies are expected:

- Transponders are installed on all aircraft (and ground vehicles as necessary).
- Data Communications (DataComm) are available as a means of communication between air traffic controllers (ATCo) and flight deck for transmission of runway assignment and taxi routing information. Time-urgent or safety-critical communications could be issued by voice or datalink.
- Data sharing between ATC, ramp tower, and Airline Operational Control (AOC) are in place.
- Some form of ADS-B for surveillance with Ground-Based Augmentation Systems (GBAS) and/or multilateration exists to provide identity, position, and velocity of aircraft and transponder-equipped vehicles.
- Terminal Flight Data Manager (TFDM), a suite of controller decision support tools based on advanced schedulers and optimizers, are in use to manage airport configuration, runway assignment, scheduling and sequencing, and (2D) taxi routing.
- Electronic flight data management (aka electronic flight strips) is in use and has replaced paper flight strips.
- Air traffic control (ATC) and flight deck have access to real-time state of runways and taxiways.
- Taxi Navigation Displays (TND) capable of showing airport database, ownship, traffic, routes are integrated into flight decks.

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[5] The flight object is a collection of common information elements describing an individual flight and available electronically for use by both the NAS users and the ATM service providers (Viets & Taber, 2000).

3. A Far-Term STBO ConOps

The goal of the far-term STBO ConOps is to leverage and extend the FAA's intended mid-term STBO capabilities of information sharing, planning and scheduling, and taxi route management, to further increase efficiency, throughput, and predictability of airport surface operations, while reducing the environmental impact, by incorporating a time-based component to surface operations.

3.1 Purpose and Rationale

This far-term STBO ConOps seeks to address the following current-day surface operations issues:

1. Inefficient departures with long departure queues
2. High temporal uncertainty resulting in frequent aircraft 'stops and starts'
3. Inability to support other NextGen ConOps

Each is discussed and summarized in Table 2.

Table 2. Problem Statements, NextGen Improvement, and Operational Impact

Problem Statement	*NextGen Improvement*	*Operational Impact*
Inefficient departures with long departure queues	• Reduce departure queue size by delivering aircraft to runway with minimal wait times • Reduce separation between departures with strategic sequencing • Reduce uncertainty of aircraft arrival time at runway	• Increase capacity • Increase runway throughput • Fewer missed departure slots • Reduce fuel burn • Reduce emissions • Reduce delay
High temporal uncertainty resulting in frequent aircraft 'stops and starts' on the airport surface	• Increase timing precision of aircraft arrival and key airport resources • Cross aircraft between arriving and departing aircraft in a non-interfering manner • Strategic scheduling of aircraft to reduce holds or waiting for other aircraft; reduce long departure queues	• Reduce fuel burn • Reduce emissions • Reduce delay • Increase capacity • Increase predictability of traffic
Inability to support, or realize maximal gains from, NextGen Concepts	• Absorb increased throughput from NextGen arrival concepts (TAPSS, CSPO, reduced separation) • Improve surface traffic control for efficient transition between runway configurations to realize NextGen runway configuration management concepts • Extend uses of DataComm for surface • Enable efficient departure sequences to support concepts such as paired departures; metroplex operations; trajectory-based operations for all phases of flight	• Enable NextGen benefits to be realized to their full potential: increase throughput, efficiency and safety; minimize fuel burn, emissions, and delays.

Notes: CSPO = Closely Spaced Parallel Operations; TAPSS = Terminal Area Precision Scheduling System; TBO = Trajectory-Based Operations

3.1.1 Inefficient Departures with Long Departure Queues

In current-day operations, due to the complex sequencing and spacing constraints that controllers must meet, a reservoir of flights with different characteristics (e.g., departure fix, aircraft type, weight class, engine type, runway requirements, etc.) is maintained at the departure queue from which the controller can select the best sequence for departure. The departure queue is generally created such that the target departure queue length agreed by the local Surface CDM Stakeholders at an airport is maintained, and includes an appropriate diversity of aircraft (Surface CDM ConOps, 2010). Due to the current inability to accurately pre-plan for departure fix balancing, fleet mix, and inter-aircraft spacing requirements, and because there is no way to precisely predict when aircraft will arrive at the runway for departure, the ATCo must respond to aircraft in a tactical manner as they arrive at runways.

The current-day need to maintain this departure queue results in excessive delays and fuel burn/ emissions. As per the Shortfall Analysis Report for TFDM (FAA, 2010) “Departing aircraft may have to hold short or be diverted to a holding area as they approach the runway for the departing flight to meet separation requirements and traffic management constraints” and “Aircraft engines running while in queues results in noise, air pollution and wasted fuel.” The TFDM shortfall report estimates a total potential savings from queue reduction of 24 million hours over the proposed 20-year TFDM lifecycle. And, as a result of inefficient departure scheduling, runway capacity is not fully utilized, with reduced throughput and missed departure slots.

This far-term NextGen concept aims to reduce departure schedule inefficiencies by delivering an aircraft to the runway at a specific time such that aircraft can depart in a timely manner and with efficient sequencing. By strategically sequencing aircraft, for example, so that heavy aircraft are grouped together and sequenced after smaller aircraft, the local controller can effect reduced separation between departing aircraft, and do so with smaller departure queues. Specifically, this far-term NextGen STBO ConOps attempts to alleviate long delays in departure queues by the following:

- maintain queue length of no more than three aircraft by allowing aircraft to hold at gate instead of at runway and strategic scheduling of departures
- reduce uncertainty of aircraft arrival time at runway by providing support to pilots to meet a specific required time of arrival (RTA) to the runway or runway queue area

3.1.2 High Temporal Uncertainty Resulting in Frequent Aircraft ‘Stops and Starts’

Current-day operations are often characterized by frequent stops and starts as taxiing aircraft are required to hold short of taxiway intersections and active runways, hold short for crossing traffic, and wait in lengthy departure taxi lines (“conga lines”) and departure queues with engines running preparing for takeoff. In current-day operations, the ATCo often queues aircraft waiting to cross active runways until there is a break in the arrival or departure stream or until the number of aircraft being queued is sufficiently large and then crosses all aircraft at once. This occurs because of a lack of capability to predict when arriving / departing aircraft will be clear of the runway, and when taxiing aircraft will arrive at the runway to be crossed.

The Shortfall Analysis Report for TFDM (FAA, 2010) stated that “It is a well-known result of queuing theory that the greater the variance in service rates the greater the delays” and further that “a savings in delay of approximately 1.5 minutes per flight could be achieved via the reduction of uncertainty in service times.” The long delays experienced by aircraft waiting to cross active runways results in excessive delays, fuel burn and emissions. As stated in the TFDM Shortfall Analysis report, “Of significance to the environmental impact of this queuing operation are both the time engines spend idling and the need for flights to make small incremental steps along the taxiway as each flight ahead of it departs and the queue moves forward. This procedure significantly increases the amount of engine emissions that are produced because of the number of times the aircraft must apply 'break-away' power to start taxiing, only to have to stop again after moving just a short distance." Recent studies (Nikoleris, Gupta, and Kistler, 2011) of surface traffic data from Dallas/Fort Worth International Airport (DFW) revealed that as much as 18% of fuel consumption during taxi operations was due to stop-and-go activity. This research concluded that if this stop-and-go activity can be eliminated by improving the efficiency of taxi operations, it would result in 2.5 million gallons of jet fuel savings per year. A further study showed that the average stopped time of aircraft at DFW in crossing queues during busy traffic times was over 2 minutes, which was the most significant contribution to the taxi delay of arrival aircraft at DFW (Monroe, Jung, & Tobias, 2008).

This far-term NextGen ConOps aims to reduce uncertainty of aircraft position on the airport surface and arrival at key airport resources (runways and gates). Rather than predicting when an aircraft will arrive at a runway or destination based on historical trend data or average taxi time, the ConOps enables pilots to act as active participants in achieving the goal of on-time performance and reduced uncertainty. This far-term NextGen ConOps attempts to reduce the delays to cross active runways by increasing the timing precision with which aircraft arrive at runways to be crossed and allowing crossing at efficient taxi speeds between arriving and departing aircraft in a non-interfering manner without waiting for a break in the arrival[6] or departure stream. This is expected to yield not only savings in fuel, but also a smaller required runway crossing time window, which would mean less interruption to arriving and departing flights. Further, this far-term ConOps aims to minimize start-and-stop taxiing by:

- delaying the release of aircraft from the gate or ramp spot until a continuous taxi can be ensured
- providing RTAs for to-be-crossed runways so that aircraft arrive at runways 'just-in-time' without the need to stop prior to crossing whenever possible
- reducing departure queue length
- in conjunction with TRACON, strategically scheduling aircraft to prevent the need for aircraft to hold / wait for other aircraft

3.1.3 Inability to Support NextGen Concepts

The full potential of many of the NextGen Arrival, Departure, and En route Concepts that are currently at varying stages of research, development, and implementation, may not be realized unless the STBO concept is implemented.

The far-tem NextGen STBO concept supports these NextGen concepts by:

- absorbing increased throughput from NextGen arrival concepts that push the bottleneck at the runways onto the airport surface such as closely spaced parallel arrivals, reduced separation, and Terminal Area Precision Scheduling and Spacing (TAPSS; Swenson, et al., 2011)
- providing the necessary surface traffic control for efficient transition of the surface traffic between runway configurations to help realize the benefits of advanced Runway Configuration

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[6] Note that precision crossing of an arrival runway will be benefitted by precision control of arriving aircraft. This can be achieved through a more advanced auto-land capability. If uncertainty of the arrival flight is still large, then the precision control of the crossing traffic would need more real-time updates of the crossing time window, increasing the complexity of both the automation and ATC/pilot interfaces.

Management (RCM) concepts (e.g., System-Oriented Runway Management, SORM; Lohr, et al., 2011)

- accommodating extended use of digital clearances and DataComm for pilot-ATCo communication
- enabling departure flights to get to the departure runways on schedule and in the strategically planned sequence, to suport NextGen concepts such as potential future augmentations of Precision Departure Release Capability (PDRC; Engelland & Capps, 2011)
- realizing the benefits of timing departure flights to merge into en route streams for trajectory-based operations and metroplex concepts
- supporting other NextGen concepts that rely on future precision timing capabilities, such as paired departures for wake avoidance; Lunsford, 2008)

3.2 Driving Principles

The following three key features guide the far-term NextGen ConOps:

1. Increase emphasis on strategic planning.
2. Increase information sharing among automation, flight deck and ATC.
3. Adhere to human-centered design principles.

3.2.1 Increase Emphasis on Strategic Planning

A fundamental shortfall of current-day operations is that they are tactical and reactive (FAA, 2010) as opposed to being strategic and proactive. ATCos react to aircraft as they request pushback, arrive at the Airport Movement Area (AMA), or arrive at the runway for crossing or departure.

In NextGen, advanced automation will develop strategic STBO Gate-to-Gate plans for each aircraft. With regards to surface operations, each departing aircraft's taxi plan will be established 30 minutes prior to the Proposed Departure Time (PDT; Ashley et al., 2011). In the far-term concept, this taxi plan will include the following:

- departure (wheels-up) time
- spot release time
- gate pushback time
- 4D taxi route

The taxi plan for each arriving aircraft will be established more than 100 miles out of the destination airport (Ashley, et al., 2011), and will include the following:

- runway touchdown time
- preferred runway exit
- scheduled gate arrival time
- 4D taxi route

Although there is an increased emphasis on developing strategic plans, a tactical component will remain allowing for the strategic plans to be updated and amended as needed to support traffic flow.

3.2.2 Increase Information Sharing Among Automation, Flight Deck, and ATC

The TFDM Shortfall Analysis (FAA, 2010) determined that one fundamental shortfall of current-day operations is that all stakeholders do not share situation awareness of airport operations. In current-day operations, when pilots are informed of the airport or larger system-wide goals, they are often able to adjust their taxi speed to support those goals. However, frequently pilots are not provided this 'big picture' of airport operations and thus have no way to support it (Hooey, 2005). Similarly, the ATCo has no insight into flight deck activities and communications and therefore does not know when pilots have problems in the cockpit, are troubleshooting equipment "glitches," are awaiting final weights from the loadmaster, are behind schedule, etc. For example, the ATCo may need an aircraft to expedite while the Captain is purposefully taxiing slowly to let the First Officer catch up or resolve the above problems. DataComm has potential to exacerbate these discrepancies unless efforts are taken to identify and address information sharing requirements.

Bales and Sekhavat-Tafti (2011) report that in current-day operations, the communication of surface-related information among ATC, flight operators, and ramp operators is limited. The Ground Controller (GC) and Local Controller (LC) get periodic updates from various stakeholders on availability of surface resources and surface conditions. Based on this information, the GC and LC need to re-evaluate taxi route assignments to ensure safety of operations. This may lead to long delays if applicable stakeholders have not provided the necessary information. Electronic taxi route information will improve coordination by allowing this information to be shared via data exchange.

This increased collaboration will be realized in the following ways:

- Pilots and ATCos are informed of time-based goals and work to achieve the same goal.
- Communication interfaces are designed to support negotiations.
- Information including traffic sequencing, departure slots, RTA windows, potential hazards, runway status, 4D trajectories, pushback, spot release, non-conformance alerts, and aircraft intent are broadcast to AOC, flight deck, and ATC as warranted.

3.2.3 Adhere to Human-Centered Design Principles

NextGen STBO operations and technologies will adhere to human-centered design principles. Foyle et al. (2011) define a human-centered design for a display or system as one that:

- is intuitive and natural
- has readily accessible information
- supports human capabilities (e.g., perceptual processing)
- mitigates human limitations (e.g., memory failures)
- enables appropriate task-usage strategies
- has specific features supported by a design trace of human factors principles or empirical results

The challenge in a multi-operator environment such as airport surface operations is to balance the diverse needs of each operator, while achieving overall system efficiency and safety. The following operator requirements are assumed for each category of operators considered in this ConOps.

Pilot:

- *Enable appropriate task-usage strategies.* Surface operations are a busy phase of flight. Many tasks are completed during taxi, which must be completed before takeoff including programming the departure into the flight management system (FMS), finalizing weights and balance, and checklists (Hooey, 2005). There must be adequate time to complete, and crosscheck these tasks. Pilots/AOCs must not be penalized for delaying departure if necessary for safety reasons.

- *Maintain manageable workload.* Provide information earlier (at gate) to allow sufficient cognitive processing with appropriate task workload without interfering with taxi.
- *Optimize situation awareness*. Allow sufficient time, and avionics support, to preview clearances and routes, and traffic conditions.

ATCo[7]:

- *Maintain manageable workload.* Reduce workload by using automation to generate taxi routes and enable automation-based conformance monitoring.
- *Optimize situation awareness*. Maintain sufficient awareness to allow ATCo to override the automation when necessary.
- *Prevent complacency.* ATCo must remain 'in-the-loop' and not simply be passive monitors of automation.

3.3 Far-Term STBO Concept Overview

The far-term STBO concept aims to increase airport efficiency, throughput, and reduce the environmental impact by incorporating a time-based component to surface operations. Airport surface operations will transition from current-day first-come, first-served operations, to strategically scheduled operations in which pilots are recruited as active participants in meeting the precise time-based goals of NextGen surface operations. The far-term STBO concept includes a two-phase development approach (see Table 3 and Figure 1) to address the problems identified in Section 3.1. Far-term Phase 2 enables increased efficiency, precision, and throughput over and above Phase 1, but also requires more advanced technology capabilities.

Table 3. Far-Term NextGen Phase 1 and Phase 2 Concepts

Concept Feature	*Far-Term Phase 1 (Traffic Flow Constraint Points)*	*Far-Term Phase 2 (Full 4D STBO)*
Taxi Clearance	2D route with timed traffic flow constraint points.	4D trajectories.
Traffic Management	Sequence accomplished by strategic assignment of RTAs at traffic flow constraint points.	Sequence accomplished by strategic assignment of 4D trajectories that ensure conflict-free routes and departure sequence.
DataComm	DataComm used for routine taxi clearances, not for active runways. (Voice used for active runways.)	DataComm used for routine taxi clearances and active runway crossings.

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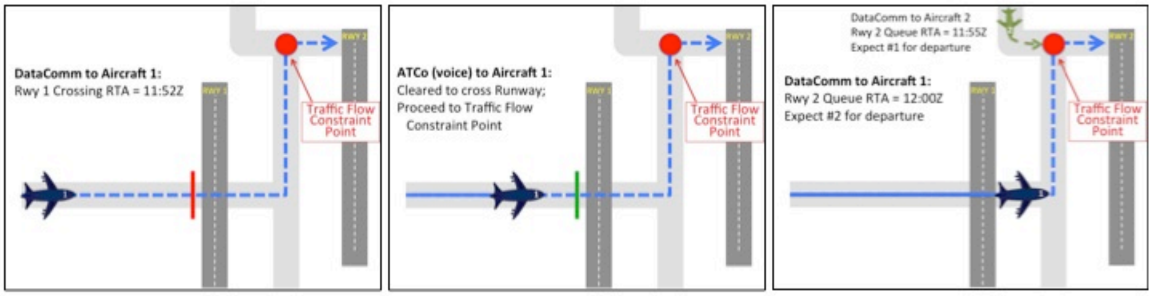
[7] Air Traffic Controller (ATCo) is used to represent any human operator fulfilling an ATC role (e.g., Ground Controller or Local Controller). No assumptions are made about future ATC staffing in the far-term NextGen timeframe.

Far-Term Phase 1: Traffic Flow Constraint Points. In Phase 1, strategic aircraft sequencing is accomplished by implementing traffic flow constraint points along the taxi route. The traffic flow constraint points divide the taxi route into segments, and each is assigned a RTA, which the pilot aims to meet. Minimal augmentations to the flight deck are required to support RTA management, which provides temporal certainty only near the traffic flow constraint points, but not in between. Also in far-term Phase 1, DataComm is implemented as the primary mode of communication between pilots and ATC for taxi clearances, however voice will be used for tactical and time-critical communications (as per RTCA Segment 2 DataComm implementation plan; Mutuel, 2010) including taxi onto, or across, active runways. Traffic sequencing is accomplished by assigning non-overlapping RTAs at common traffic flow constraint points.

Far-Term Phase 2: Full 4D STBO. Phase 2 assumes adoption of advanced flight deck equipage enabling higher temporal precision sufficient to support aircraft conformance to 4D trajectories, with an *x*-*y* location for all times *t*. This allows more precision and less temporal uncertainty at all times along the route. Phase 2 also expands the use of DataComm for all pilot-ATC communications including active runway crossings (consistent with RTCA Segment 3 implementation plan, Mutuel, 2010). Note that the human ATCo is expected to maintain authority over runway occupancy, even though clearances are communicated by DataComm rather than voice. Sequencing is accomplished by generating deconflicted 4D trajectories.

Far-term Phase 1: Traffic Flow Constraint Points

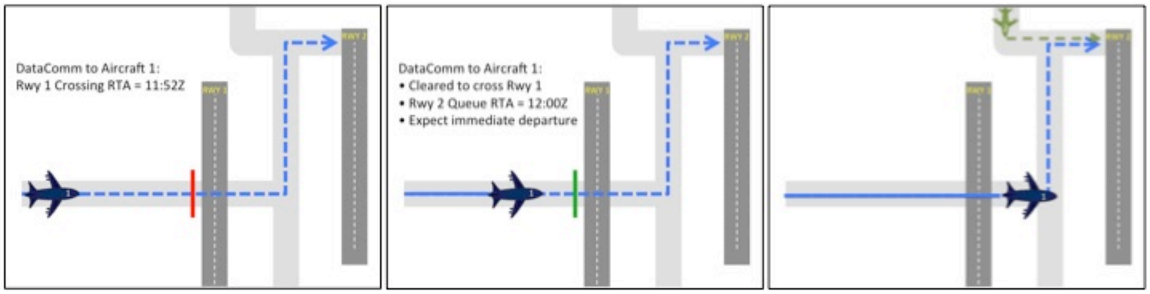


Taxi Clearance
Taxi clearance, including RTAs to runways and traffic flow constraint points, is sent by DataComm

Runway Crossing
Active runways have 'contingency holds', released by voice control

Traffic Sequencing
Departure sequencing is accomplished by assigning non-overlapping RTAs at traffic flow constraint points

Far-term Phase 2: Full 4D STBO



Taxi

Clearance
Taxi clearance including full 4D trajectory is sent by DataComm

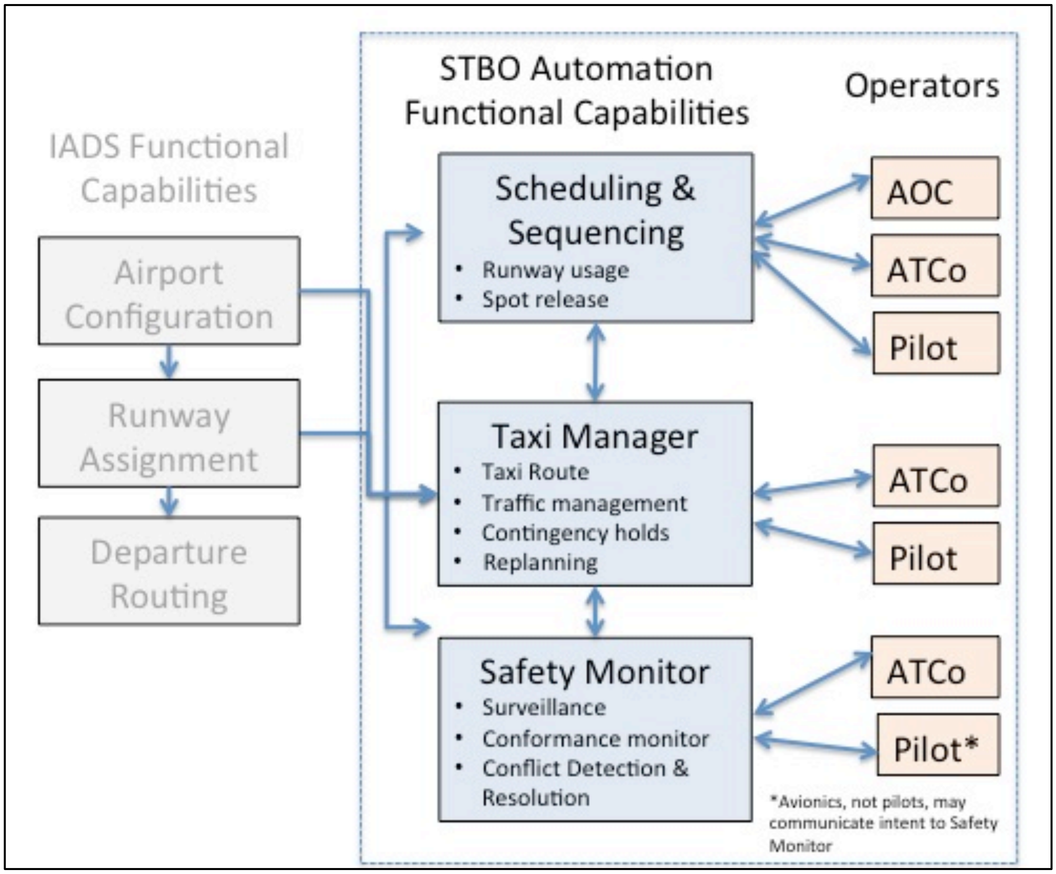
Runway Crossing
Active runways have 'contingency holds', released by DataComm

Traffic Sequencing
Departure sequencing accomplished by deconflicted 4D trajectories

Figure 1. Far-Term NextGen Phase 1 and Phase 2 concepts.

3.4 Far-Term STBO Concept Functional Capabilities

To fulfill this far-term ConOps, it is expected that the functional capabilities, and operating and technical assumptions as specified by the FAA's MidTerm ConOps (v2. 2011), and summarized in Section 2 of this document, are developed and integrated into operations. This far-term ConOps adds functionality to support far-term NextGen operations as specified in Table 4, and described next. Note that the TFDM's Airport Configuration Management, Runway Assignment, and Departure Routing tool may require augmentations to support other far-term operations, but these fall under the purview of other Integrated Arrival, Departure, and Surface (IADS) concepts and are not addressed here. Also note that a new Safety Monitor function is added that was not included in the FAA TFDM ConOps. It includes advanced conformance monitoring of schedules and automated conflict detection and resolution (CD&R). These are required because of the close coordination and reduced separation of aircraft and are in place to ensure safety at runway crossings and taxiway intersections. Figure 2 shows the STBO automation functional capabilities and the human operators of the far-term NextGen concept. The three components of the STBO automation (Scheduling & Sequencing, Taxi Manager, and Safety Monitor) are intended to represent functional capabilities, and not necessarily distinct pieces of automation of software. No definition of the underlying automation architecture is implied. Also, at this time, specific ATCo roles and positions are not defined, as no assumptions of future ATCo staffing are made.



Note: AOC = Airline Operational Control; ATCo = Air Traffic Controller; IADS = Integrated Arrival, Departures, and Surface Operations

Figure 2. STBO automation functional capabilities and human operators.

Table 4. Functional Capabilities of Current-Day, Mid-Term, Far-Term Phase 1 and Far-Term Phase 2 Operations

Functional Capability		*Current-Day*	*FAA Mid-Term (through WP2)*	*Far-term Phase 1 (Traffic Flow Constraint Points)*	*Far-term Phase 2 (Full 4D STBO)*
Scheduling and Sequencing (S&S)	Departure Runway	ATCo sequences aircraft 'first-come, first-served' as flights enter AMA[a]	Departure runway **sequence** determined by automation[a]	Departure runway **schedule** determined by automation	Same as Phase 1
	Runway Crossing	ATCo queue aircraft; cross between departures/arrivals	ATCo queue aircraft; cross between departures/arrivals	Runway crossing time windows **scheduled** by automation	Same as Phase 1
	Spot Release	ATCo allows entry to AMA on first-come, first-served basis[c]	Target Movement Entry Time (TMAT) assigned by automation[c]	Same as mid-term, but coordinated with runway scheduler and taxi manager	Same as Phase 1
Taxi Manager	Taxi Clearance Delivery	At AMA entrance issued by voice	At AMA entrance issued by voice (DataComm when equipped)[d]	Expect clearance at gate/on approach; confirmed at AMA entrance by DataComm	Same as Phase 1
	Taxi Route Clearance	2D route generated by ATCo [e]	2D route recommended by automation [e]	2D route with timed traffic flow constraint points	4D trajectory
	Traffic Management		Sequence points; ATCo manual release[b]	Timed traffic flow constraint points; automatic release	4D trajectory
	Runway Contingency Holds		Hold/proceed verbally managed by ATCo[b]	Contingency hold; released by voice	Contingency hold; released by DataComm
	Replanning		ATC-generated ad hoc routes permitted[e]	Automated; initiated by pilot, ATCo, Surveillance, or Conformance Monitor.	Same as Phase 1
Safety Monitor	Conformance Monitoring	Manual; 2D route and control instructions [b]	Automated; 2D route and control instructions [b]	Mid-term capability plus automated monitoring of RTA performance	Phase 1 plus automated monitoring of 4D trajectory
	Conflict Detection & Resolution	Automated detection of potential runway incursion [b]	Automated detection of potential runway incursion [b]	Automated detection and conflict resolution of lead-follow conflicts, intersection conflicts, and runway incursions	Same as Phase 1

Sources: [a] Morgan, 2011; [b] Diffenderfer, Ashley, & Morgan, 2011; [c] Diffenderfer & Ashley, 2011; [d] Ashley et al., (2011), [e] Bales & Sekhavat-Tasfti (2011).

3.4.1 Scheduling and Sequencing

The Scheduling and Sequencing automation component is responsible for the following:

- runway usage schedule
  - departure runway
  - active runway crossings
- spot release schedule

3.4.1.1 Runway Usage

Current work at NASA Ames Research Center (e.g., Jung et al., 2011) has developed runway scheduler tools that provide an optimal sequence for take-offs and runway crossing with an objective of maximizing runway usage. This far-term ConOps extends these tools to schedule runway occupancy time windows for runway usage.

The Scheduling and Sequencing automation schedules a *runway entry time*—this refers to the time that the ATCo clears the aircraft onto the departure runway for immediate departure—as well as the runway occupancy duration. The Scheduling and Sequencing automation also schedules runway-crossing windows with the goal of efficiently crossing aircraft between arrivals and departures without breaking either stream, and minimizing the need for taxiing aircraft to hold at the runway for an available crossing window. The runway scheduler tool takes inputs from the Airport Configuration Management and Runway Assignment automation and considers other factors such as aircraft weight class, departure route, departure fix constraints, and RNAV procedures (Jung, et al. 2011) to strategically schedule runway occupancy time windows.

The runway usage schedule is then used to generate spot (see Section 3.4.1.2) and pushback windows as well as to set traffic flow constraint times as necessary to realize the schedule (see Section 3.4.2.1). The Scheduling and Sequencing automation also supplies the runway occupancy time windows to the Taxi Manager automation and the Safety Monitor automation for further processing. While the pilots may be aware of the runway schedule to improve overall situation awareness, all runway clearances are reviewed, approved, and issued by ATCo, not directly from the automation.

Far-Term Phase 1 (Traffic Flow Constraint Points) vs. Phase 2 (Full 4D STBO) Implementation. RTA windows at runway crossings and departure runways are expected to be tighter (reflecting more precision) in the Phase 2 implementation.

3.4.1.2 Spot Release

Based on the runway schedule, the Scheduler and Sequencing automation develops a spot release schedule (also known as Target Movement Entry Time, TMAT in some contexts; Diffenderfer & Ashley, 2011), which includes a window of time in which the aircraft is to be cleared to begin taxiing in the AMA. Researchers at NASA Ames Research Center (see Malik, Gupta and Jung, 2010) have developed a set of algorithms that provide advisories to the controllers informing them about upcoming spot releases. The algorithms have both long-term and short-term components. The long-term element calculates the optimal spot release schedule for aircraft that are scheduled to pushback and reach the spot approximately an hour in the future with a planning horizon of 15 minutes. The short-term element works in the immediate time window of 0 to 15 minutes and accounts for uncertainty in the airline schedule, ramp operations, aircraft turn-around time, and other factors. It also allows for immediate re-calculation due to significant changes in the airport traffic environment.

The goal is to minimize stop-and-go taxi and minimize time spent in departure queues at the runways by maintaining the departure queue to a maximum of three aircraft. The spot release schedule is transmitted not only to the ATCo, who is responsible for issuing the spot release clearance within the window, but also to flight deck and AOC who collectively are responsible for ensuring the aircraft is pushed back from the gate and arrives at the spot within the spot release window.

Far-Term Phase 1 (Traffic Flow Constraint Points) vs. Phase 2 (Full 4D STBO) Implementation. No differences expected between Phase 1 and Phase 2.

3.4.2 Taxi Manager

The Taxi Manager automation component is responsible for the following:

- taxi route generation
- traffic management
- runway contingency holds
- replanning

3.4.2.1 Taxi Route Generation

In both Phase 1 and Phase 2, the Taxi Manager automation develops a full 4D trajectory for each aircraft, which consists of an expected x-y location for each time t. Routes deliver aircraft from the spot (or ramp) to a designated point on the airport surface (at small airports, this may be the runway threshold, and at larger airports this may be the beginning of the runway queue area). The 4D trajectory must consider aircraft type and other safety constraints including safe separation, sole runway occupancy, destination timing, and speed constraints (Rathinam, Montoya, & Jung, 2008). This 4D trajectory is generated for planning purposes to determine conflict-free routes and appropriate sequencing assuming nominal speeds but is not necessarily transmitted to the flight deck as a 4D route, depending on flight deck equipage (see Phase 1 vs. Phase 2 differences next).

Phase 1 (Traffic Flow Constraint Points). In Phase 1, the 4D clearance is transmitted to the flight deck as a 2D taxi clearance, divided into segments by traffic flow constraint points each with an RTA window. Pilots are free to taxi at any speed deemed safe, while ensuring on-time arrival at traffic flow constraint points. Aircraft are expected to hold at the traffic flow constraint point unless cleared to proceed prior to arriving at the point. Clearances to 'proceed' beyond the traffic flow constraint point may be issued by automation via datalink, assuming the aircraft is in conformance of the RTA window and all sequencing constraints have been met. The clearance to proceed beyond the traffic flow constraint point should be issued prior to arrival at the traffic flow constraint point to prevent the aircraft from slowing to prepare to stop; a value of 30 sec was used for the pre-RTA clearance time window in a flight deck-automation research system used in a human-in-the-loop usability test and was deemed acceptable to the test subjects (Cheng, Andre, & Foyle, 2009). The goal is to minimize or eliminate stops during taxi, but the traffic flow constraint point provides a mechanism to hold the aircraft for sequencing or traffic deconfliction as necessary.

The traffic flow constraint points may be located anywhere along the taxi route and may be dynamic (in different locations for each aircraft) or standardized (e.g., all aircraft converge to a traffic flow constraint point located at the entrance to the runway queue area to accomplish departure queue sequencing). When multiple aircraft converge on the same traffic flow constraint point, assigned RTA windows are non-overlapping with safety margins. While all traffic flow constraint point locations should be identified as part of the initial taxi clearance, it may be counterproductive to issue RTAs for all segments at taxi start in view of the dynamic nature of surface operations. A robust plan must handle larger uncertainties if the plan must be frozen (i.e., not subsequently changed) farther in advance (Atkins, Brinton, & Jung, 2008). Consequently, there exists the option that the RTA to the next traffic flow point will be issued along with the automated clearance to proceed. This allows for ongoing replanning to optimize surface flow without disruptions to the flight deck from revised RTAs.

Given the increased coordination and competition for airport resources (including both gate and runway usage), both early arrival and late arrival are considered equally disruptive to system efficiency and could possible trigger replanning, rerouting, and changes to departure sequences.

Phase 2 (Full 4D STBO). In Phase 2 (Full 4D STBO), it is expected that aircraft are equipped with advanced avionics necessary to support high-precision taxi, and adhere to a 4D trajectory. The 4D taxi route is transmitted to the flight deck as a continuous 4D trajectory with an expected *x-y* location for each given time, *t*, and an associated positional error tolerance. This requires additional flight deck support such as continuous positional guidance which may be in the form of: 1) a positional display showing where the aircraft should be at all times; or, 2) inputs to an auto-throttle/auto-taxi system to automate taxi (see Flightdeck Automation for Reliable Ground Operations [FARGO], Cheng et al., 2008, 2009). While some traffic flow constraint points may be required for sequencing, airport reconfiguration, or other traffic scenarios, it is expected that the number of traffic flow points may be reduced, or optimally, eliminated in Phase 2.

This Phase 2 concept marks a radical transformation from current-day pilot-paced operations to ATC-paced operations as pilots are no longer free to determine their own safe speed for the conditions (e.g., taxi slower near other traffic, around terminal areas, or when flight deck crew coordination requires it, and taxi faster on straight away sections when traffic is not a concern). Albeit the 4D trajectory will conform to a reasonable range of speeds, which should take into account aircraft type, taxiway geometry, weather, visibility, and airport surface conditions. Still, there is insufficient research to date to determine whether high-precision operations can be conducted safely and within reasonable pilot workload levels. This will depend on the specific flight deck avionics implementation, and may require some form of auto-taxi capability. Research is required to evaluate whether various flight deck interfaces or auto-taxi can support high-precision 4D trajectories with reasonable workload levels.

Far-Term Phase 1 (Traffic Flow Constraint Points) vs. Phase 2 (Full 4D STBO) Implementation. In Far-Term Phase 2 (Full 4D STBO), when aircraft can adhere to full 4D trajectories, it is expected that the number of traffic flow constraint points can be greatly reduced, or eliminated all together. If traffic flow constraint points are required at all, the likelihood of a contingency hold being released before the aircraft initiates slowing is greatly increased in Phase 2 because of improved ability to conform to the 4D trajectory. As such, Phase 2 is expected to yield greater benefits in terms of temporal predictability resulting in operational improvements of reduced delay and fuel burn/emissions.

3.4.2.2 Traffic Management

The way that traffic is sequenced on the airport surface differs between the Phase 1 and Phase 2 concepts as shown in Figure 3 and is described next.

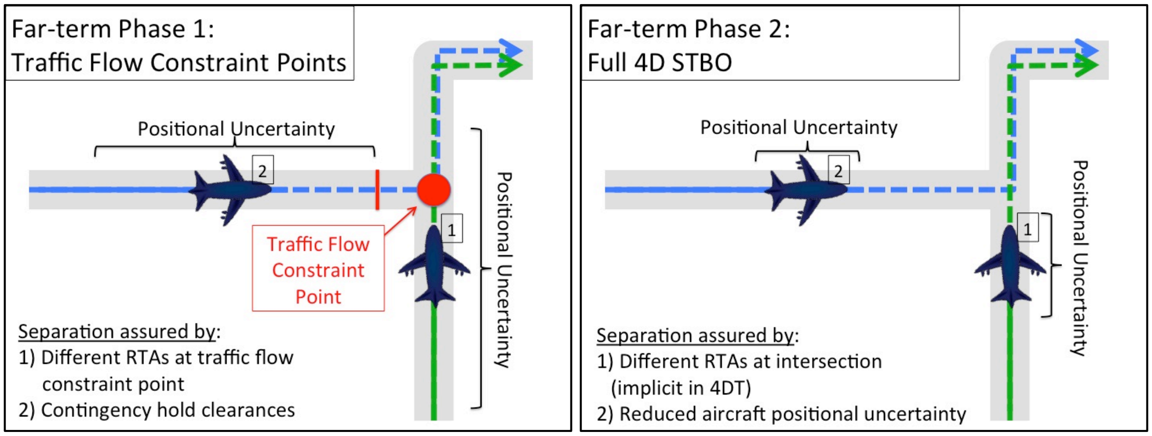


Figure 3. Traffic sequencing using traffic flow constraint points in Phase 1 (shown in left panel). Traffic sequencing using 4D trajectories in Phase 2 (right panel).

Phase 1 (Traffic Flow Constraint Points). To effect the overall strategic plan for traffic management on the airport surface, the 4D trajectory is transmitted to the flight deck as a route with a series of RTA windows at traffic flow constraint points. The traffic flow constraint points are implemented only when needed to ensure aircraft arrive at the departure runway in the required sequence for departure. Sequencing constraints at a traffic flow constraint point are reflected in the RTAs issued to the flights for crossing this constraint point; hence if all the flights conform to their respective RTA windows, they will meet the intended sequencing constraints. For example, as shown in Figure 3, left panel, to ensure that Aircraft 1 arrives at the departure queue before Aircraft 2, both aircraft are issued RTAs to a common traffic flow constraint point located just prior to the entrance to the queue area with Aircraft 1's RTA earlier than Aircraft 2's. As long as both aircraft arrive at the traffic flow constraint point within their assigned RTA window, both receive an automated clearance to proceed to the queue and Aircraft 1 will enter the queue before Aircraft 2. If, for some reason, Aircraft 2 arrives at the traffic flow constraint point ahead of schedule, and before Aircraft 1, Aircraft 2's hold is not released and the pilot holds at the traffic flow constraint point. After surveillance detects that Aircraft 1 has crossed the traffic flow constraint point, Aircraft 2 is released to continue to the queue.

Traffic flow constraint points may also be used to ensure safe separation between aircraft. For example, if two aircraft are expected to be at the same intersection at the same time, a traffic flow constraint point may be established in the lower-priority aircraft's route to indicate that it should be held until the higher-priority aircraft passes. Traffic flow constraint points are not intended to be used at all taxiway intersections, or at all locations where taxi routes intersect. For example, taxi routes may intersect without requiring traffic flow constraint points if there is sufficient time between the aircraft's expected RTA at the intersection assuming a range of safe operating speeds. HITL research (Foyle et al., 2009) recommends limiting the number of traffic flow constraint points to fewer than five, but this is dependent on flight deck equipage (see discussion in section 5.3.1.2).

It is possible that some traffic flow constraint points may be used solely by the conformance monitoring system to monitor the progress of the aircraft for sequencing, and early detection of late arrival at the departure queue which might trigger a replan. These 'implicit' traffic flow constraint points would not require that pilots meet an RTA, and as such could be invisible to the pilots. They would be generated as part of the taxi route, but not transmitted with an RTA to the flight deck. If warranted by the automation to support conformance monitoring and scheduling and sequencing functions, there could be an unlimited number of these implicit traffic flow points as they would not add to pilot workload.

Phase 2 (Full 4D STBO). In Phase 2, traffic sequencing is accomplished through the 4D trajectories. Each aircraft is expected to be at a known *x-y* locations at all times, *t*, within specified tolerance bounds. This allows the strategic Taxi Manager automation to develop routes that deliver aircraft to runways and taxiway intersections in a conflict-free manner, assuming all aircraft are in conformance with their clearance. As shown in Figure 2, right panel, as long as both aircraft maintain their position within the acceptable bounds, Aircraft 1 will pass through the intersection before Aircraft 2, and the aircraft will be sequenced for departure upon arrival at the departure queue.

Conformance monitoring is somewhat simplified in Phase 2, relative to Phase 1, because there is a known x-y location for each aircraft at all times t. This also enables potentially earlier detection of non-conformance, rather than only determining conformance at traffic flow constraint points. When an aircraft is more than a pre-determined distance from their required location, route replanning is triggered.

Far-Term Phase 1 (Traffic Flow Constraint Points) vs. Phase 2 (Full 4D STBO) Implementation. Assuming a feasible flight deck solution for full 4D operations, it is expected that conformance would be higher, and traffic conflicts less frequent with the higher-precision operations expected in Far-term Phase 2 (Full 4D STBO), thus yielding potentially safer and more efficient operations.

3.4.2.3 Runway Contingency Holds

To preserve the safety of runway crossings, all runway crossings will be implemented as Runway Contingency Holds (as per Cheng, et al., 2008 and 2009). Pilots should expect to stop for all runway crossings unless cleared to proceed. This is similar to the procedure expected at traffic flow constraint points (in Phase 1), but differs in that the ATCo, aided by automation decision support tools, is actively required to issue all clearances to proceed onto or across an active runway. This serves as a fail-safe mechanism, such that if the ATCo is busy, the default position is that the aircraft stops.

Phase 1 (Traffic Fow Constraint Points). In Phase 1, the clearance to proceed across an active runway is issued by voice, by the ATCo.

Phase 2 (Full 4D STBO). In Phase 2, the clearance to proceed across an active runway will still be issued by the ATCo, but may be delivered to the cockpit by DataComm. The pilot interface may be a visual text-based or graphical-based display or an auditory presentation.

Far-Term Phase 1 (Traffic Flow Constraint Points) vs. Phase 2 (Full 4D STBO) Implementation. In Phase 2, DataComm release of contingency holds will allow the ATCo to clear several aircraft to cross an active runway, yielding substantial reductions in runway occupancy times of taxiing aircraft (FAA, 2009b). However, this represents a large paradigm shift from current-day where all runway crossings are issued by positive voice control by the ATCo. Integration of DataComm will be a gradual and incremental process, and the rate of adoption may depend on both aircraft equipage and pilot/ATCo acceptance.

3.4.2.4 Replanning

The 4D taxi route is generated well in advance; however, there are many conditions which may trigger the need to replan and issue a revised clearance such as:

- an aircraft must return to gate for maintenance issues or a declared emergency
- an aircraft makes a wrong turn, taxies too fast or too slowly
- an arriving aircraft may be slower or faster than expected, thus changing the taxiing aircraft's RTA at a runway to be crossed or the takeoff time
- an arriving aircraft may take a different runway exit than expected
- a departure slot may be moved early or later
- unplanned taxiway closure for maintenance or obstruction
- airport configuration change
- runway change

The system periodically replans to optimize surface efficiency but also accommodates replans that are initiated by the:

- pilot
- ATC
- Runway Assignment Tool (change in runway, change in departure time)
- Safety Monitor Tool (detection of non-conformance or conflict)

During taxi, pilots may request a clearance to return to gate, request a later RTA at a traffic flow constraint point or a runway, or notify that they cannot make their assigned RTA. Depending on equipage, this may be accomplished either by voice or DataComm. The latter requires an advanced DataComm interface to support complex requests by allowing pilots to select options from a menu or with a single button press, without requiring pilots to type lengthy text requests.

When initiated by the ATCo, the system allows ad hoc entry of routes. For changes to the 2D route, the system allows the ATCo to enter a new route (if a specific route is required), or a new destination. Similarly, for changes to the RTA, the system allows an ATCo to specify a new RTA (i.e., an equality constraint for the planner), or either a not-before or a not-after RTA (i.e., an inequality constraint). All clearances must be electronically entered into the planning computer to support conformance monitoring and traffic deconfliction. As such, ATCos must be equipped with tools to support route entry (keyboard, touch interface, voice recognition) while minimizing workload. Research is required to determine the extent to which these ad hoc modifications can be accomplished given the ATCos task load.

If the Runway Assignment Tool determines a need to change the departing runway because of an airport configuration change, weather, or runway balancing, it communicates directly with the Taxi Manager automation to trigger a replan for all affected aircraft. The resulting taxi clearances are transmitted to the flight deck, and the ATCo is notified of the change.

When non-conformance (route, control, or scheduling) is detected by the Safety Monitor automation (see Section 3.4.3.2), it must determine if the non-conformance is within tolerable limits. If not, a replan is triggered.

Regardless of the source that triggers the replan, the automation must determine the optimal solution that:

- balances the number of affected aircraft with the anticipated benefits from the replan
- prioritizes aircraft with time-constraints (i.e., an aircraft taxiing to the runway for a paired departure might take priority over an aircraft taxiing to gate)
- favors adjusting RTAs first, re-routing aircraft second
- does not penalize aircraft for requesting a new route or RTA for safety reasons

Far-Term Phase 1 (Traffic Flow Constraint Points) vs. Phase 2 (Full 4D STBO) Implementation. As flight deck equipage in Phase 2 allows for improved temporal precision, it is expected that the instances of replanning due to non-conformance would be reduced, assuming 4D trajectories result in reasonable speed requirements for the taxi conditions, and allow sufficient positional error tolerance.

3.4.3 Safety Monitor

The Safety Monitor automation component is responsible for the following:

- surveillance
- conformance monitoring
- conflict detection and resolution (CD&R)

3.4.3.1 Surveillance

In far-term NextGen (both Phases 1 and 2), it is expected that surveillance, using ADS-B (based on GPS [global positioning system] and GBAS) and/or multilateration, is in place to monitor the location of all vehicles (aircraft and ground vehicles) on the airport surface at all times, including in the ramp area. It detects and broadcasts location, heading, altitude, and speed. The surveillance detects when an aircraft is approaching a control point (spot, traffic flow constraint point, runway to be crossed, or the departure runway or queue area). When automation detects that the aircraft is approaching a traffic flow constraint point it determines if sequencing constraints have been met, and if the aircraft can be cleared to proceed. When automation detects that the aircraft is approaching the spot, runway to be crossed, or the departure runway, it alerts the ATCo, who is responsible for clearing the aircraft.

3.4.3.2 Conformance Monitoring

Three forms of conformance monitoring are addressed:

1. 2D Taxi Route. Non-conformance may include:
    - wrong turn (wrong direction, right direction but wrong taxiway)
    - fail to turn (taxi straight when should have turned)
2. Control Instructions (Clearance into AMA, line up and wait, cleared for takeoff, clear to cross runway, cleared to land). Non-conformance may include:
    - fail to taxi
    - fail to stop/hold
3. Schedule Error (RTA or 4D trajectory). Non-conformance may include:
    - aircraft too fast
    - aircraft too slow
    - RTA cannot be attained

Route and Control errors are included in the mid-term ConOps[8] under the Taxi Manager function. Schedule Errors result from the additional time-based component inherent in the far-term ConOps. Neither current-day operations, nor the mid-term ConOps, have a need for schedule monitoring; however, the introduction of 4D routes, RTAs at runways and traffic flow constraint points, and the increased precision with which aircraft are intended to be sequenced for departure, dictates its need.

Route errors are detected by comparing the aircraft position (from the Surveillance function of the Safety Monitor automation) to the aircraft route (generated by the Taxi Manager automation) to detect when an aircraft has travelled off the cleared route. These errors are indicated by alerts to both the flight deck and the tower simultaneously, in both Phases 1 and 2.

Control errors are detected by comparing the aircraft's speed to the aircraft status as indicated by the electronic flight strip. The flight strip reflects the commands issued to each aircraft to proceed or hold short of a runway, enter/exit the AMA, or hold/proceed at traffic flow constraint points. These errors are indicated by alerts to both the flight deck and the tower simultaneously, in both Phases 1 and 2.

Schedule errors are identified when the aircraft is either ahead or behind expected positions relative to the planned 4D trajectory.

<u>Phase 1 (Traffic Flow Constraint Points).</u> In the Phase 1 implementation, warnings and alerts for schedule errors are NOT sent to the flight deck when an aircraft is ahead of, or behind its expected position. Pilots are free to taxi at any speed they deem safe to arrive at each traffic flow constraint point within the RTA window. Pilots will be required to contact the ATCo if they believe they cannot make the RTA. Flight deck tools, which indicate the average speed required, or provide pilots with an estimated time of arrival (ETA) to the runway, can support pilots in making this determination (Bakowski, et al., 2012). When the automation determines that the aircraft cannot make its RTA, given the safe performance envelope of the aircraft, the Taxi Manager automation is notified and replanning is initiated, followed by a taxi clearance change to the affected aircraft.

<u>Phase 2 (Full 4D STBO).</u> In the Phase 2 implementation, conformance-monitoring automation indicates when the aircraft is deviating from the 4D trajectory by taxiing too slowly or too fast. Alerts are sent to the flight deck and ATC when this deviation affects the overall sequencing and scheduling of the airport flow.

Far-Term Phase 1 (Traffic Flow Constraint Points) vs. Phase 2 (Full 4D STBO) Implementation. The Safety Monitor automation monitors conformance for route, control, and schedule errors. In Phase 2 (Full 4D STBO) non-conformance monitoring can be fully automated for all aspects of conformance. In Far-Term Phase 1 (Traffic flow constraint points), schedule non-conformance is more difficult to ascertain, even by automation, and an aircraft's inability to meet the RTA will be detected later than will be the case in Phase 2 (Full 4D STBO). Phase 1 will rely on pilots' ability to detect that they cannot make the RTA and to communicate this to ATCo; this procedure will increase the workload of both pilots and the ATCo.

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[8] The mid-term concept uses the term 'Position' error, instead of route error. It is renamed here to reduce confusion because in the time-based environment, 'positional errors' may also be interpreted as conformance to the 4D trajectory (*x*-*y* position at all times).

3.4.3.3 Conflict Detection and Resolution (CD&R)

Traffic conflicts fall under three categories:

1. *Lead-follow (inline) conflict:* Two aircraft taxiing in the same direction on the same taxiway. No conflict detection or resolutions are implemented. Pilots are responsible to 'see-and-avoid' aircraft as in current-day operations. In the event that a slower lead aircraft is preventing a following aircraft from attaining its RTA at a traffic flow constraint point, it is the following aircraft's responsibility to notify ATC. The ATCo may also intervene and re-route one aircraft if necessary to meet scheduling goals.
2. *Intersecting taxi route conflict:* Two aircraft arrive at intersecting taxiways at the same time. The automation uses look-ahead prediction to determine if two aircraft's trajectories are expected to intersect and provides notification to ATCo. The ATCo, with support from the Scheduling and Sequencing automation, provides tactical resolution to determine which aircraft proceeds and which holds.
3. *Runway conflicts:* Aircraft taxiing onto an occupied runway. Surveillance information is used to determine when a runway is occupied by a departing or arriving aircraft, and when a taxiing aircraft is approaching a runway threshold. Because this surveillance information is broadcast, it can be made available to both flight deck and the ATC tower for monitoring. As the first line of defense, flight deck Taxi Navigation Displays (TNDs) and local control stations depict when a runway is occupied to increase situation awareness. As the last line of defense, if any aircraft does cross the threshold to an active runway, runway-incursion alerts are issued to the relevant flight decks and ATC simultaneously.

The far-term ConOps includes integrated tower automation (Cheng et al., 2011) and flight deck automation (Jones, 2008) for CD&R (see Section 5.3.3.2 and Cheng et al., 2012 for discussion of various options for integrating these two types of automated CD&R systems). The level of integration hinges upon the type and amount of information exchanged between the two automation systems. This far-term concept envisions a *tightly integrated* CD&R system in which alert and intent information are exchanged between the tower and flight deck automated CD&R systems. Different levels of alert information exchanged include conflict detection, resolution, and reconciliation, where the last type of information refers to specific information to reconcile the difference in conflict alert from the two automated CD&R systems. Intent information from the flight deck includes such information as the intent to cross a runway or the intent to start the takeoff roll, where such intent is generally inferred from the aircraft's control signal, e.g., throttle and brake. Intent information from the tower includes sequence and route information that the tower has sent to the flights as clearances; this information when made available to individual flight decks will allow the flight deck automation to have a more accurate understanding of the state of the nearby vehicles. The exchange of intent between tower and flight deck automated CD&R systems will enhance the situation awareness of both systems, allowing them to be more accurate and consistent in their CD&R functions, reducing disagreement in conflict alerts and consequently false alarms and missed alerts.

Phase 1 (Traffic Flow Constraint Points). Even though the Taxi Manager automation calculates conflict-free 4D trajectories, only selected RTA windows are sent to the flight deck as part of the clearances. In this phase, the taxi routes as coded in the clearances do not include enough timing details along the route to be completely conflict-free, because of the assumption that pilots can taxi at any speed within a safe operating envelope. Creating routes that do not overlap assuming a large range of speed is not feasible at large airports with the level of flight deck automation assumed in Phase 1. Conflicts may occur between traffic flow constraint points, where two aircraft are cleared to taxi on the same segment of a taxiway, or cleared on intersecting taxiways. In these cases, the automated

CD&R will be relied upon to detect and resolve these conflicts and provide advisories to flight deck and/or ATCo. Prior to adoption of the Far-term Phase 1 (Traffic flow constraint points) concept, research is required from both flight deck and ATC perspectives regarding the acceptability of issuing taxi clearances that are not conflict-free and relying on the various forms of pilot, ATCo, and automated surveillance for conflict detection and resolution.

Phase 2 (Full 4D STBO). In Far-Term Phase 2 (Full 4D STBO), because aircraft are equipped to adhere to 4D trajectories with high precision, the conflict-free 4D trajectories are transmitted to the flight deck. In the Phase 2 implementation, the 4D trajectory is designed such that if all aircraft are in conformance with their 4D trajectory with the specified level of precision, lead-follow (inline) conflicts, and intersecting taxi route conflicts will not occur. When automation detects non-conformance, the affected aircraft taxi routes are replanned (as in Section 3.4.2.4).

Far-Term Phase 1 (Traffic Flow Constraint Points) vs. Phase 2 (Full 4D STBO) Implementation. The same CD&R approach is used in both Phase 1 and Phase 2, albeit with reduced frequency of conflicts expected in Phase 2. Both pilot 'see-and-avoid' procedures and automated conflict detection and resolution automation will remain in place in both phases for redundancy to ensure safety.

3.5 Inputs/Outputs and Data Flow

Table 5 outlines the transfer of information and communications among the various forms of automation (including electronic flight strips), flight deck (FD) and ATCo. The table addresses several scenarios including: Nominal departure; pilot-initiated route change, via automation and via ATC; and ATCo-initiated route change and conflict resolution. The table is applicable to both Phase 1 and Phase 2, except where noted.

Table 5. Data Flow Among Automation, ATC, and Pilots: Nominal Departure

Taxi Phase	*From*	*To*	*Information*
Gate	Automation (Taxi Manager)	FD, ATCo	Issue expect taxi clearance: • Clearance ID Number • Departure (Wheels Up) Time • Spot Release Time • Gate Pushback Time • Taxi route with Traffic Flow Constraint Points (Phase 1) / 4D trajectory (Phase 2)
	FD	Automation (Taxi Manager), ATCo	Acknowledge receipt
Spot	Automation (Safety Monitor)	ATCo	Aircraft approaching spot, ready to taxi
	ATCo	FD	Clear to taxi, confirm that expect taxi clearance (ID number) is in effect or issue new taxi clearance.
	FD	ATCo	Accept taxi clearance
	ATCo	Electronic Flight Strips	Update aircraft taxi status
Traffic Flow Constraint Point	Automation (Safety Monitor)	Automation (Schedule & Sequence)	Aircraft approaching Traffic Flow Constraint Point
	Automation (Schedule & Sequence)	Automation (Taxi Manager)	Schedule and sequencing constraints have been met
	Automation (Taxi Manager)	FD	Clear to proceed to next traffic flow constraint point with RTA.
	FD	Automation (Schedule & Sequence, Safety Monitor)	Accept clearance to proceed
At Runway (for crossing)	Automation (Safety Monitor)	ATCo	Indicates that aircraft is approaching runway for crossing
	Automation (Safety Monitor, Schedule & Sequence)	ATCo	Runway unoccupied
	ATCo	FD	Clear for immediate runway crossing
	FD	ATCo	Accept clearance
	ATCo	Electronic Flight Strip	Update aircraft taxi status via flight strips
At Runway Queue Area	Automation (Safety Monitor)	ATCo	Indicates aircraft is approaching departure queue
	ATCo	FD	Clear to taxi onto runway
	FD	ATCo	Accept clearance to taxi onto runway
	ATCo	Electronic Flight Strip	Update aircraft status

continued on next page

(Table 5 continued). Pilot-Initiated RTA Change via Automation

From	*To*	*Information*
FD	Automation (Taxi Manager)	Request new route. Flight deck interface allows pilot to choose: 1. Return to gate 2. Change RTA, ‘not-before’ time All other requests go through ATC.
Automation (Taxi Manager)	FD, ATCo	Issue new taxi clearance
FD	Automation (Taxi Manager)	Accept taxi clearance

ATC-Initiated Route Change

ATC	Automation (Taxi Manager)	Request new taxi clearance ATC interface allows ATC to: 1. Enter new route 2. Request return to gate 3. Specify new runway 4. Request new RTA; not-before, not-later-than 5. Request aircraft hold for sequencing / conflict resolution
Automation (Taxi Manager)	FD, ATCo	Issue new taxi clearance
FD	Automation (Taxi Manager)	Accept taxi clearance

Automation-Aided ATC Tactical Conflict Resolution

Automation (Safety Monitor)	Automation (Scheduling & Sequencing); ATCo	Identifies aircraft in potential conflict
Automation (Scheduling & Sequencing)	ATCo	Indicates priority aircraft
ATCo	FD of both conflicting aircraft; Electronic Flight Strip	Tactical instruction for low-priority aircraft to hold for high-priority aircraft. Instruction displayed on both aircraft displays. If hold causes aircraft to be out of conformance with taxi clearance, a new clearance is generated and issued by Taxi Manager. (This is more likely to occur in Phase 2, than Phase 1) Updates taxi status
FD (low priority aircraft)	ATCo	Accept hold command

Integrated Conflict Detection

Automation (FD Safety Monitor)	Automation (ATC Safety Monitor)	Alert information: conflict detection, resolution, and reconciliation Intent information inferred from the aircraft’s control signal
Automation (ATC Safety Monitor)	Automation (FD Safety Monitor)	Alert information: conflict detection, resolution, and reconciliation Intent information: sequence and route of traffic

3.6 Roles and Responsibilities

With the increase in automation in this NextGen ConOps, a shift of roles and responsibilities is expected, not only among human operators, but also from human operators to automation systems. The tasks allocated to automation, ATCo, and pilots are presented below in Table 6. Note that the fundamental operator roles and responsibilities are not expected to differ between the far-term Phase 1 and Phase 2 implementation, thus allowing for both mixed-fleet aircraft, and a graceful transition from Phase 1 to Phase 2 operations as aircraft equipage is augmented.

Table 6. Roles and Responsibilities

Role	*Responsibility*
Automation	• Develop strategic plan to sequence aircraft in correct order at departure runway • Generate 4D trajectories for all aircraft • Publish expected pushback time, spot release time, wheels-up time, touch down time, gate arrival time • Sequence, prioritize aircraft, and indicate when aircraft can proceed past traffic flow constraint point • Monitor conformance for route, control, and schedule • Issue conflict detection and resolution warnings and alerts
ATCo	• Issue clearances for aircraft to enter AMA • Monitor for conformance and traffic conflicts, with automation aid • Make tactical over-rides as necessary • Issue clearance to proceed through contingency hold at runway • Issue clearance to taxi onto runway • Issue clearances for aircraft to take off
Pilot	• Receive and understand taxi clearances • Acknowledge and accept clearances in a timely manner • Follow time-based clearance and arrive at all traffic flow constraint points within allowable RTA window • Inform ATCo if cannot safely achieve RTA/follow 4D trajectory (Phase 2 only) • See and avoid aircraft and obstacles • Be prepared for immediate takeoff upon arrival at departure queue runway
AOC/Ramp	• Push back aircraft as per pushback time • Deliver aircraft to spot before spot release time • Submit company fleet preferences regarding gate usage flight sequences

3.7 Requirements

The far-term NextGen Concept assumes that the FAA mid-term STBO Concept and TFDM have been implemented. Following are additional requirements needed to support this far-term concept.

3.7.1 Flight Deck Requirements

The Phase 1 concept requires minimal flight deck equipage upgrades. Most notable, is the need for on-board avionics to support RTA conformance. Bakowski, et al., 2011 and Foyle, et al., 2011 showed that speed guidance on the primary flight display (PFD), driven by an error-nulling algorithm, effectively supported on-time RTA performance. However, the extent to which this requires modification to the PFD or whether a simpler retrofit approach using electronic flight bags, would be suitable has not been thoroughly investigated. Additionally, Bakowski et al (2012) demonstrate a need for route and trajectory preview and prediction tools to enable pilots to determine whether they will be able to comply with an RTA. These displays may include an indication of the required taxi speed needed to meet the RTA, updating in real-time to reflect the aircraft performance. To ensure ATC can issue voice commands for hold commands and other urgent situations, auto-tuning radios are required to ensure the emergency radio frequency is always tuned, even when communicating via DataComm for routine communications.

To support phase 2, further flight deck equipage upgrades are required including either avionics such as positional displays to support manual control of 4D trajectories or auto-throttle/auto-braking capabilities, both of which would required mechanisms to upload and display complex 4D trajectories. Given the assumption of a full DataComm environment, there will be a need for enhanced DataComm interfaces to support clearance negotiation between flight deck and ATC.

Flight deck requirements for Phase 1 implementation include:
- on-board avionics to support RTA
- preview and prediction tools to support early detection of RTA non-compliance
- updated situation awareness display for traffic sequencing and conflict alerts
- auto-tuning radios to ensure urgent ATCo voice commands can be received at all times, even in a DataComm environment

Additional flight deck requirements for Phase 2 implmentation include:
- avionics or automation to adhere to 4D trajectories such as positional displays or autopilot, auto-throttle and auto-braking (Cheng, et al., 2008, 2009)
- enhanced DataComm to support complex clearance transmission and negotiations with ATC/automation
- flight deck graphical routing capability to upload and display complex 4D trajectories

3.7.2 ATC Requirements

ATC requirements include displays to depict each aircraft's assigned taxi clearance and RTA and more advanced tools that depict 4D intent to support early identification of aircraft that might not meet their RTA. Augmentations to ATCo tools to support conflict detection and resolution are required including alerts and warnings for route, control, and schedule non-conformance, projection of future conflicts, and the display of conflict resolution advisories. For ATCo to maintain situation awareness of the airport environment, and understand the taxi routes generated, it will be important to include displays for traffic management that indicate runway occupancy as wekk as aircraft priority, sequencing, and schedule constraints. ATCo input devices to enable route and RTA entry and modification, and DataComm interactions with pilots, without imposing excessive workload demands are required.

ATC requirements to support the far-term ConOps include:

- display of aircraft and assigned taxi clerances and RTAs
- display 4D intent of any aircraft (timeline viewer)
  - tools to help predict which aircraft might not meet RTA
- updated CD&R displays
  - alerts/warnings for route, control, schedule non-conformance
  - project future conflicts
  - display conflict resolution advisories
- updated situation displays for traffic management
  - runway occupancy
  - indicate priority aircraft; indicate sequencing priority; indicate schedule constraints
- mechanism to enter new route, new destination, new RTA, not-before RTA/not-later-than RTA
- interface to send DataComm directly to the flight deck

3.7.3 Automation Requirements

New automation will be required to support the above flight deck and ATC requirements. Automation is required for the generation and handling of optimized 4D trajectories, sequencing and scheduling planners, and surveillance and conflict detection and resolution. These needs are outlined below.

Flight Deck Automation Capabilities

To support the far-term ConOps, the following automation capabilities are required on the flight deck:

- clearance handling capability to deal with 4D-trajectory clearances
- automatic guidance function to geneate reference trajectories in compliance with 4D-trajectory clearances
- pilot interface for executing 4D-trajectory clearances by tracking guidance-generated reference trajectories
- DataComm for exchange of 4D-trajectory operation data including clearances, acknowledgement, conflict alerts, etc.
- advanced navigation to support 4D-trajectory tracking and conformance monitor

Further benefits are expected with the following flight deck automation capabilities:

- auto-taxi capability for precise tracking of guidance-generated reference trajectories
- advanced guidance function for generating ecofriendly reference trajectories in compliance with 4D-trajectory clearances that also saves fuel and reduces emissions and noise
- flight deck automated CD&R system
- advanced surveillance to support flight deck-based CD&R

ATC Automation Capabilities

To support the far-term ConOps, the following automation capabilities are required in the ATC tower:

- spot release planner
- runway departure planner
- runway crossing planner
- 4D-trajectory planner for the surface traffic
- Safety Monitor including surveillance, conformance monitoring, and CD&R
- ATC interface for handling 4D-trajectory clearance, conformance monitor, and interaction with planners
- DataComm for exchange of 4D-trajectory operation data including clearances, acknowledgement, conflict alerts,, etc.

Further benefits are expected with the following tower automation capabilities:

- pushback planner
- tower automated CD&R system

Integrated Automation Capabilities

Further benefits are expected with the following integrated automation capabilities:

- integration with terminal operation planners to coordinate arrival and departure traffic and to coordinate airport configuration changes
- integration with en route planner to coordinate departure insertion into en route traffic stream (Engelland & Capps, 2011)
- integrated automated CD&R systems between tower and flight deck

3.8 Provision for Safety

This far-term ConOps explicitly includes functional capabilities to support system safety as described next.

Contingency Holds

All taxi clearances that include a traffic flow constraint point for sequencing or that cross an active runway will include a contingency hold instruction. This procedure requires all aircraft to assume the hold is in place at each segment end and runway, unless cleared to proceed. Ideally, in efficient operations, the hold is cleared before the pilot initiates slowing. However, this serves as a fail-safe mechanism, such that if the controller is occupied, or another aircraft is out of conformance, the default position is that the aircraft holds and awaits further instruction.

Safety Monitor Automation
The Safety Monitor automation is responsible for surveillance, conformance monitoring, and conflict detection and resolution. These features support the detection of possible conflicts along taxi routes and during runway operations, and aids controllers to develop safe resolutions while supporting overall efficiency goals.

Enhanced Situation Awareness by Information Sharing
The broadcast of relevant surveillance information with intent (i.e., cleared route) to both flight deck and ATC enables an improved awareness of traffic including potential conflicts, traffic sequencing, and runway status.

3.9 Provisions for Off-Nominal (Non-Conformance)

This far-term NextGen ConOps addresses the following forms of off-nominal conditions:

- pilot non-conformance
- priority aircraft (e.g., medical / mechanical emergency)
- adverse runway conditions (e.g., obstruction on runway, microburst on runway or along arrival/departure path)
- automation failure

3.9.1 Pilot Non-Conformance

The Safety Monitor automation includes surveillance and non-conformance automation to detect route, control, and schedule non-conformance. Further it assumes advanced flight deck support to minimize or nearly eliminate route errors and control errors, and support on-time performance.

3.9.2 Priority Aircraft

The Schedule and Sequencing automation considers a number of factors in determining aircraft sequence. Aircraft can be identified as priority aircraft due to medical, mechanical, or other unexpected emergencies. More ‘nominal’ time-based constraints (e.g., the need to reach a departure runway in a timely manner for a paired departure, or priorities for international departures) can also be accommodated.

3.9.3 Adverse Runway Conditions

An obstruction on runway can wreak havoc on an airport. Upon noticing the obstruction, the ATCo updates the Runway Assignment automation, which automatically reconfigures departure runways for all affected aircraft. This triggers a replan by the Taxi Manager automation and the Schedule and Sequencing automation determines new traffic flow constraint point RTA windows, and new Runway Occupancy schedules. These are transmitted directly to the flight deck, and ATCo is notified of the change. This capability to temporarily close down a runway also helps with other conditions such as microbursts on or near the runway that render the runway unsafe for arrival and departure operations.

3.9.4 Automation Failure

Contingency hold, fail-safe mechanisms, are in place (see Section 3.4.2.3) which require pilots to hold short of all active runways and traffic flow constraint points, unless positively cleared. Therefore, if the automation fails, it does so without compromising safety. Each aircraft would continue to taxi to the next traffic flow constraint point and stop. The ATCo continues to issue taxi clearances via radio as in current-day operations.

3.10 Modes of Operation

3.10.1 Low/High Traffic Demand Periods

This NextGen ConOps allows for varying degrees of precision requirements depending on operating conditions such as peak traffic demand times and weather conditions. Variable RTA windows, dynamic traffic flow constraint point locations, and variable allowable error tolerance in *x-y* position at any time (Phase 2) allow the automation to balance operator demands and efficiency demands accordingly. For example, in low-volume traffic operations, the RTA windows (Phase 1) / allowable positional error (Phase 2) can be sufficiently large to place minimal demand on the flight deck but still support efficient sequencing (i.e., getting aircraft to the departure queue in the right order, but without adherence to a tight schedule). As traffic demand increases, the RTA windows/allowable error tolerance can be reduced to accommodate more precision required to ensure optimal runway occupancy.

3.10.2 Mixed-Equipped Fleets

This ConOps allows for an incremental transition of fleets from current-day equipage to include avionics to support full 4D control on the surface. With minimal equipage modifications, such as electronic flight bags (EFBs), the Phase 1 implementation can be implemented, in which aircraft can adhere to RTAs at traffic flow constraint points, albeit with larger windows than might be attained with advanced flight deck avionics. As avionics are developed to support continuous 4D trajectories in Phase 2, and more aircraft are equipped, the number of traffic flow constraint points, and the need for ATC conflict detection and resolutions may be reduced, thus increasing system predictability and efficiency. The roles and responsibilities of the operators do not change from Phase 1 to Phase 2, but the nature of the information that is communicated changes (i.e., those equipped with Phase 2 technology may receive a more complex full 4D STBO clearance, whereas those equipped with Phase 1 technology may receive a 2D taxi clearance with traffic flow constraint points); the method of transmission changes (e.g. runway clearances change from voice transmission in Phase 1 to DataComm in Phase 2); and the nature of conformance monitoring changes (more precise, automated conformance monitoring of 4D trajectories in Phase 2, relative to manual conformance monitoring of 2D trajectories in Phase 1). As aircraft and towers are equipped with Phase 2 technologies, operations become more efficient and safer. Naturally, full benefits will be achieved only when the fleet is fully equipped, and a fractionally equipped fleet may require some traffic segregation to squeeze out even marginal benefits.

4. Operational Scenarios

These scenarios are designed to highlight the unique time-based capabilities of the far-term NextGen ConOps.

4.1 Nominal Departure Scenario: Phase 1 (Traffic Flow Constraint Points)

Thirty minutes prior to the Proposed Departure Time (PDT) from the gate, the Taxi Manager automation generates an expect taxi clearance for Flight XYZ based on input from the Airport Configuration, Scheduling and Sequencing, and Runway Assignment automation. The expect taxi clearance is sent via DataComm to Flight XYZ while still at the gate and contains the following:

1. Reference ID number
2. Expected departure (wheels-up) time
3. Expected taxi clearance with RTAs to traffic flow constraint points
4. Expected spot release time
5. Expected push back time

Although not an actual clearance, the expect taxi clearance allows pilots to preview relevant taxi information, with the understanding that the expect taxi clearance does *not* constitute a clearance to pushback or taxi onto the AMA and that the actual taxi clearance may change if airport circumstances warrant a modification to the expected taxi plan.

The pilots review the expect taxi clearance and note that their taxi route includes two traffic flow constraint points. Each has an associated RTA that indicates the time that the aircraft must arrive at the traffic flow constraint point location. The electronically transmitted taxi clearance is automatically uploaded to the pilots' taxi navigation display (TND) showing the location of the traffic flow constraint points along the route.

The pilots prepare the aircraft and aim to be ready to pushback before the expected pushback time. It is acknowledge however that ensuring flight readiness before pushback time is a large source of uncertainty. At the expected pushback time, the ramp controller issues the pushback clearance and the pilot taxies to the assigned spot (or designated ramp location). As Flight XYZ approaches the spot, the Safety Monitor automation detects the presence of the aircraft and notifies the ATCo. ATCo selects the flight on the electronic flight strip, changes status to "ready for taxi." This updates the Taxi Route automation that indicates that the expected taxi clearance (with time-stamped reference ID number) remains in effect. This also engages the Safety Monitor (conformance monitoring) automation that compares Flight XYZ's current position to the expected position continuously from that time forward until the aircraft arrives at the departure runway queue.

Because the taxi clearance is unchanged from the expect taxi clearance previously issued at the gate, the ATCo clears Flight XYZ to taxi onto the AMA, referencing the time-stamped reference ID number. The taxi route is already loaded in the TND. Consistent with current-day practices, pilots are expected to comply with the clearance, unless it poses a safety threat. Pilots accept the clearance by referencing the Clearance ID number.

The pilot checks his TND to determine the location of the first traffic flow constraint point. The flight deck is equipped with avionics to support on-time arrival at the point. At the outset, the avionics display recommends a speed of 15 kts, but this advised speed may increase if the pilot taxies slower than 15 kts or decrease if the pilot taxies faster than 15 kts. Following the guidance, Flight XYZ arrives at the traffic flow constraint point. As Flight XYZ approaches the traffic flow constraint point, the automation surveillance detects the presence of the aircraft. It determines that Flight XYZ is arriving at the point within the assigned window, and that all other sequencing constraints have been met (Flight ABC has already passed by that point). Before Flight XYZ initiates slowing, the automation sends a DataComm to Flight XYZ clearing the aircraft to proceed to the next traffic flow constraint point and provides an RTA for the second traffic flow constraint point. The first officer of Flight XYZ presses 'accept' on the DataComm interface and the flight status in the electronic flight strip is updated.

Without stopping at traffic flow constraint point 1, the Captain continues taxiing to the second traffic flow constraint point that is located at the departure queue entrance. He checks his TND and sees that the initial advised speed is 13 kts so the Captain slows the aircraft to ensure that the aircraft does not arrive at the departure queue too early. Along the way, the First Officer notices that there is a problem with the loading of the departure route in the FMS. The Captain slows down to give the First Officer time to trouble shoot the problem. Once resolved, the Captain glances at the TND, and sees that the

TND is now recommending a taxi speed of 16 kts to ensure on-time arrival at traffic flow constraint point 2. The Captain increases speed to 16 kts and arrives at the traffic flow constraint point on time.

At traffic flow constraint point 2, the traffic flow constraint point contingency hold is not automatically released. The Captain holds at the point and checks the TND. He sees that he is sequenced #2 for takeoff. He watches as the #1 aircraft passes by the traffic flow constraint point for immediate departure. After that aircraft has been cleared to take off, the ATCo clears Flight XYZ onto the runway for immediate departure and updates the electronic flight strip.

4.2 Nominal Departure Scenario: Phase 2 (Full STBO 4D Trajectory)

Thirty minutes prior to the PDT from the gate, the Taxi Route automation generates an expect taxi clearance (as in Scenario 4.1) and transmits it to the flight deck via DataComm. The electronically transmitted taxi clearance is automatically uploaded to the pilots' TND. Pilots review the expect taxi clearance and view the graphical taxi route on their TND. They note they have a direct taxi to the runway for immediate takeoff. The pilots program their FMS and complete all necessary preparations before leaving the gate, knowing they will have to be prepared for takeoff by the time they arrive at the departure runway.

The pilots pushback and arrive at the spot just prior to the expected spot release time. The Safety Monitor automation detects the presence of the aircraft and notifies the ATCo. ATCo selects the flight on the electronic flight strip, changes status to "ready for taxi." This updates the Taxi Manager automation, which indicates that the expected taxi Clearance (with time-stamped reference ID number) remains in effect. This also engages the Safety Monitor (conformance monitoring) automation that compares the aircraft's current position to the expected position continuously from that time forward until the aircraft arrives at the departure runway queue.

The ATCo clears the aircraft to taxi onto the AMA, referencing the time-stamped ID number. Pilots accept the clearance by referencing the Clearance ID number. The pilot monitors the 4D TND, which indicates the aircraft's expected position on the airport surface at all times. The on-board avionics have computed that a taxi speed of 15 kts on straight taxiways and 10 kts on turns is required to follow the 4D trajectory. This is within the pilot's acceptable range of speeds because the 4D trajectory has already taken into account the aircraft type, taxiway geometry, and weather conditions. The on-board avionics convert the 4D trajectory to a positional display that shows the ownship's actual position, expected position, and allowable positional deviation on the airport surface at all times which the pilot monitors while the aircraft throttles are either controlled manually by the pilot or automatically by an advanced auto-throttle system.

When the aircraft arrives at the departure runway, the pilots receive a DataComm issuing a clearance to taxi onto the departure runway for immediate departure. Having completed the final taxi and takeoff checklists, the First Officer accepts the DataComm. This changes the status of the electronic flight strip and notifies all operators that the departure runway is occupied.

4.3 Nominal Arrival Scenario with Runway Crossing: Phase 1 (Traffic Flow Constraint Points)

The nominal arrival scenario begins when the aircraft is approximately 100 miles out from the destination airport. As in the mid-term ConOps, the flight operator sends the gate and ramp assignment to the automation. The Runway Assignment automation assigns the landing runway and

NextGen technology (such as TAPSS) predicts when the aircraft will touch down. The Taxi Manager automation develops a 4D taxi route directing the aircraft from the runway to the ramp area. The clearance includes a preferred runway exit; however pilots are not required to take that exit if unsafe.

Each arriving aircraft's plan will be established by the Taxi Manager automation more than 100 miles out from the destination airport, and will include the following:

1. Reference ID number
2. Expected runway touchdown time
3. Preferred runway exit
4. Expected taxi route with RTA windows at Runway Crossing/Traffic flow constraint points
5. Expected RTA at gate

At the appropriate moment, the ATCo updates the surface automation system to indicate that the aircraft is cleared to land and issues landing clearance to the flight. The automation detects landing (based on speed) and notifies the flight operator and ramp tower that the flight is on the ground and updates the predicted surface trajectory. The aircraft does not take the first high-speed turnoff, as anticipated by the surface automation system. The system recalculates the taxi route, and determines that no route modifications are necessary. The ATCo clears the aircraft to taxi, referencing the clearance reference ID number.

The pilot follows guidance on the TND to taxi to the threshold of the active runway that they are required to cross en route to the gate. The aircraft arrives at the runway to be crossed within the assigned RTA window. To ensure runway safety, the clearance includes a contingency hold indicating that the aircraft should hold short of the runway unless cleared to proceed by the ATCo. The ATCo is actively controlling all runway activity. ATCo monitors the display, checks out the window, and determines that because the taxiing aircraft arrives at the runway within the RTA window and the runway is not occupied by a departing aircraft, the contingency hold can be removed. Before the aircraft begins to spool down the engines to hold, ATCo clears (via radio) the aircraft to cross the active runway and proceed to his next Traffic Flow Constraint Point.

The pilot cross-checks his TND, sees that the runway is clear, and continues taxiing across the runway. Because the aircraft is crossing at taxi speed, and not from a stop, the aircraft crosses efficiently between two departing aircraft without disruption to the departure stream. The ATCo updates the electronic flight strip to indicate that the aircraft has crossed the runway so that the electronic flight strip is automatically handed off to the next ATCo.

After crossing the runway, the pilot follows the taxi clearance to the gate, using avionics guidance to arrive at the ramp entrance within the RTA window so that he is assured that the gate is available.

4.4 Nominal Arrival Scenario: Phase 2 (Full 4D STBO)

Similar to Scenario 4.3, the arrival taxi clearance is transmitted to the fight deck when the aircraft is approximately 100 miles from the departure runway. The 4D trajectory clearance is automatically uploaded to the TND after the First Officer accepts the DataComm. This allows the pilots an opportunity to preview the taxi route and identify the preferred runway exit.

Upon landing, the automation detects landing (based on speed) and notifies the flight operator and ramp tower that the flight is on the ground and updates the predicted surface trajectory. The final 4D trajectory is recalculated and transmitted to the cockpit via DataComm.

As the aircraft clears the runway edge, surface conformance monitoring is initiated and the flight deck is notified that they are cleared to taxi following the assigned 4D trajectory to the gate. The pilot follows guidance on his 4D taxi display to conform to the 4D trajectory directly to the gate without stopping.

4.5 Traffic Conflict Management - Lead/Follow Conflict (Phase 1, Traffic Flow Constraint Points)

Aircraft XYZ has been cleared to taxi from the spot to a traffic flow constraint point with an assigned RTA. Aircraft XYZ begins taxiing on taxiway Alpha. His avionics guidance advises a speed of 15 kts to achieve the assigned RTA window. However, shortly after, another aircraft (Aircraft ABC) turns onto Alpha in front of Aircraft XYZ. Aircraft ABC is taxiing at 10 kts. XYZ’s pilot sees Aircraft ABC and slows down accordingly to ensure a safe following distance. XYZ’s pilot checks his TND, and sees that Aircraft ABC is expected to turn off at the next taxiway. He follows ABC at 10 kts until ABC turns off taxiway Alpha. The taxiway is now clear all the way to the traffic flow constraint point. He checks his on-board avionics guidance and determines he can still make the RTA window if he taxies at 16 kts. XYZ’s Pilot deems this is safe for the weather conditions, and proceeds to the traffic flow constraint point at 16 kts.

4.6 Traffic Conflict Management - Lead/Follow Conflict (Phase 2, Full 4D STBO)

Aircraft XYZ has been cleared to taxi from the spot to a traffic flow constraint point with an assigned RTA. Aircraft XYZ begins taxiing on taxiway Alpha following his 4D TND to maintain conformance with the 4D trajectory. Shortly after, another aircraft (Aircraft ABC) turns onto Alpha in front of Aircraft XYZ. Aircraft ABC is taxiing at 10 kts. Pilot XYZ’s TND shows the traffic. The 4D trajectory has already accounted for Aircraft ABC. Pilot XYZ continues to follow his 4D trajectory guidance. Flight ABC turns off Alpha without incident.

4.7 Traffic Conflict Management - Intersection Conflict with Lower-Priority Aircraft (Phase 1, Traffic Flow Constraint Points)

Pilot XYZ is taxiing to his final traffic flow constraint point located just outside the departure queue area. The pilot checks his speed advisory and sees that he can arrive within the RTA window if he taxies at 14 kts. Approximately halfway to the departure queue, Pilot XYZ sees that his TND is indicating a potential conflict with another taxiing aircraft that will cross approximately 2500 ft ahead on taxiway Kilo. Aware of the potential conflict, he continues to monitor his TND. At the same time, the ATCo is also notified of the potential conflict at Bravo and Kilo. The flight deck displays for both aircraft, and the ATCo’s displays, highlight the potential conflict and identify Aircraft XYZ as the priority aircraft because XYZ is departing, while the other aircraft is returning to the gate after landing. The automation issues a resolution requiring the crossing/arriving aircraft to hold prior to the conflict intersection, which is displayed on the TND of both aircraft and the ATCo display. Pilot XYZ sees that the other aircraft is expected to hold and continues to maintain his 14 kt taxi speed to the departure queue.

4.8 Traffic Conflict Management - Intersection Conflict with Higher-Priority Aircraft (Phase 2, Full 4D STBO)

Pilot XYZ is taxiing to a final traffic flow constraint point located just outside the departure queue area. He is following guidance on his 4D taxi display that shows that he is in conformance with his assigned 4D trajectory. Approximately halfway to the departure queue, Pilot XYZ sees that his TND is indicating a potential conflict with another taxiing aircraft (Aircraft ABC) that will cross approximately 2500 ft ahead on taxiway Kilo. That pilot knows that taxi routes are nominally designed to be conflict-free and now has heightened awareness to a potential issue that Aircraft ABC may be out of compliance. At the same time, Aircraft ABC has contacted ATCo by voice and declared a medical emergency. The ATCo has directed the Taxi Manager automation to issue a ‘direct-to-gate’ clearance to Aircraft ABC. All affected aircraft, including Flight XYZ, receive a new 4D taxi clearance. Flight XYZ receives the new clearance by DataComm. The First Officer previews the new clearance. He notes that the RTA at the departure runway is now 30 sec. later, thus requiring a slower taxi speed. He verifies that the runway assignment has not changed. When the First Officer accepts the DataComm, it automatically uploads to the TND. The captain adjusts his speed to adhere to the new 4D trajectory. He sees that Aircraft ABC passes in front, with neither aircraft needing to stop.

4.9 Runway Contingency Hold Cleared (Phase 1 and Phase 2)

Flight XYZ approaches an active runway for which there is a contingency hold in place in his taxi clearance. When Flight XYZ is approximately 30 sec from the runway threshold, the ATCo is noted by the Safety Monitor automation system. The ATCo checks his display, sees that Flight XYZ is within the assigned crossing window, and confirms that the runway is unoccupied. He issues a clearance to cross to Flight XYZ. (Clearance to cross is issued by voice in Phase 1, or DataComm in Phase 2). The electronic flight strip is updated (Manually in Phase 1, automatically in Phase 2) to indicate that the runway contingency hold has been cleared. The pilots of Flight XYZ check out the window and their TND, confirm that the runway is unoccupied, and proceed across without slowing.

4.10 Runway Contingency Hold Enforced (Phase 1 and Phase 2)

Departing Flight XYZ is required to cross Runway 22R, en route to the departure runway and arrives at the runway for crossing within the runway crossing RTA window. The pilots of Flight XYZ expect to hold unless they receive a clearance to proceed across the runway. They check their TND and see that the arriving aircraft is just about to touch down on Runway 22R. The TND alerts Pilot XYZ that the runway to be crossed is occupied. Because the arriving aircraft is late to touchdown, and the runway is occupied, the ATCo does not clear Flight XYZ to cross. Flight XYZ comes to a stop and holds short of the runway as per the contingency hold procedure. The ATCo monitors to ensure Flight XYZ holds short of the runway. If it had continued both aircraft (Flight XYZ and the arriving aircraft) and ATCo would have received aural and visual alerts. While this is happening, the Safety Monitor automation’s conformance monitoring function detects the hold and notifies the other automation functions; Taxi Manager automation picks up this information and recalculates the next and last RTA window in response to the change in timing caused by exercising the contingency hold. After the arriving aircraft lands and exits the runway, the ATCo clears Aircraft XYZ to cross. As the controller issues the command to XYZ he modifies the electronic flight strip to reflect taxi status. Pilot XYZ checks his TND, verifies that the runway is unoccupied, and proceeds to taxi across the runway.

4.11 Pilot Schedule Non-Conformance (Phase 1, Traffic Flow Constraint Points)

Aircraft XYZ has been cleared to taxi from the spot to a traffic flow constraint point at the departure queue with an assigned RTA of 11:45Z. His avionics guidance advises a speed of 15 kts to achieve the assigned RTA time. However, shortly in to the taxi, the Captain is notified that a passenger is standing in the cabin. The Captain stops the aircraft for approximately 5 minutes until the passenger is seated. When he begins taxiing again, the avionics advise that a taxi speed of 25 kts is required to reach his RTA. The Captain instructs the First Officer to request a new RTA at the departure runway, not earlier than 11:50. The DataComm message is sent to the Taxi Manager automation, which revises the taxi clearance and issues the new clearance to Aircraft XYZ and notifies ATCo. The Taxi Manager automation and the departure runway Scheduling and Sequencing automation coordinate to fill the departure slot with another aircraft.

4.12 Pilot Schedule Non-Conformance (Phase 2, Full 4D STBO)

Aircraft XYZ has been cleared to taxi from the spot to the departure queue with an assigned RTA of 11:45Z. The pilot is following guidance on the 4D TND. However, shortly in to the taxi, the Captain is notified by the First Officer that there is a potential problem with the hydraulics. The Captain slows the aircraft speed and works with the First Officer to diagnose the problem. The Captain knows that he won't make his RTA, but prioritizes the aircraft hydraulics issue over requesting a new RTA. Within a short amount of time, the aircraft has slowed sufficiently to fall outside the allowable positional deviation. The Safety Monitor automation detects a schedule non-conformance and notifies both the flightdeck and the ATCo. The pilot uses the advanced DataComm interface to communicate the nature of the delay, and requests a new RTA, not earlier than 11:55Z. The Safety Monitor automation communicates with the Taxi Manager automation and the Scheduling and Sequencing automation. A new 4D trajectory is sent to the flightdeck, delaying the RTA. ATC is notified of the change.

4.13 Nominal Departure Scenario - Mixed-Fleet

This scenario represents mixed-fleet operations, in which Aircraft P1 is equipped for Phase 1 (traffic flow constraint points) and Aircraft P2 is equipped with Phase 2 technologies to enable full 4D STBO. The ATCo station and ground-based automation have been upgraded to accommodate Phase 2 operations and allow the ATCo to distinguish between Phase 1-equipped and Phase 2-equipped aircraft via a data tag on their displays.

For both aircraft, pre-taxi preparations and taxi to spot are the same for the relative scenarios (4.1 and 4.2 above). P1's taxi clearance includes a 2D route with four traffic flow constraint points. Given the complexities of the traffic environment, and the importance of time conformance, four traffic flow constraint points were deemed warranted to ensure on-time arrival, by preventing the RTA error from building over a single lengthy segment. P2's taxi clearance includes a 4D trajectory directly to the departure runway that accounts for traffic sequencing, without the need for traffic flow constraint points, assuming pilot conformance to the 4D trajectory. P1 begins taxiing to the first traffic flow constraint point using on-board guidance to arrive at the designated time (as in Scenario 4.1), while P2 taxies a 4D trajectory to the runway (as in Scenario 4.2).

The ATCo display indicates the equipage of each aircraft. He knows that the Safety Monitor automation is comparing P1's position compared to the assigned route, but does not receive any indication as to whether the aircraft will arrive early or late at the RTA. The ATCo also monitors the performance of P2. His display shows not only that P2 is following the assigned 2D route, but also that P2 is maintaining on-time performance by staying in the allowable speed range.

When a snow squall hits the airport, both P1 and P2 slow down to accommodate the low-visibility conditions. The ATCo and the pilot of P2 receive an alert that P2 is no longer conforming to the 4D trajectory. Once the automation determines that P2 is outside of the allowable positional error tolerance, and cannot make the RTA at the departure runway, the automation configures a new 4D taxi route, with a later RTA. The route is sent via DataComm to P2s flight deck. The pilots confirm that the new taxi route allows for a safe speed in the poor-visibility conditions and accept the new 4D trajectory. P2 pilots continue taxiing to the runway following their new 4D taxi route.

Because there is no speed-related conformance monitoring for P1, there is no advance warning that P1 will arrive late to the traffic flow constraint point. As P1 arrives late to the traffic flow constraint point, the contingency hold is not released. P1 comes to a stop and waits for the hold to be cleared. After the hold is released, a new RTA is issued for the next traffic flow constraint point reflecting the slower speed. ATC monitors P1's conformance to the 'hold' and 'proceed' clearances.

5. Far-Term STBO ConOps Overview

In Section 5.1, the ConOps is summarized by describing how three main functions of surface operations are accomplished: Scheduling and Sequencing, Taxi Manager, and Safety Monitor. Following, in Section 5.2, the main differences between the Far-term Phase 1 (Traffic flow constraint points) and Phase 2 (Full 4D STBO) implementations are identified. Finally, Section 5.3 presents a number of research issues that must be addressed to ensure safe implementation of this far-term ConOps. Recommendations for next steps are presented in Section 5.4.

5.1 Far-Term STBO ConOps Summary

As presented in Table 7, the three main functions of this far-term NextGen Concept are summarized: 1) Scheduling and Sequencing; 2) Taxi Management; and 3) Safety Monitor. The Scheduling and Sequencing function include scheduling aircraft for spot release, runway crossing, and departures while minimizing delay and queuing. The Taxi Manager function supports the generation of more complex taxi clearances that provide pilots with preview information (e.g. expect clearances) to support situation awareness and increased precision with time-based components. The Taxi Manager supports system robustness and flexibility through means such as contingency holds and route replanning when necessary given environmental and traffic conditions. The Safety Monitor function includes surveillance, conformance monitoring, and conflict detection utilizing both tower and flight deck based systems. The key features of each are summarized in Table 7.

Table 7. Far-Term NextGen Concept Overview

Feature	*Description*
Scheduling and Sequencing	
Departure Queue	Maintained to a maximum of three (may be subject to adaptation for individual airport requirements)
Departure Schedule	Aircraft scheduled to ensure arrival at departure runway in pre-determined sequence, and at a pre-determined time.
Runway Crossing	Aircraft runway crossings are scheduled to minimize runway-crossing holds and interruption on arrivals/departure operations.
RTAs	Each surface destination (gate, runway, traffic flow constraint point) is assigned an RTA time. RTAs are non-overlapping, with safety margins.
Spot release	Spot release times are designed to minimize stop-and-go taxi and minimize time spent holding in departure the queue.
Taxi Manager	
Expect Clearances	For departures, expect taxi clearances are issued at the gate and include: • Clearance ID Number • Departure (wheels-up) Time • Spot Release Time • Gate Pushback Time • Taxi route with RTAs for Runway Crossing / Traffic flow constraint points For arrivals, expect taxi clearances are issued 100 nmi from airport and includes: • Reference id number • Expected runway touchdown time • Preferred runway exit • Expected taxi route with RTA windows at Runway Crossing / Traffic flow constraint points • Expected RTA at gate
4D routes	4D trajectories are created for planning purposes, but not necessarily sent to the flight deck as a 4D trajectory, depending on flight deck equipage (see Phase 1 vs Phase 2 differences in Section 5.2).
Traffic Flow Constraint Points	If needed, taxi routes may be divided into segments defined by traffic flow constraint points that are specific locations on the airport surface such as taxiway intersections or the entrance to the departure queue area.
Contingency Holds	At all runway crossings and traffic flow constraint points, pilots expect to hold, unless cleared to proceed beyond the traffic flow constraint point or runway threshold. The hold is released prior to the aircraft initiating slowing, if aircraft arrives within the RTA window and sequencing constraints are met.
Replanning	May be initiated by pilot, ATCo, or automation to optimize surface operations.

continued on next page

Table 7 (continued). Safety Monitor

Feature	*Description*
Surveillance	Surveillance detects when aircraft is arriving at the spot, traffic flow constraint point, runway, or departure queue and notifies ATCo
Conformance Monitoring	Three forms of conformance monitoring are supported by automation: • Route • Control • Schedule
Conflict Detection	- Lead-follow conflicts Pilots see and avoid - Intersections conflicts Automation identifies conflict resolution and identifies priority aircraft. - Runway conflicts Automation broadcast alerts to flight deck and ATCo
Integrated CD&R	Tower and flight deck automated CD&R systems exchange information to reduce false alarms and missed alerts on either side

5.2 Comparison of Far-Term Phase 1 and Phase 2

In this section, the main differences between Far-term Phase 1 (Traffic flow constraint points) and Phase 2 (Full 4D STBO) are delineated, and specified in Table 8. Compared to Phase 1 (Traffic flow constraint points), Phase 2 (Full 4D STBO) is expected to yield:

- improved precision/temporal predictability
- fewer stops and starts during taxi
- tighter RTA windows
- improved safety via conflict-free routes, conformance monitoring, improved conformance
- fewer traffic conflicts
- faster detection of temporal non-conformance, fewer missed departure slots
- improved runway occupancy

However, the magnitude of these benefits, and any accompanying tradeoffs that can be expected in terms of operator workload and situation awareness remain to be researched.

Table 8. Comparison of Far-Term Phase 1 and Phase 2

Feature	*Far-term Phase 1: Traffic Flow Constraint Points*	*Far-term Phase 2: Full 4D STBO*
Time component	Time-based traffic flow constraint points	4D trajectories
Conflict-free routes	No, only conflict-free at traffic flow constraint points	Yes
Pilot-ATCo communication	DataComm + Voice for runway clearances and complex negotiations	DataComm; (Voice for emergency only)
Conformance monitoring	Automation monitors compliance to 2D route, control commands, and schedule performance	Automation monitors compliance to 2D route, control, and full 4D trajectory

5.3 Research and Implementation Issues

A consequence of the far-term nature of this ConOps is that there are many research issues that must be addressed prior to implementation. Clearly, a great deal of research is required to refine and further develop the far-term STBO concept. Research issues for consideration are presented next.

5.3.1 Concept Definition Issues

5.3.1.1 Feasibility of 4D Trajectories from the Flight Deck Perspective

One of the more urgent research issues, for concept feasibility assessment, is to determine whether the full 4D trajectories as proposed in Phase 2 of this ConOps can be implemented in a way that is acceptable to pilots from a workload and safety stand point. Without a feasible flight deck solution for full 4D STBO, the intended gains of the far-term NextGen Conops will not be realized.

While research (Foyle, et al., 2009; Bakowski, et al., 2012) has developed and evaluated flight deck display options for Phase 1 (Traffic flow constraint points), no research to date has adequately addressed flight deck solutions to support Phase 2 (full 4D trajectory) operations. It is unknown whether a feasible solution can be reached which maintains pilot workload at manageable levels. Two options were proposed earlier in this document: 1) positional displays showing where the aircraft should be at all times; or 2) an auto-throttle/auto-taxi system to automate taxi. Before the Phase 2 concept can proceed, human-in-the-loop research is required to evaluate the suitability and implications of these options in terms of pilot workload, situation awareness, complacency, and safety.

5.3.1.2 Traffic Flow Constraint Points Definition

The far-term Next-Gen ConOps (Phase 1) proposes that, when needed for traffic sequencing, taxi routes are issued in segments, defined by traffic flow constraint points, each with an assigned RTA. Generally, greater predictability can be attained as the number of traffic segments increases. Also, as the number of traffic flow points increases, pilot conformance improves. Foyle et al. (2009) showed that RTA conformance was significantly improved when taxi routes were divided into 3 or 5 segments versus a single segment route. As shown in Figure 4, temporal uncertainty is zero at the segment start and end of a segment, but increases as a function of the distance to a segment end point. Therefore, a route divided into multiple, shorter, segments will yield lower overall temporal uncertainty than the same route taxied as a single segment.

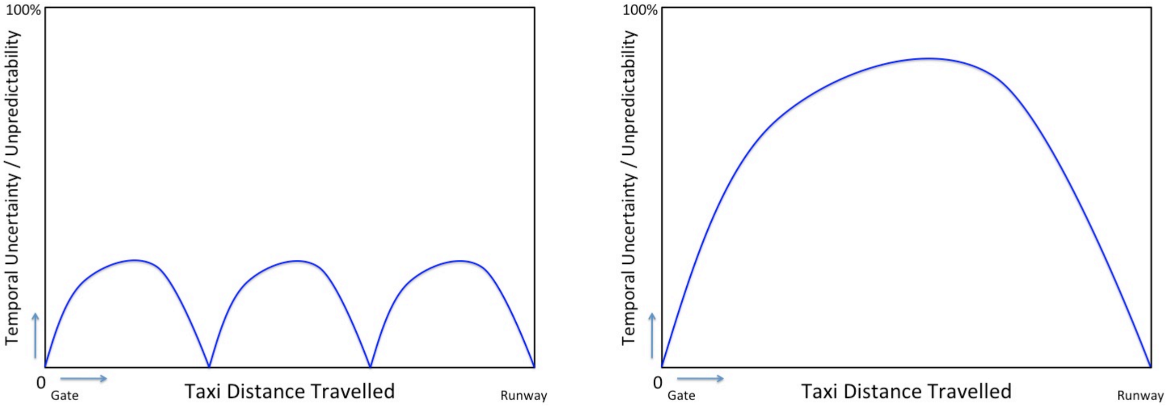

Figure 4. Temporal uncertainty as a function of the number of segments in a taxi route for far-term NextGen Phase 1 (Traffic Flow Constraint Points).

However, one caveat is noted. Human-in-the-loop (HITL) research (Foyle et al., 2009) suggests that dividing a taxi route into smaller segments can reduce time-of-arrival error, with manageable workload consequences *as long as the number of traffic flow constraint points is kept to fewer than five*. This was tested with a similar NextGen Concept to the Phase 1 concept proposed here, in which pilots were using an error-nulling algorithm to meet RTAs at 1, 3, or 5 traffic flow constraint points along a taxi route. This is because with each traffic flow constraint point, the pilot must divert his attention from taxiing to determine the location of the end point, calibrate the aircraft speed accordingly, and as the aircraft nears the end point make a series of control adjustments to ensure on-time arrival at the end point. The nature of this closed-loop control process is excessively demanding. This finding may not hold for other concepts or flight deck equipage. If more than five traffic flow constraint points are required to meet the demands of sequencing aircraft at large and complex airports, alternative display concepts may be required.

Research is also required to determine how to communicate the location of the traffic flow constraint points on the airport surface in a manner that supports shared situation awareness among pilots and ATCo. The use of consistent, standardized traffic flow constraint point locations should be explored as familiarity with the standardized procedures would be expected to increase pilot conformance and reduce ATCo's monitoring workload, relative to traffic flow constraint points that change dynamically for each flight.

5.3.1.3 Required Time of Arrival Specification

As RTAs do not exist in current-day surface operations, research is required to specify a number of factors relating to RTAs at both traffic flow constraint points and runway crossings including:

- Should RTAs be presented as a time window, an RTA +/- x seconds (with the window around the RTA either explicit or implied via procedures), or a 'no-later-than' time?
- What is the appropriate RTA window size at traffic flow constraint points and runway crossings?
- What factors must be considered in determining window size?

- Can the duration of runway crossing windows be reduced in the Phase 2 concept? And if so, by how much?
- How acceptable are variable RTA window sizes, in which a pilot may experience different-size windows at each traffic flow point within the same taxi route, or across different taxi routes based on time of day or airport flow demands?
- After the RTA is attained, and the pilot is cleared to cross an intersection or runway, how is the duration of the safe crossing window communicated to the pilots?

5.3.1.4 Contingency Holds

Contingency hold procedures are implemented as a fail-safe procedure at active runways and traffic flow constraint points. Pilots are expected to hold unless cleared by ATCo. Ideally, if RTAs and sequencing constraints are met, the aircraft is cleared before the pilot initiates slowing. Research issues include:

- How are contingency holds, and the status of the hold/proceed command, indicated in the cockpit? In the tower?
- Under which conditions can the automation release contingency holds, and under which conditions must the human ATCo release the hold?
- If the human ATCo manually releases a contingency hold, can he/she reliably update the electronic flight strips in a timely manner to support surveillance, conformance monitoring and CD&R functions?
- How should the contingency hold release be communicated to pilots: Can contingency holds be released by DataComm? Or is a positive voice clearance required? Or both?
- How far in advance of the hold point should a contingency hold be released so that the pilot does not initiate slowing unnecessarily?
- Would safety be compromised if the default position was to ‘proceed’ and an active command was required to hold aircraft. What flightdeck interfaces would be required to support this?

Also, there may be cases in which the traffic flow constraint point requires a definitive hold (instead of a contingency hold) e.g., in the case of an airport configuration, an aircraft emergency, or a closed taxiway. Should these definitive holds be depicted differently in the cockpit than a contingency hold?

5.3.1.5 Expect Taxi Clearances

Expect taxi clearances (also referred to as pre-clearances in Cheng, Yeh, & Foyle, 2003) are issued at gate, or on approach, and consist of the planned taxi route that will be issued by ATC, assuming no disruptive modifications to the traffic plan. They are intended to allow pilots to better manage workload and increase situation awareness by providing sufficient time to review and load taxi clearances. However, little research has explored whether there are potential pitfalls and dangers associated with expected clearances. For example, it is unknown how frequently the expected taxi clearance will be modified, leaving pilots vulnerable to change detection errors (Rensink, 2002) and plan revision errors (Burian, Orasanu, & Hitt, 2000; Orasanu, Fischer, & Davison, 2004).

Expect taxi clearances on arrivals also require further research to ensure receiving this information during approach does not interrupt or distract pilots at a high workload phase of flight. One previous study (Hooey, Foyle, & Andre, 2000) explored issues related to issuing taxi routes by datalink while on approach, including safety issues pertaining to preferred runway exits and pilots’ ability to process datalink clearances and detect clearance errors. However, further research is required to evaluate airborne taxi clearances in the context of this far-term NextGen concept, and when integrated with the demands of other NextGen concepts such as closely spaced parallel operations.

5.3.1.6 Role of Humans and Automation in Taxi Route Management

Research is required to better define the role of automation in the generation of taxi routes and to determine to what extent should ATC/flight deck/AOC operators be involved in taxi route planning. The central research issue revolves around defining the taxi route broker: Does the ATCo manage all taxi routes and route modification requests or does the Taxi Manager automation? Specific research questions include:

- Can pilots request a new route by interacting directly with the automation or does the pilot request a new route from the ATCo who then interacts with the automation?
- Can routes be issued directly to flight deck via automation or must ATC approve all clearances?
- What effect will ATCo-developed ad hoc taxi routes have on the overall strategic plan of the automation? Should ad hoc route generation be permitted?
- Does AOC have a role in taxi planning?
- Can pilots reject a taxi clearance? a RTA?
- Does pilot behavior/willingness to comply differ when responding to the ATCo via datalink or responding to the automation?
- Is it acceptable that automation releases aircraft through contingency holds at traffic flow constraint points or must the human ATCo be ‘in-the-loop’?
- If the automation is the taxi route broker, what is the impact on ATCo situation awareness, complacency, and ability to intervene when necessary?

Answers to these questions will depend, at least in part, on the sophistication of the operation-automation interface tools, trust in automation, and the frequency with which taxi routes modifications are required.

5.3.2 ATC Research Issues

The introduction of the time component, and new sequencing and scheduling demands, in the highly automated environment brings a host of research questions that must be addressed including:

- What information and interfaces are required to support sequencing and scheduling tasks?
  - Previous research has evaluated ATCo display options for various sequencing and scheduling tasks including spot release and departure runway sequencing (Hoang, Jung, Holbook, Malik, 2011; Holbrook, Hoang, Malik, Gupta, Montoya, & Jung, 2012; Cheng et al., 2007; Martin et al., 2007; Verma et al., 2010). This research should be leveraged and expanded to consider the research needs unique to this far-term NextGen ConOps,
- What information, interfaces, and input devices are required to enable ATC to review, approve, generate, or modify taxi clearances with a time component?
- What information and interfaces are required to enable the ATCo to effectively monitor aircraft for conformance in this automated environment, given the increased complexity of time-based taxi clearances?
- What information and interfaces are required to support runway safety?
- Can ATC reliably update electronic flight strips so they can be used for conformance monitoring, especially under high workload or when multiple clearances to cross a runway are issued in near succession?

- What tower display features are required to support ATCos in the detection and resolution of impending conflict? How is aircraft priority indicated?
- In this highly automated environment, what interface design principles will minimize ATCo complacency and optimize situation awareness and workload?
- What warnings and alerts are required, and in what format?
- Can ATC resume control in the event of a partial or full system failure?
- Does this concept alter tower staffing levels, positions, and responsibilities? Is a new position required to support conformance monitoring and detection and resolution?

5.3.3 Flight Deck Research Issues

Research questions specific to the flight deck implementation include:

- What information, interfaces, and avionics are necessary to support conformance in Phase 1 and Phase 2 while maintaining manageable workload levels?
- What information and interfaces are required to support sequencing and scheduling tasks?
    - Little research exists on flight deck requirements to support scheduling and sequencing on the airport surface. In current-day operations, pilots receive knowledge of aircraft position and sequencing intent via partyline radio communications. With voice communications expected to be eliminated or greatly reduced in the far-term NextGen environment, this information must be provided to pilots by other means.
- When expect taxi clearances are modified, how is the change indicated on the flight deck to prevent plan continuation errors?
- What warnings and alerts are required and in what format?
- What information and interfaces are required to ensure awareness of runway status and runway safety?
- What information and interface is required to depict safe runway crossing window?
- What DataComm interfaces are required to manage the expected complexity of pilot-ATCo negotiations?
    - If a pilot requires a new taxi clearance, how is this communicated? If pilots accept clearances, but later find they are unable to comply, how do they communicate this to ATC? What is the nature of communications and format?
- How do these new STBO taxi requirements interact with departure and arrival operations? Do pilots still have sufficient time to prepare for departure? Do expect taxi clearances distract pilots on arrival?

5.3.4 Automation Research Issues

5.3.4.1 Algorithm Requirements

Initial research to develop conformance monitoring (Pledgie, et al., 2009) and surface CD&R (Cheng et al., 2009) has resulted in algorithms for establishing feasibility of the concepts in computer simulations, and flight deck-based CD&R algorithms (Jones, 2008) has even been tested with pilot-in-the-loop simulations. Additional research will be necessary in furthering these concepts for operational deployment.

- The automation algorithms will need more-detailed development to address more realistic operational requirements. For example:
  - Do the algorithms need to be tuned differently for different types of surveillance technologies?
  - For algorithms with a more strategic approach to anticipate conflicts with a farther look-ahead time horizon, will the human operators even care about the resulting “potential” conflicts?
  - Since these long-look-ahead potential conflicts are not imminent, what is the best way to display advisories to the human operators to increase their awareness of the emerging conflicts so that safety is enhanced without increasing the operator’s workload?
- Deterministic CD&R algorithms address the issue of uncertainty in the surveillance data and trajectory prediction accuracy by padding the calculations with safety margins. Will a stochastic approach that actively estimates these uncertainties be able to provide more accurate results, leading to fewer false alarms without reducing overall safety?
- The research activities thus far have focused on operational conditions closer to mid-term than far-term, meaning that no RTA information is available for conformance monitoring or CD&R. For the far-term STBO ConOps, RTA and/or 4D-trajectory information is available to aid these processes:
  - Conformance monitor can detect when a flight is too slow to make an RTA, or too fast and too close to the constraint point to accomplish a contingency hold if needed. When these situations happen, what lead-time to the RTA would the human operators need to allow them to react adequately? What is the best way to alert the human operators of these conditions?
  - In these situations where RTAs cannot be made, what would be the best course of action?
  - Under what conditions should the automation system recommend re-routing instead of a hold and restart with new RTAs?

5.3.4.2 Replanning

Given that when flights receive 4D-trajectory clearances their trajectories have to be planned with consideration of all flights that may interfere with them along the way, the planning for all these other flights have to be initiated even if their own clearances are not imminent. This explains why the initial planning of flight trajectories has to be very far in advance. Even after a flight has been issued its clearance, the dynamic nature of surface operations necessitates replanning when events different from what have been anticipated emerge.

A big challenge of the replanning function is to avoid a simple replanning event (such as adjusting one aircraft’s timing to address non-conformance) from massively affecting other aircraft on the airport. Such a problem can occur especially when there is a significant number of aircraft taxiing on the airport, and the temporal occupancy of the real estate on the airport is so closely spaced that any aircraft missing its time to cross a runway will require a delay in every other aircraft behind it.

It should be noted that the nominal planning process takes place recursively non-stop through the day for flights expected to operate within some planning horizon, but only a fraction of these flights would have received their clearances or expected clearances. Replanning should try to balance efficiency benefits with the number of flights that have already received their clearances or pre-clearances so as to keep the workload related to the re-issuance of clearances and pre-clearances manageable; flights which have not yet received pre-clearances can be freely replanned without impacting operator workload.

More major events such as airport reconfiguration due to change in wind pattern are likely to be anticipated far ahead in advance, so that transition into the new taxi pattern can be handled by the planning process and not part of replanning. On the other hand, events such as sudden runway closures due to an accident will cause wholesale replanning. The replanning process will need to be researched to ensure robustness against a full range of replanning needs. Previous simulations had touched on the replanning issue with controllers serving as test subjects in the loop (Cheng, et al., 2007). Future research should address the development of automation for selecting flights to be replanned and for performing the replanning; procedures for handling replanning including initiation of replanning process by either ATC or the automation system; and assessment of the replanning efficacy and impact on human operations.

5.3.4.3 Airport Adaptation of Surface Planners

The adage "When you've seen one airport, you've seen one airport" applies to the implementation of STBO as much as it does to other surface operations. There are a wide variety of airport layouts and requirements in the U.S., and even when airports have similar layouts, local convention in operations and airline preferences may differ. The airport layout and configuration can limit effective sequencing. An airport without a layout to accommodate merging several streams into a single taxi queue, without parallel taxiways to handle moving a flight ahead or taking a flight out of the sequence or without surface pavement for holding aircraft will have less flexibility to implement or to make changes to the sequence (Morgan, 2011). Consequently, the STBO concept needs to address adaptation issues related to individual airports.

The uniqueness of the major terminals in terms of airport surface geometry, runway configuration and noise/weather issues, may impact the realization NextGen STBO at any given airport. For effective deployment to the wide variety of airports, development of the STBO planners will benefit from a systematic survey and classification of airport and operational features, including layout of runways, AMA, and ramp area, nominal operational procedures and oddities associated with specific airports, weather patterns, traffic demand patterns, etc. The ability to design the planning functions to address this rich classification of airports will provide long-term benefits in the reduced adaptation efforts required for individual airports. Furthermore, many scheduling algorithms are based on optimization principles; the use of a set of standardized taxi routes to serve as the search space for optimization should be included as an option for individual airports, as both ATC and pilots tend to be more comfortable with familiar procedures, thus increasing the chance of success in deployment of the automation systems.

5.3.4.4 Integrated CD&R Requirements

The far-term ConOps includes tower automation (Cheng, et al., 2011) and flight deck automation (Jones, 2008) for CD&R and various options have been identified for integrating these two types of automated CD&R systems (Cheng, et al., 2012). The level of integration hinges upon the type and amount of information exchanged between the two automation systems:

1. *Non-integrated*. The two automated CD&R systems operate separately and there is no datalink-based information exchange between them.
2. *Tower CD&R Alerts Shared*. The tower has an automated CD&R system but the flight deck does not. Conflict alerts from the tower automation system are datalinked to the flight deck, which has a pilot interface for displaying the conflict and traffic information to the pilots.
3. *Alerts Exchanged*. Both the tower and flight deck have automated CD&R systems, which exchange conflict alert information between them. Different levels of automation within this category involve the exchange of different types of alert information, including conflict detection, resolution, and reconciliation, where the last type of information refers to specific information to reconcile the difference in conflict alert from the two automated CD&R systems. If the reconciliation involves exchange of intent information, then the option would be categorized as a Tightly Integrated option as discussed in Item 5 below.
4. *Intent Exchanged.* Both the tower and flight deck have automated CD&R systems, which exchange intent information between them. Intent information from the flight deck includes such information as the intent to cross a runway or the intent to start the takeoff roll, where such intent is generally inferred from the aircraft's control signal, e.g., throttle and brake. Intent information from the tower includes sequence and route information that the tower has sent to the flights as clearances; this information when made available to individual flight decks will allow the flight deck automation to have a more accurate understanding of the state of the nearby vehicles. The exchange of intent between tower and flight deck automated CD&R systems will enhance the situation awareness of both systems, allowing them to be more accurate and consistent in their CD&R functions, reducing disagreement in conflict alerts and consequently false alarms and missed alerts.
5. *Tightly Integrated* .This refers to the exchange of both alert and intent information between the tower and flight deck automated CD&R systems, expected to produce synergistic benefits when compared to the separate benefits from exchange of alerts or intent alone.

Research issues pertaining to integrated CD&R requirements include:

- For the Alert Exchanged integration option, if there exists some difference in conflict alert between the tower and flight deck systems, what types of information can be exchanged between the two systems to help them reconcile the difference? If these types of information are exchanged on a regular basis instead, can the systems be designed to obviate any difference in conflict alert from appearing that the need for reconciliation never presents itself?
- What intent information is available for exchange between the tower and flight deck automated CD&R systems? How effective is the exchange of intent information in the Intent Exchanged integration option in reducing false alarms and missed alerts of the tower and flight deck-automation systems?
- If intent information is exchanged for the purpose of reconciliating conflict alerts for the Alerts Exchanged integration concept, will the resulting system perform similarly to a Tightly Integrated system where the intent information is exchanged on a regular basis?

- What are the DataComm requirements for the different integration options, including message sets, bandwidth, etc.?
- What are the operator procedures in dealing with detected conflicts?
- What are the operator procedures in dealing with disagreements in conflict alerts?
- For the Tower CD&R Alerts Shared integration concept, the conflict alerts should be identical between the tower display and the flight deck display, except possibly for a small time delay on the flight deck side? Should the procedure for resolution be different from (and likely simpler than) those for the other integration concepts?
- In high-energy conflict situations when the time to react is minimal, should the pilots disregard ATC directions and follow established rules for evasive maneuvers (analogous to TCAS requirements)?

5.4 Next Steps

Concept Refinement. Further development and refinement of the far-term NextGen STBO concept is required. Next steps include detailed Concept of Usage documents to further specify the specific functions of the Sequencing and Scheduling, Taxi Manager, and Safety Monitor automation. Human-in-the-loop simulations, fast-time simulations, and human performance modeling are required to address the research questions identified above. System studies are also required to quantify the benefits and costs of the Phase 1 and Phase 2 implementation.

Cross-Domain Coordination. NextGen Surface Operations concepts cannot be developed in isolation without consideration of other flight domains. Surface operations are an integral part of an overarching set of concepts for the Integrated Arrival, Departures, and Surface (IADS) concept (Ashley, et al., 20011). The far-term concept also must be coordinated with other surface concepts such as Collaborative Decision Making (CDM) concepts for gate management and runway configuration management concepts. Next steps include integration of this concept with these other concepts.

Cross-Agency Coordination. There is a need for cross-agency and industry collaboration to ensure that this NextGen Concept is compatible with FAA goals for NextGen. AOC, Pilot, and ATCo acceptance and input into automation and interface development will also be critical for the future adoption of this concept.

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