Established on Required Navigation Performance (EoR) (RNP) Concept Validation and Implementation Plans: Human Factors Gap Analysis

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This research was funded by the Federal Aviation Administration's NextGen Human Factors Division under contract DTFAWA-15-D-00025, TORFP 5092, Established on Required Navigation Performance Human Factors Implementation Guidance Support. Architecture Technology Corporation subcontracted to Evans Incorporated to provide research expertise in human factors in operational air traffic control. This research is believed to represent one of the first investigations into operational human factors associated with the use of RNP-AR approaches in air traffic control in the United States; previous human factors research in the domain of Performance Based Navigation has primarily addressed human factors on the flight deck. This research was conducted in two phases: Phase I was an analysis of human factors considerations within EoR operations, while Phase II involved the development of implementation guidance materials. This report is the first of two associated with the project, providing results from Phase I. This report has been slightly modified from the contractual deliverable to improve accessibility.

16. ABSTRACT

The Federal Aviation Administration (FAA) NextGen Human Factors Division commissioned this research to identify and share lessons learned from two air traffic control facilities that were "early adopters" of Established on Required Navigation Performance (EoR) (RNP) procedures. Seattle-Tacoma International Airport and Denver International Airport were the first two airports within the United States National Airspace System (NAS) to operationalize EoR. Phase I of the research involved reviewing the relevant concept validation documentation and research literature. This was followed by 38 interviews with personnel at Seattle and Denver Terminal Radar Control (TRACON) facilities, including 24 Certified Professional Controllers. The results include consideration of how air traffic controllers integrate new procedures into their controlling style and practice within dependent operations (Seattle) and widely spaced operations (Denver). This report also addresses some organizational and operational factors that either support or hinder controller utilization of new procedures. The results may assist in realizing the potential benefits of EoR at other airports and could also be used to support the wider implementation of trajectory-based operations within the National Airspace System. The research also provides some human factors and change management insights into the introduction of new technology, new procedures, and automation in operational air traffic control.

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1. Executive Summary

"Established on Required Navigation Performance" (EoR) is an operational concept that utilizes Required Navigation Performance (RNP) approach procedures in simultaneous operations. "Established on RNP" refers to an operation where an aircraft may be considered established on an initial path, not aligned with the landing runway to a straight-in final, without requiring either 1,000 feet vertical or 3 miles radar separation from aircraft established on other approved simultaneous instrument approaches to parallel runways. EoR operations so far utilize "authorization required" RNP approaches (RNP-AR), since highly accurate aircraft equipment and enhanced crew training were initially required for a flight to be eligible for an EoR approach. Seattle-Tacoma International Airport and Denver International Airport were the first two airports to operationalize EoR, doing so in their dependent and widely-spaced operations respectively. The Federal Aviation Administration (FAA) commissioned this research to identify and share lessons learned from these "early adopter" EoR sites, to assist in realizing the potential benefits of EoR at other airports within the National Airspace System (NAS), and to maximize the uptake of EoR operations where it might be appropriate.

The aim of this project is to identify human factors issues that may impact on the success of implementing EoR at other NAS airports with simultaneous approach operations. As such, this report is explicitly focused on applied human factors in air traffic control, rather than on theoretical considerations. The report takes the form of a gap analysis, examining the "gap" between current knowledge based on research and analysis, and the human factors considerations necessary for successful EoR operations. As such, this report draws on several key sources of information, as follows:

1. A review of some of the relevant human factors research literature within the field of Performance Based Navigation (PBN), including both flight deck and air traffic human factors considerations.
2. A review of research and analyses conducted for concept validation and implementation planning purposes, in support of the early adopter EoR sites. These reports were provided to the research team as Government Furnished Information and are specific to Seattle and Denver.
3. Visits to Seattle and Denver Terminal Radar Approach Control Facilities (TRACONs), to observe EoR operations and speak with a range of facility personnel. This report includes details of both site visits and includes analysis of these interviews. Interviews were also conducted with representatives of selected airline operators at each airport to provide insight into the flight deck and airline perspective; the results of these interviews are also included in this report.

The research undertaken within this project identified the following human factors considerations as success factors in the design of RNP approaches:

1. A simple baseline for designing a sound RNP approach is to overlay a visual approach. Another option is to attempt to improve the efficiency of an ILS approach. It is also possible to design an innovative approach based on operational feedback, ideas and suggestions. To maximize use of RNP approaches, it helps to enable the controller to make a comparison between the efficiency of the visual/ILS approach, and the RNP approach[1].

[1] "Efficiency" in this context may refer to reduced track miles, reduced transmissions, and/or reduced workload.

2. In designing RNP approaches, stakeholder involvement is paramount. This will ideally include engaging all parties with interests, and formally considering/analyzing the different motivations between them. As well as the intended use of the approach, "anticipated under-use" might also need to be considered. For example, at some airports pilots may prefer to land at runways closer to the terminal, and this may impact requests for runways and approaches. Differences between operator business models also need to be considered - what works for the dominant carrier might not work for all operators. Successful design initiatives are likely to be those that include some short-term wins for all operators, including those not yet fully equipped to fly an RNP approach.

3. Some safety systems provide advisories, alerts and/or alarms[2] that notify pilots and/or air traffic controllers of potentially critical situations or conditions that may require attention or action. If a system triggers an advisory, alert or alarm inappropriately, users may lose confidence in those communications. In designing RNP approaches, there is a need to analyze impacts on advisories, alerts and/or alarms, and to make provision for monitoring advisories, alerts and/or alarms once the procedure is implemented.

4. In designing RNP approach procedures, there is a need to consider what a controller may be able to achieve by vectoring. For a controller to assign/clear an EoR approach, the controller needs to believe that at that time, this is the best option available. The design must be sufficiently effective to overcome some common controller beliefs, habits and preferences. These might include perceptions such as "you can't beat a straight-in," "vectoring is best," and "I can run finals tighter myself." RNP provides repeatability and predictability, with stabilized approaches and fewer go-arounds.

5. The approach design should be "error-resistant" as far as possible and should consider the flight-deck aspects of performance as well as the controller perspective. Note that both pilot and controller errors are likely to be more frequent when the procedure is first introduced, and then may be expected to dip off slightly. Pilot and controller errors are then likely to rise again as users become more familiar and comfortable with the newly-implemented procedure[3].

The research undertaken within this project identified the following human factors considerations as success factors in the <u>implementation</u> of EoR approaches:

1. Plan a stepped or phased implementation – start simple, and work progressively upwards. For example, this may include:
   - Operating initially in visual meteorological conditions (VMC).
   - Operating initially in lower complexity/traffic levels.
   - Segregating EoR operations onto a different runway (if possible).

2. Use dynamic audio-visual aids to support briefing, training, and familiarization for controllers:
   - Depending on the design of the procedure, these approaches can seem counter-intuitive.
   - It is difficult for controllers to know that these approaches will work until they see them.

[2] Examples of such systems include Final Monitor Aid (FMA) and Traffic Collision Advisory System (TCAS). Since terms pertaining to "nuisance" and "false" advisories, alerts and alarms can mean different things in different contexts, these terms have been purposefully avoided here (see Friedman-Berg, Allendoerfer & Phoa, 2008 and FAA, 2014).

[3] The "U" shaped human performance curve is a well-known principle in human factors (e.g. Hancock & Warm, 1989). The types of errors made by people operating new procedures and those made by experienced personnel are different in nature and frequency (e.g. Reason, 1990).

- Using, videos, radar replays and simulations helps controllers to understand how implementing EoR approaches works “on the glass.”

3. Find collaborative and creative ways to build shared controller/pilot understanding of RNP approaches and EoR operations, particularly with regards to:
   - Encouraging joint facility/airline involvement in the approach design, training, and implementation meetings, including both operational controllers and line pilots.
   - Providing opportunities to discuss differences in terminology. Controllers often refer to EoR approaches using the relevant approach “label” (such as “Mike” at Seattle and “Zulu” at Denver), and understandably tend to focus on the separation aspects of these approaches. Pilots tend to refer to these approaches as RNP-AR approaches, and tend to be more focused on early assignments and the predictability and stability of the approach.
   - Support mechanisms and initiatives that help controllers and pilots understand the limitations of EoR operations (such as the availability of a space within the sequence), and the constraints of flight deck automation (such as the time it takes to reprogram).

4. Provide decision support tools for controllers in merging traffic on the RNP approach with traffic on the base leg:
   - Adapting the Converging Runway Display Aid (CRDA) to support RNP operations was a clever engineering innovation, and adaptations have made sequencing significantly easier at both Seattle and Denver TRACONs. However, CRDA does not include all relevant information that may be helpful to a controller (e.g. wind), and it may not be as useful in all types of EoR operations. All local adaptations of CRDA need to be tailored to the specific application at each facility.
   - Where the full functionality of the Denver CRDA adaptation is not available or appropriate for other facilities, SPLAT-T, range rings and tie-point markers may also provide useful decision support information to controllers.

5. Encourage proactive speed control and defensive controlling techniques:
   - Controllers who most successfully integrate EoR approaches into their controlling repertoire seem to be those who proactively manage the sequence with speed control.
   - Controllers remain responsible for monitoring aircraft on RNP-AR approaches to ensure that they do not deviate from the intended path. Although RNP technology provides high precision tracking on the approach, rare events may still require controller intervention.

These findings are based on research results from the two “early adopter” sites that participated in EoR concept validation work undertaken by the FAA. This research is believed to represent one of the first investigations into the human factors elements of RNP-AR approaches from an operational air traffic control perspective. The lessons learned may support wider implementation of trajectory-based operations within the NAS. There is an option for this research to be extended to develop and validate human factors implementation guidance at a third operational site. There may be value in using that opportunity to validate whether results from early adopter EoR sites extend to other types of RNP approaches and PBN procedures within the NAS.

2. Acknowledgements

The research team would like to record their appreciation to Bill Kaliardos and Sabreena Azam (FAA NextGen ANG-C1), Mitchell Bernstein (FAA NextGen ANG-C51) and Phil Hargarten (Seattle TRACON and NATCA) for providing support, guidance and subject matter expertise throughout this project.

The research team also thanks the management and staff at Seattle and Denver TRACONs, as well as the team at Denver Operational Support Facility (OSF). These teams assisted with the coordination and planning of the site visits, and willingly shared their time and expertise so that other air traffic control facilities might benefit from their experience with EoR approaches.

The team is grateful for the time and expertise shared by pilots from Alaska, Horizon, South West, United and Frontier in the operator interviews. These data have provided the team with valuable insights into the challenges of RNP-AR on the flight deck, and into the potential benefits of RNAV for operators.

The views and opinions expressed in this document are not necessarily those of the NextGen Human Factors Division, the FAA, or the United States Government. All interviews were conducted in a non-attribution environment, so the interview data is not directly attributable to a specific individual. To provide greater assurance of non-attribution, the interviews were not recorded. Hence, the responses provided in this document are of necessity described and/or summarized based on the interview notes. While every effort was taken to capture views and opinions accurately, and to represent them fairly within this report, responses shared may not be verbatim quotations.

3. Introduction

3.1. Scope of Work

The FAA's NextGen Human Factors Division commissioned Architecture Technology Corporation (ATCorp) to conduct an applied research project to identify human factors best practices and share lessons learned in the operationalizing of a Performance Based Navigation (PBN) concept known as "Established on Required Navigation Performance" (EoR). EoR utilizes Required Navigation Performance Authorization Required[4] (RNP-AR) procedures for clearing a suitably equipped aircraft with an appropriately authorized crew onto a pre-defined approach to an airport, without requiring either 1,000 feet vertical or 3 miles radar separation from aircraft established on other approved simultaneous instrument approaches to parallel runways. Evans Incorporated conducted the work under subcontract to ATCorp, bringing operational human factors expertise in air traffic control (ATC) to the research team.

Introducing a new procedure or concept into an air traffic operation requires consideration of the human impact of the change. "Human factors" is a discipline which focuses on the multiple perspectives of varying end users and attempts to integrate these "user" concerns into the wider system and organizational context. Within the context of PBN, the end users of the "Established on Required Navigation Performance" concept might include air traffic controllers, front line managers, operational managers, and air traffic managers, as well as safety, quality assurance and training departments. A comprehensive human factors approach may also extend to considering the impact on airlines, including pilots, airline operations and planning personnel. While the current work focuses primarily on the air traffic impacts, it is inevitable that there will be some overlap with flight deck and airline considerations.

3.2. Background

a. Performance Based Navigation

PBN is an advanced form of navigation that specifies a precise flight path. Rather than certifying specific systems (including sensor equipment, procedures and crew requirements), PBN protocols specify the navigational performance that is required to permit proposed operations in the defined airspace. PBN protocols may include requirements in terms of the navigational system's accuracy, integrity, availability, continuity and functionality. There are approximately 9,000 PBN procedures within the NAS, including departures, routes, arrivals and approaches.

A Required Navigation Performance (RNP) level is specified for each PBN procedure, route or element of airspace. RNP is expressed as a value that represents a performance tolerance in nautical miles from the

[4] There are plans to extend EoR operations to other forms of RNP approaches, including RNAV (GPS) and Advanced RNP (A-RNP). The current research considered only RNP-AR approaches, since these were the approaches used for EoR at the "early adopter" sites in Seattle and Denver. Different types of RNP approaches may introduce different human factors considerations, depending on the context of use and the intended application.

intended position to the actual position of an aircraft. Hence, the lower the number, the higher the performance standard required. Using PBN procedures can result in highly accurate, consistent and replicable flight paths. The benefits can include more efficient airspace management, particularly in congested areas or airports near difficult terrain. There are also operational benefits including optimized descents and repeatable paths. The environmental benefits include reduced fuel burn and exhaust emissions, as well as the potential for improved noise management with routing around noise sensitive areas.

b. "Established on Required Navigation Performance" Approaches

"Established on Required Navigation Performance" (EoR) is an operational application of PBN that is based on the path-keeping capabilities of RNP technology. EoR refers to RNP instrument approach procedures that are designed to guide aircraft established on initial paths that are not aligned with the landing runway to a straight-in final, without requiring either 1,000 feet vertical or 3 miles radar separation from aircraft established on other approved simultaneous instrument approaches to parallel runways. For example, a common type of EoR approach considers that an aircraft is established on its approach while still downwind of the airport, prior to turning inbound and aligning with the extended runway center line for landing. The downwind leg and the inbound turn-to-final are incorporated within the pre-defined procedure. The design of this type of EoR approach means that aircraft can turn to final sooner than they would on a vectored approach, and they do not need to receive air traffic control instructions to make the turn. These approaches reduce flight time, flight distance and approach variability, as shown in Figure 1.

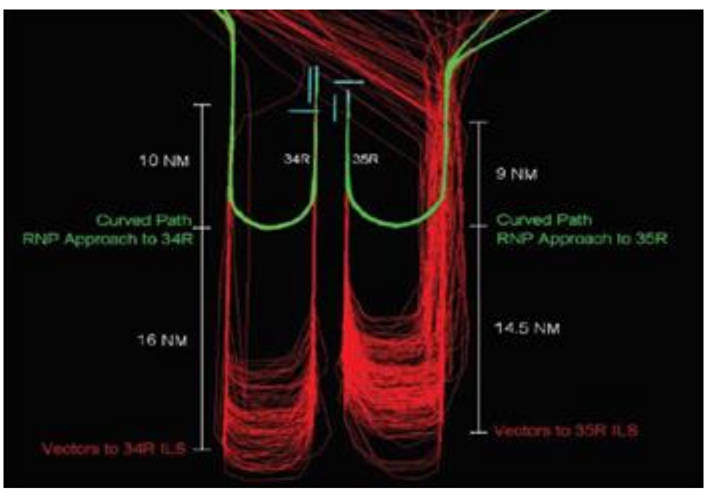

Figure 1: EoR operations provide a shorter final approach for equipped aircraft at Denver International Airport. Source: FAA, 2016a, p. 19.

c. Required Navigation Performance Turns

Two types of turns have been designed for RNP procedures; all are flown by the autopilot (AP) or Flight Director (FD). Radius-to-Fix (RF) turns use a Computer Navigation Fix (CNF) to generate a constant radius turn about the fix. RF turns follow a very precise ground track. Track-to-Fix (TF) fly-by turns employ the use of interim waypoints to define a curved path. These curved paths are tangent to lines between consecutive waypoints on the turn. All RNAV equipped aircraft are capable of using TF turns, while a smaller proportion of aircraft are equipped and authorized for RF turns. Figure 2 illustrates the design of RF and TF turns.

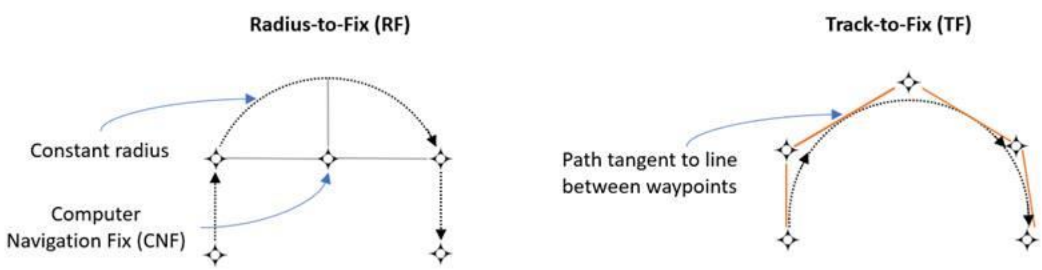

Figure 2: Radius-to-Fix and Track-to-Fix turns (adapted from Walls, Nichols, McCartor, Greenhaw, Ramirez, Reisweber, Rodzon, Smith, Dulli & Foster, 2016, p. 16).

The difference in flight tracks between an RNP approach using TF rather than RF turns is nominal, but there are some potential safety benefits to using RF turns (Walls, Branscum, Nichols, Foster, & Dulli, 2017). A safety analysis of RF turns showed that an aircraft is less likely to experience path deviations following an equipment failure when it is in a stable turning state, compared to when the turns are variable. Procedures that contain only constant or increasing bank angles can be designed using RF turns; these turns may be preferable where it is possible to use them.

There are over 390 RNP-AR approaches in the NAS. These are designated as “Authorization Required” meaning that special aircrew and aircraft authorization is required to fly these approaches. The EoR concept can be used in various simultaneous approach configurations, depending on the nature of the operation (FAA,2017a):

- Simultaneous dependent approaches (“staggered” approaches)
- Simultaneous independent approaches (widely-spaced)
- Simultaneous independent approaches (duals and triples-

Each of these approach types will be described in turn, as the operational human factors considerations may vary for each type of application.

d. Simultaneous Dependent Approaches ("Staggered" Approaches)

The runway centerlines for dependent approaches are between 2,500 and 9,000 feet apart. These approaches require that simultaneous approaches to the runways are staggered to maintain diagonal separation - in other words, approaches to one runway are *dependent* on approaches to the other runway. This is illustrated in Figure 3.

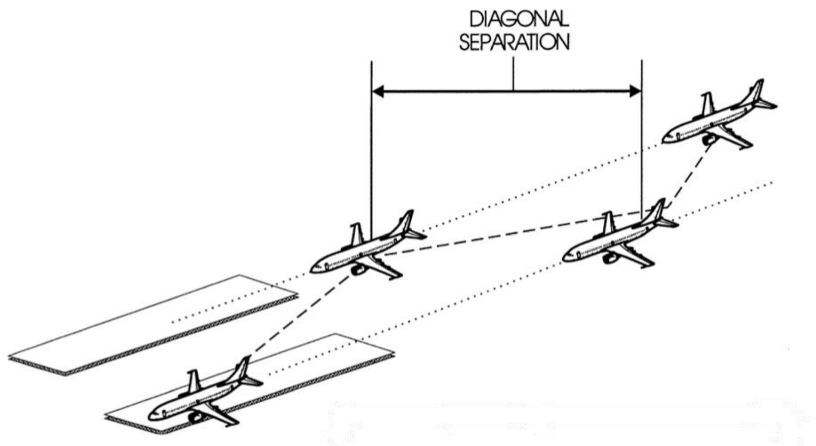

Figure 3: Representation of diagonal separation on dependent approaches. FAA 2017a, Section 5-9-6

The required diagonal spacing depends upon the distance between the runway centerlines, as shown in Table 1. Currently, simultaneous EoR approaches to dependent runways are only authorized via waiver.

Distance between runway centerlines	Diagonal spacing requirement
2,500 ft. to 3,600 ft.	1 nautical mile
3,601 ft. to 8,300 ft.	1.5 nautical miles
8,301 ft. to 9,000 ft.	2 nautical miles

Table 1: Diagonal separation spacing requirements

Seattle-Tacoma International Airport runs a dependent runway operation; EoR approaches have been implemented at Seattle TRACON (S46). Dependent approaches are utilized at 40% of the 20 busiest U.S. airports (by number of operations), including LAX, JFK, PHX, MIA, MSP, SEA, PHL, and DTW.

e. Simultaneous Independent approaches (Widely Spaced)

Simultaneous approaches to independent widely-spaced runways can be used when the runway centerlines are separated by more than 9,000 feet. This type of simultaneous approach does not require the use of No-Transgression Zones (NTZs) or final monitoring. Denver International Airport runs a widely-spaced operation on “outboard” runways; EoR approaches have been implemented at Denver TRACON (D01).

Simultaneous approaches to widely-space runways are used at 30% of the 20 busiest U.S. airports (by number of aircraft movements). Some of the airports using simultaneous approaches to widely-spaced runways include ATL, ORD, DFW, DEN, CLT, and IAH.

f. Simultaneous Independent Approaches (Duals and Triples)

“Duals and triples are a type of independent approach where two or three parallel (or close parallel) runway centerlines are separated by distance within the range of 3,000 to 9,200 feet. Because of the proximity of runway centerlines, a No-Transgression Zone (NTZ) at least 2,000 feet wide is mandated between runways and an air traffic controller must monitor the aircraft on the radar scope during the final approach (the “final monitor controller” (FAA 2017a). For dual and triple approaches to closely spaced parallel runways, additional mitigations are required including automated alerting when an NTZ violation is anticipated, additional flight crew training, and separate dual frequencies. EoR approaches were recently approved for duals and triples.

3.3. From Concept to Implementation

The current research is focused on the human factors considerations from “early adopter” EoR sites: Seattle-Tacoma International Airport (dependent runways) and Denver International Airport (widely-spaced runways). Initial concept validation and proof-of-concept work was undertaken prior to operationalization, and some of this work is discussed within later sections of this report. However, the primary focus of this research is to identify some of the human factors issues associated with increasing the adoption and utilization of RNP approaches, specifically within EoR operations utilizing RNP-AR approaches. High rates of adoption and utilization are required for the maximum benefits to be realized. From the human factors and change management literature, it is known that certain conditions support the successful introduction of a new technology. A model that illustrates some of the factors associated with successful change implementation in the context of RNP-AR and EoR is shown in Figure 4.

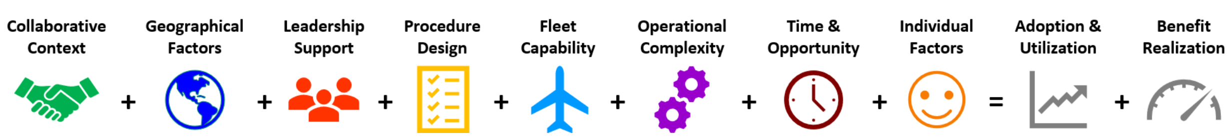

Figure 4: RNP-AR and EoR success factors for adoption, utilization and benefit realization

Although some of the factors in Figure 4 interact to a certain degree, the model provides a broad classification of the success factors to be considered within EoR implementation. Each of these categories is summarized below:

- **Collaborative context:** this refers to collaboration between all stakeholders, including air traffic controllers at towers and TRACONs, pilots, as well as airlines and airport authorities. Strong working relationships lead to stronger solutions.
- **Geographical factors:** RNP procedures are often a solution to geographical challenges, such as noise in residential areas, mountainous terrain, nearby airfields, and so on. Successful procedure design requires all such factors and all possible solutions to be taken into account. This may include considering airport limitations (such as runway use and runway availability) as well as local terrain.
- **Leadership support:** successful implementations require leadership support, meaning that leaders provide the time and resources necessary to reach successful design solutions, and to plan a managed and progressive implementation. This includes ongoing reinforcement, including encouraging air traffic controllers and pilots to use the new procedure.
- **Procedure design:** successful procedures tend to be “win-win” solutions, meaning that there is something in the design of value to every stakeholder. The smallest operator needs to see a gain from implementation as much as the dominant carrier.
- **Fleet capability:** there is likely to be a mixed fleet with varying RNP capabilities at most TRACONs and airports. The most successful implementations are those that find ways to “manage the mix” - such as by segregating the RNP operation to a different runway, or using procedures in visual conditions only until air traffic controllers and pilots become comfortable with the change.
- **Operational complexity:** every air traffic control facility has a unique combination of factors that drive complexity, including the traffic volume and mix, and the operational tempo. Successful implementation requires considering the operational context at each facility, since a “one-size-fits-all” approach is unlikely to be successful.
- **Time and opportunity:** air traffic controllers need time to figure out how to integrate a new procedure into their repertoire of controlling techniques. If air traffic controllers are working at maximum capacity levels, they will find it a challenge to try something new. Successful implementations are those that find ways to support controllers with integrating new procedures into their own controlling style—through training, simulation or exposure during low traffic and/or low complexity periods.
- **Individual factors:** there are also subjective factors that play a role in whether a new procedure will be widely used. Some pilots and air traffic controllers are very open to trying new things, while others tend to prefer tried and tested techniques. Workload, motivation, confidence and the level of training are all factors that influence an individual’s decision to try a new procedure. Assignment and clearance of EoR approaches is a significant determinant of adoption, utilization and benefit realization.

Some of these factors are organizational factors; some are associated with the use of technology and supporting training and procedures. Nevertheless, all of these are relevant to “human factors” in the widest sense of the term. Without understanding the underlying factors that influence the actions and decisions people make in preparing for the implementation of EoR approaches at the facility, and how well those activities address the needs and concerns of the end users who will be required to adopt and utilize these approaches, benefit realization will be limited. Lessons learned from the “early adopter” sites will support other facilities in preparing for implementation, which in turn will maximize the probability of high levels of EoR adoption and utilization where this is appropriate.

3.4. Structure of this Report

The purpose of this research is to support the FAA with the implementation of EoR operations and increase adoption and utilization where it is appropriate. The current document is a gap analysis which will consider the human factors issues already addressed within concept validation and the facility implementation plan and will identify where enhancements might be made via a) additional human factors or change management interventions, or b) the conduct of additional research. Possible enhancements are informed by two main data sources – the research literature and interviews conducted with representatives at "early adopter" facilities. Since the human factors research literature on PBN is more general than the site-specific considerations, this report is structured as follows:

1. A literature review of some of the relevant human factors research within the field of PBN, including both air traffic and flight deck human factors. This review is not intended as a comprehensive survey of domain knowledge but focuses on relevant reports made available to the research team.
2. A review of the research and analyses conducted for concept validation and implementation planning purposes, in support of the early adopter EoR sites. These reports were provided to the research team as Government Furnished Information and are specific to Seattle and Denver.
3. The research protocol included visits to Seattle and Denver TRACONs, to observe EoR operations and speak with a range of facility personnel. This report includes details of both site visits and includes analysis of these interviews. Interviews were also conducted with representatives of selected airlines at each airport to provide into the flight deck and airline operator perspective; the results of these interviews are also included in this report.

This research is the first opportunity for the FAA to investigate the human elements of EoR implementation at the "early adopter" facilities and is a valuable opportunity to learn more about the operational considerations driving success.

4. Literature Review

4.1. Air Traffic Considerations

a. Human Factors in PBN

Barhydt and Adams (2006a) reported on a joint NASA/FAA human factors study conducted to identify some of the key human factors issues associated with the transition to a PBN strategy within the NAS. The overall aim of the work was to raise awareness among air navigation service providers (ANSPs), regulators, manufacturers, and training professionals of the human performance issues related to PBN. One of the outputs of the project was a prioritized "issues list," which was developed based on a literature review, subject matter expert (SME) discussions, and attendance at government and industry committee meetings. The following are the top five issues on the prioritized list:

- **Development of human factors guidelines for RNAV/RNP procedure design**, possibly supported by research studies to help with design trade-off decisions, and possibly including the development of a "procedural complexity" metric that would support evaluation of alternatives.
- **Utilizing "lessons learned" from "Special Aircraft and Aircrew Authorization Required (SAAAR) RNP approaches**. These were originally named "special" and were designed specifically for airline utilization and are not generally available for "public" use. Incorporating lessons learned from "specials" in terms of procedure design, flight crew operations and training was identified as a possible mechanism for enhancing the design of publicly available RNP procedures.
- **Collaboration among NAS stakeholders** including pilots, controllers, navigation data providers, avionics and airframe manufacturers and government agencies, to ensure harmonized solutions and effective allocation of resources in identifying and mitigating operational problems.
- **Consideration of potential changes to approach naming, approach classification and flight plan suffixes**, based on an assessment of perceived problems with existing naming and classification systems, and including a change impact assessment to consider the impacts on training, documentation, regulations, and procedures etc.
- **Resolution of high priority differences between navigation databases and published charts**. One example given was the assignment of waypoint names to DME fixes used on instrument approach charts.

b. Confidential Safety Reporting Data

A second NASA study on the human factors considerations for area navigation departure and arrival procedures was undertaken as part of the same project (Barhydt & Adams, 2006b). This work included a review of the NASA Aviation Safety Reporting System (ASRS) database for human factors related reports pertaining to RNAV procedures. ASRS is an industry wide confidential reporting scheme administrated by NASA, and it includes self-reports of safety issues that are provided on a voluntary and non-punitive basis. 124 RNAV departure and arrival related reports were found for the period between 2000 and 2005, and these included reports within the following categories:

- **Air Traffic Control Procedures**: Terminology, phraseology, timing of clearance information, inter-facility coordination.
- **Airline Operations**: Training, company procedures, pilot actions, airline/flight deck communication.
- **Aircraft System Capabilities**: Equipment availability/performance, path tracking, mode transitions, navigation database.
- **Procedure Design and Charting**: Waypoint proximity, use of waypoint constraints, interference with non-RNAV procedures, chart clutter.

Barhydt and Adams (2006b) noted that most reports were made by pilots, which perhaps accounts for the predominance of flight deck perspectives in the accounts provided. However, the "air traffic control procedures" category represented more than a third of these reports, and included issues such as ambiguity in terminology, altitude assignment confusion, and changes to runway assignments. One of the main issues associated with terminology was the term "descend via". When it becomes necessary for a controller to change the assigned runway (for a departure or arriving aircraft), there are several steps the flight crew are required to take to reprogram the Flight Management System (FMS). Reprogramming errors were reported to have led to path deviation errors and traffic conflicts.

The Barhydt and Adams work was revisited and updated by another research team (Butchibabu, Midkiff, Kendra, Hansman & Chandra, 2010). This work was undertaken to investigate the emerging operational human factors issues associated with the initial implementation of Area Navigation (RNAV) and RNP approaches. A total of 285 relevant reports were filed between January 2004 and April 2009, and these were grouped based on the type of procedure involved: Standard Instrument Departures (SIDs), Standard Terminal Arrivals (STARs), or Instrument Approach Procedures (IAPs). The categories developed by Barhydt & Adams (2006b) were further refined to allow a more detailed analysis. For example, the "Procedure Design and Charting" category was subcategorized into chart format, chart density, graphic, notes, complexity, waypoint constraints, and other factors. Examining STAR reports, the most common issues were a) chart & procedure design issues, b) air traffic control "descend via" clearances, and c) clearance amendments and Notices to Airmen (NOTAMs). Insufficient reports were available from approach procedures to allow a more detailed analysis, since only 14 reports related to this type of procedure.

Berry, Sawyer, and Austrian (2012) also conducted a human factors analysis of safety events from a sample of confidential safety reports. ATSAP is the Air Traffic Safety Reporting System, a non-punitive confidential reporting system that allows air traffic controllers to volunteer information on safety events. Between April 2011 and July 2012, there were 408 narratives pertaining to RNAV incidents. The analysis used a sample of 100 ATSAP reports, comprised of all reports generated at six airports of interest, and 58 randomly selected reports. The air traffic control reports were analyzed according to the AirTracs classification system, an analysis framework created from the merging of two well-known human factors analysis frameworks, HERA-JANUS and HFACS. To provide insight into the flight deck perspective, 68 ASRS reports citing RNAV procedures filed between the same dates were included in the analysis and were analyzed using an annotated version of AirTracs adapted for flight deck considerations.

In analyzing events from the air traffic control perspective, AirTracs utilizes four tiers of categories. These are:

- **Agency influences**, including as examples - equipment and facility resources, organizational structure, policies, process and culture.
- **Facility influences**, including as examples - supervisory planning, staffing, sector combinations, airport configuration, and operational tempo.
- **Operating context**, including as examples - the physical and technical environment, airspace design, airport conditions, and communication and coordination.
- **Operator acts**, including as examples - auditory and visual errors, decision and execution errors, and willful acts (such as disregarding rules).

Overall, the analysis showed that track deviations occurred in 54 of the 100 ATSAP reports, with the most frequent event being a lateral deviation, and the majority of these resulted in near or actual loss of separation minima. Seventeen of the ATSAP reports included "unexpected aircraft performance", meaning that the aircraft performance or flight path did not meet the controller's expectation or plan. Controller-flight deck communication concerns were evident in 30 of the ATSAP reports, and in 14 of the 68 ASRS reports. Hearback/readback errors were the most prominent communication issues, although the "descent via" phraseology also featured significantly. Automation issues (both air traffic control and flight deck) were cited in 23% of ATSAP reports, and in 31 of the 68 ASRS reports. For pilots, the most frequently reported automation issue was that the FMS navigational database was out of date, causing the programmed RNAV procedure to be inconsistent with the assigned RNAV procedure.

RNAV procedural issues were identified in 55 of the 100 ATSAP reports. They included airspace issues, route interactions, application of procedure, charting issues, update cycle/NOTAMS, and procedure design. Of note is the low percentage of ATSAP reports that were found to include Operator Acts as a causal factor. Typically, 40%-50% of ATSAP reports include an Operator Act – so this result suggested to the authors that RNAV procedural issues were not generally associated with controller error.

c. Safety Studies and "Human in the Loop" Simulations

The FAA's Flight System Laboratory regularly conducts safety studies, as well as "Human in the Loop" (HITL) simulation research to explore operational human factors issues in a non-operational environment. Through 2015 and 2017, the team conducted various studies on the safety and human factors aspects of EoR approaches.

A safety study published in 2016 aimed to determine the risk of aircraft-to-aircraft collisions during EoR operations on simultaneous independent approaches to dual or triple runways using Track-to-Fix (TF) turns to the final approach course. A secondary aim of the research was to evaluate some of the controller and pilot human factors consideration of these approaches (Walls, Nichols, McCartor, Greenhaw, Ramirez, Reisweber, Rodzon, Smith, Dulli & Foster, 2016). The pilot research considered qualified and current type-certified crews flying into Denver International Airport, using 630 simulated EoR approaches as shown in Figure 5.

Vertical Navigation (VNAV) simulations were conducted using the FAA Boeing 737-800 simulator and the Airbus A330 simulator, both located at the Mike Monroney Aeronautical Center in Oklahoma City. Non-VNAV simulations were conducted using the Embraer ERJ145 full-motion flight simulator at the CAE Simulflite Training Center in Dallas, Texas. The air traffic controller research involved 38 hours of simulated traffic with pairs of certified professional controllers in the final monitor position, using a generic TRACON facility configured to display realistic airspace for the Denver TRACON environment. The simulation scenarios involved investigating non-normal situations where an aircraft that was established on the approach deviated from the approach path. The research assessed how flight crews reacted to an equipment failure that could potentially cause a path deviation, and how quickly the flight crew could return to course. The analysis included both safety considerations and human factors data.

The acceptable safety level for collision risk was defined as one collision in a billion operations ($1x10^{-9}$). The study found that dual and triple simultaneous EoR approaches to parallel runways met the required safety level when the runway centerlines were separated by at least 3,600 feet (for duals) and 3,900 feet (for triples). However, this analysis did not incorporate the risk of wrong runway selection, which was a risk the authors suggested could be eliminated by "*ensuring an aircraft is on a path that is unique to the intended landing runway prior to being considered established on the approach*" (Walls et al., 2016, p98).

The results of the human factors analysis from the pilot simulations indicated that more than half of the flight crews first responded to a non-normal situation by contacting air traffic control, while attempting to diagnose the situation. Pilots generally were not prepared to execute approach break-out procedures when instructed to by an air traffic controller, resulting in reaction times approximately five seconds slower. This was hypothesized to be partly due to differences in automation between aircraft types associated with take-off/go-around (TOGA) functionality.

Human factors data from the air traffic control simulations revealed that compared to existing simultaneous independent operations, controllers reported subjectively feeling that they had less capacity to resolve proximity conflicts with EoR approaches. Eye tracking data indicated that controller scanning patterns changed, with a focus on the third turn of the approach (the TF turns were angled at 60-60-50-10°, to help reduce nuisance TCAS alerts within the scenarios). Controllers expressed a consensus view that this turn would be where "bad things" would most likely happen. If a deviation occurred at that turn, controllers were concerned there would not be sufficient time available to take corrective action because of the proximity to the approach. The authors suggested that controllers felt "there was a significant chance that they would not be able to process the visual information, formulate a strategy, and successfully intervene quickly enough to keep the aircraft separated" (p. 56). Controllers indicated that they needed to maintain higher vigilance when the aircraft were "head to head" than if they were staggered. This is perhaps not surprising – for an air traffic controller to permit two aircraft to fly "head to head" at the same altitude runs counter to the most fundamental principles of air traffic control.

A further safety study on the use of EoR incorporating Radius-to-Fix (RF) turns for simultaneous independent approaches to parallel dual or triple runways was published the following year (Walls et al., 2017). This study utilized the HITL data from the previous TF study, adapting inputs to the mathematical model to make it representative of the RF approach design. The safety analysis showed that the mid-air collision risk was between 10^{-9} and 10^{-10} per operation, for simultaneous independent EoR operations to dual parallel runways separated by 3,600 feet or greater, and to triple parallel runways separated by 3,900 feet or greater. Availability of a Final Monitor with Final Monitor Alert (FMA) lowered the mid-air collision risk, as would be expected. In the case of both duals and triples, a controller was assumed to be the primary mitigation of mid-air collision risk. There was essentially no difference in the level of safety between TF and RF turns.

Relevant to a human factors consideration of EoR approaches is the rate of what Walls et al., (2017) term "nuisance" or "false" alerts and/or advisories, meaning that these communications do not correspond to a real collision risk event. Both the TF and RF turn studies considered the impact of EoR approaches on these events for both the Final Monitor Aid (FMA)[5] and Traffic Collision Avoidance System (TCAS).[6] The authors found with FMA that these events occurred more frequently with RF turns, whereas for TCAS event rates were similar with both RF and TF procedures. According to Walls et al., (2017), both types may be reduced by including key mitigations within the design of the approach procedure, such as:

- Adding a straight segment final approach course to the approach prior to intercepting the final approach course, to separate the turn from the adjacent traffic;
- Staggering turns onto the procedure by at least 2 nautical miles or ensuring that the last 50° of the turn occurs below 2,350 feet above ground level.

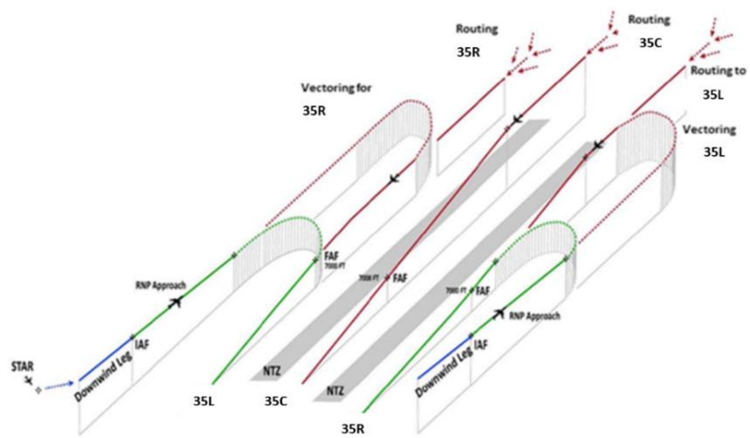

Figure 5: Illustration of the EoR concept applied to a notional triple parallel runway configuration. Downwind legs of the EoR approaches to 35R and 35R are shown in blue; after the initial approach fix (IAF) the EoR approaches are shown in green. Vectored approaches to these runways are shown in red for comparison. The diagram also shows a "straight-in" vectored approach to 35L, with the Non-Transgression Zones shown in grey. Source: adapted from Walls et al., 2017, p. 8.

A third study conducted by the Flight System Laboratory (Walls, Nichols et al., 2017) examined the risks associated with the selection of an incorrect Instrument Approach Procedure (IAP). It was anticipated that the results would help provide insights that would support facilities with existing approach procedures that were not designed with unique flight paths. The research involved developing and evaluating three different cases to characterize the risks associated with an incorrect approach selection. These were:

- **Case 1: Intended Runway Traffic Intersection** – Deviating aircraft colliding with an aircraft arriving at the deviating aircraft's assigned runway.
- **Case 2: Merge with Landing Runway Traffic** – Deviating aircraft colliding with an aircraft arriving at the runway that the deviating aircraft is incorrectly flying to.
- **Case 3: Intermediate Runway Traffic Intersection** – Deviating aircraft crosses traffic arriving to an intermediate runway to get to the incorrect runway.

[5] Final Monitor Aid is a tool within STARS that is used by Final Monitor Controllers. It provides a radar display of the current position of each aircraft, along with a 10 second prediction of its future location based on the aircraft velocity. The algorithm used to generate the predicted target does not account for turns.
[6] TCAS provides both traffic advisories (TAs) for information, and resolution advisories (RAs) which require immediate evasive action.

Based on these cases, analysts developed collision risk models. The risk of encountering wake turbulence was evaluated where in-trail separation could be lost. SMEs suggested that an input error by the flight crew would be the most probable cause of incorrect approach selection. This study assumed an incorrect runway selection rate of one per 10,000 operations, and a target collision rate of one per billion operations.

No approach considered could meet the target safety levels for collision and wake encounter risks without controller intervention. To meet the desired safety level for Case 1 and Case 3, controllers would need at least 50 seconds to intervene after observing the deviation from the assigned path. The preferred mitigation for these instances is the design of procedures that include a unique path for each landing runway. The authors suggested that where an airport or facility desired to design an approach that included intersections such as those evaluated in Case 2, work to evaluate the wake vortex encounter risk would be required before addressing the airspace design and operational considerations.

d. RNP Utilization

Salgueiro & Hansman (2017) conducted an analysis of RNP approaches at Chicago Midway, New York John F. Kennedy (JFK), Denver International Airport and Seattle-Tacoma International Airport. The initial aim of the research was to consider the extent to which RNP approaches might enhance approach stability, since unstable approaches have been associated with runway excursions, Controlled Flight Into Terrain (CFIT) and Loss of Control (LOC) events. To investigate this, a sample of radar data was obtained for 11,062 approaches at the four named airports. Of the total number of approaches, it was possible to identify only 364 as RNP approaches. The overall RNP utilization rates at these four airports was 0.84%, precluding the possibility of an analysis of approach stability. However, unpacking the overall utilization rate yielded some interesting information.

Seattle had the lowest RNP utilization rate overall, at 0.3% of its approaches within the data sample. JFK New York had the highest utilization rate, at 7.56% of approaches within the data sample. At JFK, the Canarsie approach is a visual approach to 13L that is used to deconflict traffic from La Guardia and to provide noise abatement over populated areas west of the airport. The approach requires a 90° visual turn at low altitude (around 500 feet). JetBlue pioneered the design of a “special” RNP-AR approach to 13L which essentially overlays this visual approach but provides the precise lateral and vertical guidance delivered with RNAV capabilities. Because the approach trajectory matches that of the alternative flown by non-RNP aircraft, the approach controller is relieved from dealing with mixed equipage when sequencing aircraft in visual conditions.

With the RNP-AR approach to 13L, the decision height and missed approach point were placed into the RF turn. However, it was found during testing that the autopilot disengaged when a go around was commanded at the decision height. This impacted RNP accuracy and required the flight crew to manually re-engage lateral navigation. The introduction of “TO/GA” functionality within the autopilot overcame this limitation. The entire JetBlue fleet became fully TO/GA and RNP capable in 2015, enabling the airline to sign a letter of agreement with New York TRACON (N90) such that all JetBlue aircraft are now assigned the RNP approach to 13L when 13L is the landing runway. JetBlue claimed that its pilots used the RNP procedure 97.8% of the time in 2015, saving approximately 18 gallons of fuel per flight. The “special” RNP-AR approach to 13L is also used regularly by Delta, American Airlines, Qatar, UAE and WestJet.

4.2. Flight Deck Considerations

To gain a deeper understanding of the range of human factors issues on the flight deck, a VOLPE team conducted a research program to understand more about the perspective of line pilots. Chandra & Markunas (2016, 2017), investigated the complexity factors involved in flying terminal Instrument Flight Procedures (IFPs). They interviewed 45 professional pilots, all of whom where certified and current instrument rated pilots, and 23 of whom were qualified to conduct RNP-AR operations. The interviews were conducted in small groups of two or three pilots, and pilots within each group flew for the same operator and flew the same (or a very similar) aircraft type. The aim of the interviews was to understand more about the factors driving complexity, so each interview included reviewing, briefing and discussion of two STARS, two SIDS and two IAPs in an office setting.

Subjective complexity factors were defined as factors that added extra mental or physical steps for pilots to complete. Examples included ambiguity, variability in procedures, chart variations, non-contiguous path depictions (where pilots had to “jump the gap”), multiple path transition points, waypoint names, and speed and altitude constraints. Operational complexity factors were defined as the complexity factors largely independent of the design of the IFP itself. Examples of these might include air traffic control intervention, aircraft equipment/performance factors - including differences between aircraft types in terms of the functionality of the FMS and the responsiveness of the autopilot[7], environmental factors, flight crew factors, operator factors and so on.

Poorly named waypoints may increase the complexity of pilot operations in two primary ways. First, pilots may struggle to pronounce or understand some unusual waypoint names. This is especially common for names that incorporate numbers. In some cases, ambiguous pronunciations can lead to sidebar discussions that distract pilots from their approach briefing. The second complexity factor for waypoint names occurs when the names begin with the same letter or set of letters. This can make it easy for pilots to accidentally select the wrong waypoint on the Control and Display Unit (CDU), so pilots may need to take an extra mental step to ensure that they are selecting the correct waypoint.

Pilots are required to complete an approach briefing every time they fly an instrument approach, such as EoR. During an approach, pilots often have many tasks to complete, so it is to their benefit to complete an effective briefing as quickly as possible. Under ideal circumstances, pilots would be able to complete an effective briefing in under 2 minutes. However, unfavorable weather conditions, unfamiliarity with the aircraft being flown, or unfamiliarity with the arrival airport and/or procedure may increase the length of the briefing. Chandra and Markunas (2016) cited the work of Lutat & Swah, which provides a three-step process for conducting efficient instrument approach briefings:

1. Build, load and/or select the procedure in the FMS with reference to the chart.
2. Check that the FMS is compatible with the aircraft clearance.
3. The flying pilot briefs the procedure, and the monitoring pilot checks the FMS programming against the charts.

[7] There are not only variations between manufacturers and between aircraft types, but between software versions on the same aircraft type with the same operator. Hence, the FMS/autopilot is a significant complexity factor.

Even with these guiding steps, approach briefings can be rushed, incomplete, and result in unstable approaches/landings if they are conducted too late. Ideally, approach briefings would be completed 10 minutes before the top of descent.

Many pilots reported experiencing late changes to the approach or landing runway. In some cases, the pilots interviewed by Chandra and Markunas (2016, 2017) experienced as many as three changes to a single arrival. Late clearances may leave pilots with little time to prepare for the approach and they can dramatically increase the pilots' workload. As a result, pilots must decide when to enter the flight path into the FMS. Pilots who do this early will have more time for other tasks later in the arrival, providing that the arrival is not changed. Late changes may mean that time was wasted programming the FMS. Conversely, pilots who wait to program the FMS will not have to worry about reprogramming it, but they will have more work to do during an extremely busy portion of the flight.

Chandra and Markunas developed several recommendations based on the complexity factors they identified. These included recommendations to address IFP design requirements, recommendations related to operational complexity, recommendations addressing charting issues, and recommendations for training. One of the key "take-aways" from the human factors work on the flight deck perspective is the need for an integrated approach when addressing human factors in RNAV and RNP procedures.

5. Concept Validation and Implementation Plans

5.1. Seattle-Tacoma International Airport

MITRE published a proposed plan for the validation of dependent parallel approach operations at Seattle-Tacoma International Airport (Pollock, Hudak & Spelman, 2015). Analysis activities had initially been planned to support and validate the implementation of EoR. For example, pre-implementation baseline data collection had been suggested to help address the following questions:

- What is the airport-wide EoR usage rate?
- How do methods for spacing and sequencing EoR operations change as controllers become more familiar with the operations?
- What factors may affect the usage rate of EoR in the future?
- How can varying traffic flows incentivize controllers to use EoR operations?

After implementation was completed, it was suggested that the following questions could be addressed:

- How has EoR affected runway use?
- Has runway prioritization changed due to EoR operations?
- Has the way that controllers handle aircraft crossing runways changed due to EoR?
- Did EoR operations result in traffic management initiatives for balancing sector loading? What initiatives? What were the results?

Additional suggestions for concept validation included consideration of controller thought processes and strategies for sequencing aircraft, and qualitative data on how EoR affected controller workload. Direct observations were also suggested, as were the use and analysis of quality control data such as operational errors, pilot deviations and TCAS resolution advisories.

The FAA recently completed a report on RNP-AR utilization and concept validation at Seattle (FAA, 2017c). This report provided an outline of the “Greener Skies over Seattle” (Greener Skies) project, which was the name of a ground-breaking initiative intended to deliver aircraft from the top of their descent to the ground in the quickest and most efficient way, using redesigned STARs and optimized profile descents (OPDs), along with RNP-AR approach procedures and the EoR concept. Over recent years, several factors in combination have impacted the extent to which Seattle has been able to realize some of these efficiency opportunities. These include a growth in traffic year after year, a lack of effective decision support tools, decreased RNP equipage within the fleet, runway closures, and the timing of staff training. The concept validation report identifies some possible enablers that may help stakeholders strive for increased EoR use at Seattle, including airspace redesign and improved decision support tools.

5.2. Denver International Airport

The FAA commissioned a research program to validate the concept of EoR approaches at Denver International Airport. This was to include a consideration of the benefits in terms of reductions in the variability of track distance and flight time (Mayer, 2016).

In 2015, the FAA approved a waiver allowing the conduct of simultaneous independent and parallel operations without Final Monitors between an RNP-AR approach and another instrument approach, on three pairs of widely-spaced runways. The authorized runway pairs were 34L/35L, 34L/35R, 34R/35R, 16L/17L, 16R/17R, and 16R/17L.

The MITRE evaluation utilized a data-driven approach to compare operations before commencement of EoR operations (the baseline), with operations after the introduction of EoR (the alternative). Radar track data was obtained from the National Offload Program. STARS scratchpad data was used to assign the radar tracks to the baseline or alternative conditions.

The evaluation found that following implementation, 6.7% of Denver's approaches overall utilized RNP-AR procedures. There was a 74% reduction in flight time variability and a 95% reduction in track distance variability The author reported an average 6.1 nautical miles reduction in flight distance per RNP-AR procedure flown, and there was no increase in the go-around rates. There was no detailed consideration of human factors issues within the concept validation report, although reference was made to EoR assignment and EoR clearances. The radar data from the study period showed that 83% of assigned arrivals completed RNP approaches.

5.3. Research Gap

Relatively speaking, much is known about the potential technical benefits of EoR operations using RNP-AR procedures in simultaneous operations. Radar data, mathematical models and computational simulations demonstrate both that the concept is viable, and that EoR can make meaningful contributions to NAS efficiency. However, little consideration has been given to the operational air traffic control aspects of implementing EoR procedures – including the factors that encourage or inhibit adoption and utilization. These are key drivers of benefit realization.

The identification of experiences and lessons learned from initial implementation sites might ease or enhance implementation at future facilities. For example, successful adoption of RNP procedures at future sites is likely to be influenced at least in part by the nature of the operation. These factors might include the terrain, the fleet mix and participation rates. In addition, the levels of collaboration among stakeholders, leadership and management support are likely to be factors, as are any training requirements, and local software adaptations that might be required to support implementation. In the widest sense, many of these factors may be regarded as "human factors," since they are about the actions and decisions made in preparing a facility for the successful implementation of RNP procedures.

6. EoR Approaches at Seattle

6.1. Seattle TRACON Site Visit

The Seattle TRACON (S46) site visit took place between January 30 and February 1, 2018. A research team of two human factors specialists visited Seattle TRACON for three days, spending some time observing operations on the TRACON floor and interviewing a range of personnel. The interviews were conducted in accordance with a pre-approved protocol (Thomas & Kirby, 2017a). While it was acknowledged that relevant topics and questions would vary according to who was being interviewed, the research team were seeking information on the following topics:

- EoR planning and implementation (facility preparation);
- EoR impact on workload, controlling style and practices;
- Automation, trust and confidence;
- Operational challenges/benefits of EoR (facility specific);
- Training considerations (expected or emergent);
- Supervision/management considerations and leadership support;
- Lessons learned and suggestions for improvement

For Certified Professional Controllers (CPCs), background questions included how long they had been a controller, whether they had been a controller at other facilities (FAA or otherwise), which positions they currently worked, and whether they had experience of delivering on-the-job training at Seattle TRACON. Additional questions included some of the following, depending on the time available with that controller before they were required to return to the operation:

- What issues do you most commonly encounter with RNP approaches?
- How do RNP approaches affect the way you plan air traffic?
- What factors do you consider in clearing aircraft for an RNP approach?
- What controlling strategies do you employ for using RNP approaches successfully?
- What factors helped you to trust the automation and gain confidence in the procedures?
- How do you manage your workload (especially changes as workload ramps up/down)?
- How easy was it to start using RNP approaches, and has ease of use changed over time?
- If you are an on-the-job training instructor (OJTI), how have RNP approaches impacted on the way you train?
- How has CRDA supported you with RNP approach decisions?
- What are the 3 most important factors for successful implementation of RNP at a facility?
- Do you have any tips, hints, or guidance for other controllers using RNP approaches?

6.2. Seattle TRACON Interview Results

A summary report describes the conduct of the site visit (Thomas & Serrato, 2018); the focus here is on analysis of the interview data and discussion of the results. The interviews were led by one human factors specialist, with the second taking notes. Interviews lasted in the region of 20-30 minutes and were conducted in an office located close to the operational floor. Over the three-day period of the site visit, the following interviews were conducted:

- An interview with a Front-Line Manager (FLM);
- An interview with a NATCA Facility Representative (FACREP);
- An interview with the incoming NATCA National EoR Representative, who as a CPC at the facility held a key role in the initial implementation of EoR approaches at Seattle;
- Interviews with ten currently Certified Professional Controllers;
- An interview with one Quality Assurance specialist (and former CPC/FACREP);
- An interview with two contract training instructors (formerly CPCs)

The CPCs who were interviewed had between 5 and 21 years of total controlling experience, and their experience at the Seattle TRACON ranged between 1 and 10 years. Many controllers had previous experience at Air Traffic Control Towers (ATCTs), other TRACONs, Air Route Traffic Control Centers (ARTCCs) and/or within military air traffic control.

Interviews conducted on the first day were undertaken in the presence of the outgoing NATCA National EoR representative (also a Seattle TRACON CPC). All interview data are non-attributable; the code following each quotation identifies the individual's role and allows cross-referencing to interview notes; it does not relate to the name of a specific interviewee. The data from these interviews are discussed using the categories of the model shown in Figure 6.

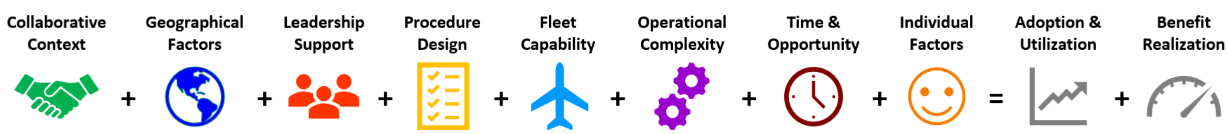

Figure 6: RNP-AR and EoR success factors for adoption, utilization and benefit realization

a. Collaborative Context

The history of RNP-AR approaches and EoR at Seattle-Tacoma International Airport is tied in with "Greener Skies", an initiative that began around ten years ago. A timeline of key events since the start of the Greener Skies initiative, which includes some of the challenges S46 has faced in achieving the benefits of RNP-AR, is shown in Figure 6 as background information.

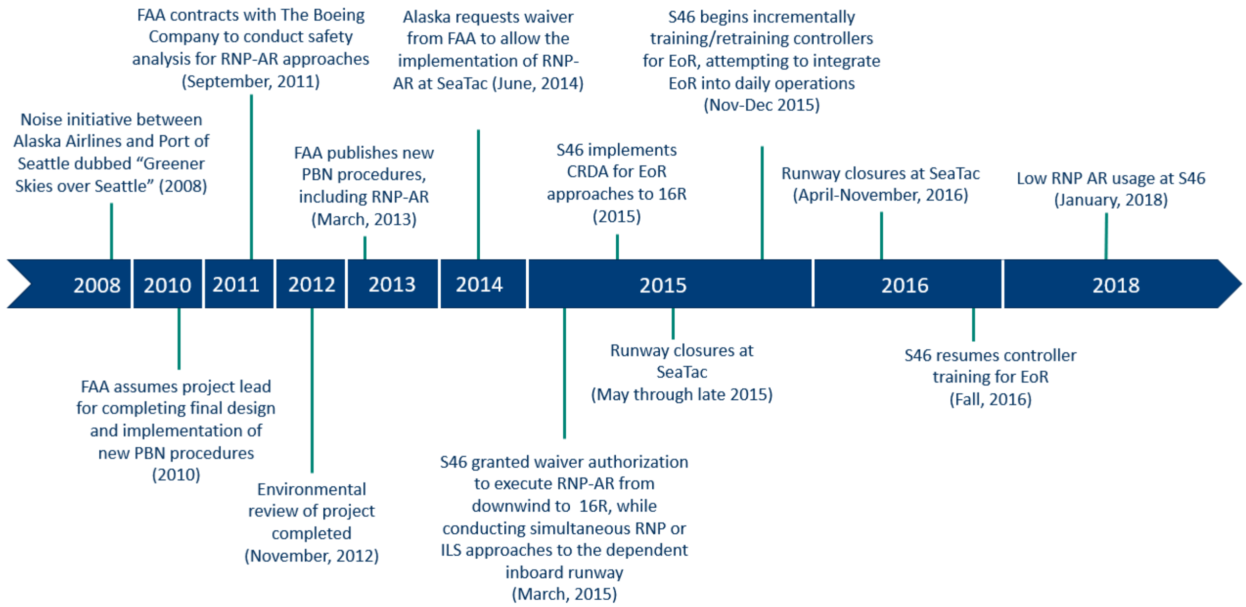

Figure 7: Timeline of the Greener Skies initiative including RNP-AR and EoR at Sea-Tac and S46

As can be seen, the Port of Seattle collaborated with an operator, Alaska Airlines, to work on potential initiatives. The FAA became involved with Greener Skies in a leadership role in 2010 and was interested in redesigning Seattle airspace to validate NextGen concepts, including the design of STARs with OPDs and RNP-AR approaches. Seattle was selected partly based on high levels of equipage within the fleet (FAA, 2017b). At the time, this work was regarded as "groundbreaking" and was aimed at delivering aircraft from top of descent to the ground in the most efficient way, utilizing highly predictable routes.

Despite the complexity of the initiatives, there was little data from the Seattle TRACON interviews to indicate that there were high levels of collaboration between stakeholders from the outset of the project. However, the information that was provided also acknowledged that the Greener Skies initiative had started a long time previously, so the data may be limited by recollection.) One comment was that:

> *"Our representative at the time was not really representing the interests of controllers, there were jokes about him wearing an airline jacket! But this was before my time…The stakeholder view was not comprehensive then though. Something like that wouldn't happen today, they'd be talking to the experts, it's a lot different these days." (CPC101)*

This is an interesting observation, since a review of PBN procedures undertaken by the U.S. Government Accountability Office (GAO) suggested this issue might not have been unique to Seattle in the earlier days of PBN. "Officials with the Port Authority of New York and New Jersey told us that the failure to include controllers early in the procedure design process for the airspace redesign… contributed to the 4-year-plus implementation delay, because some proposed routes had to be amended following controller input," (GAO, 2013, p. 44). Collaboration is important not just for sound working relationships and strong engagement and buy-in, but for helping all stakeholders understand the perspective of other parties. One of the consequences of a lack of collaboration is a lack of awareness among controllers of what happens on the flight deck, and a lack of perspective into the motivations of different stakeholders:

"Simulators would help a lot and joint trainings of controllers and flight deck would help both parties better understand each other. I don't know what the pilot is doing other than typing in fixes. It would really help to show what this all looks like from the pilot's side." (CPC104)

"We have controllers who are in working groups and go to user forums, so there's that possibility. But only one or two controllers are part of that…" (MGR114)

b. Geographical Factors

It was acknowledged by many of the controllers interviewed that geographical factors had impacted the adoption, uptake and utilization of the RNP-AR approaches at Seattle. The most significant challenge mentioned in interviews was associated with noise abatement procedures. On more than one occasion this was mentioned with reference to a wealthy residential area to the East side of the airport.

"The whole thing with noise abatement was the only way to get Greener Skies to work. We have such huge noise abatement procedures here. There's a noise abatement coalition that fights airplane noise, and they didn't look at options of making it go out further so that they didn't have to do more studies. If they were going to go further out, I think it would have given us more room to play with. But I don't think it would be more efficient than it is now, because now we have approaches coming from all over." (CPC101)

"The approaches would be easier to use if the arc was further away from the airport. Right now, it joins final at six miles out. Unless we are incredibly slow we hardly turn anyone there, it is usually further away from the airport. If we were using it for everyone then it would be easy, but as soon as you get someone on the East side it's difficult. There is no arc there because of the noise rules. Aircraft there must join much further North, eleven miles instead of six. If we could get rid of the noise abatement rules, it would be great." (CPC102)

c. Leadership Support

There was a lack of support from interviewees in leadership positions. One interviewee described the context for the implementation at Seattle, explaining that there had been timing issues which did not set up the implementation for success:

"It fell apart without support. It was sad because I thought it had potential. There was a lot of visibility at the time. When rolled it out, it was against other critical timelines, so it was damned to begin with because it wasn't timed right. It was delayed eight months due to runway closures, then when EoR did come out we were waiting on a waiver." (CPC109)

This interviewee also described the lack of support for the initiative, and the challenges in accessing supporting and reaching a "critical mass":

"It got to the point where I said, 'we have a lot of questions and no answers.' To see the support start to dwindle… I started to get jaded… Is it even going to be feasible? Confidence eroded, and people got fed up, so it all started to lose support. Small things started to add up." (CPC109)

There were also some issues that had a significant impact on the controller confidence and the willingness of leaders to support:

"On the pilot side we could see the numerous blunders because pilots would load it incorrectly. I can see it why it happened, but it can't happen… I set up a meeting with engineers, and they said this won't happen, the odds are so low. So I tell this to the controllers - but then it happened three times in one week? So I said 'I cannot support this'…" (CPC109)

The timing issues, lack of support, and the potential for pilot error also mean that there was an understandable lack of will to encourage pilots to request these approaches:

"Many times, when pilots are offered the approach, they've declined, either because they already set up for ILS or because in their mind the approach is too cumbersome. Maybe one out of ten times they'll say yes. And it's not the controller's job to persuade pilots to take the Mike[8]." (MGR114)

The manager also noted that the flexibility that comes with traditional vectoring is part of what makes air traffic control creative and enjoyable for controllers. RNP operations limit this flexibility:

"CPCs like flexibility, they don't want to be put into a box. With the increase in traffic it's been harder to keep that flexibility. Even when we have a program in place, it's getting people to do it time and time again that's been a challenge for me as a supervisor." (MGR114)

And finally, there has been a lack of direction in training and encouraging new developmental controllers to use RNP and EoR. Without seeing these approaches in regular use on the floor, it is difficult to expect junior staff members to be willing to try them – especially if their on-the-job-training instructor takes a less-than-enthusiastic view of RNP-AR approaches and EoR. One contract training instructor said:

"We are bit confused because for this to be used, the controller must have gone through the class and simulations we built. The whole facility had to do that, but we were never told what to do with subsequent people who arrive here. When we train them, do we incorporate EoR in the regular training? Do they need special classes? We never got an answer… and I think it's because it's not getting used on the floor, so no one really cares." (CTR107)

[8] The RNP-AR approaches used within EoR operations at Seattle are "specials". They are operator designed and used, and not publicly available. They are often known within the operation as "Mikes". EoR is seldom used at Seattle, so many controllers use the term "Mike" to refer to RNP-ARs and EoR somewhat interchangeably. Awareness of these approaches is generally low at the facility - the research team were unable to access the Mike approach plates at the facility, and obtained them from a CPC who knew a pilot at one of the airlines.

d. Procedure Design

The interview data indicated that RNP-AR approaches at Seattle were designed prior to the FAA's Performance Based Navigation Implementation Process, reaching current maturity levels (JO 7100.41, FAA 2016b). This means that those involved in the process may not have had clear guidance on designing a 'good' procedure, or even being aware of what might constitute a 'good' procedure. Controllers who were interviewed during the visit reported that there was limited controller input in the design of the new procedures:

> *"They looked at impact on noise so that aircraft weren't flying over houses all the time. If they had gone further North I think it would've changed things because it would've given controllers more altitude to play with. They didn't have much controller input." (CPC101)*

One of the options identified in the Salgueiro and Hansman (2017) research for designing a successful RNP approach was to overlay or mimic a visual approach (albeit that doing so may introduce additional complexities). . This was reported by one controller as being successful in the design of RNP-AR approaches at Portland, but the method was not used at Seattle:

> *"I used to be at Portland. When they were implementing RNP, they went to the tracks and asked on a visual day, which tracks get used? They got the data, and they decided to model the approaches after that, based off the visual." (CPC104)*

Another controller identified a disconnect between the last fix of the STAR and the first fix of the RNP-AR approach as a potential design factor impacting pilots:

> *"The HAWKZ arrival is to six thousand feet, and the RNAV RNP Mike is at five thousand feet. It's a thousand feet off, so there is a disconnect. Pilots can still do it but there's something that they can't do both at the same time, I think it's the way they enter it." (CPC112).*

This insight into the way that pilots may have to manually enter data in the Flight Management System to link a transition was rare; only this controller mentioned the issue at Seattle.

e. Fleet Capability

Seattle was chosen as a test site for Greener Skies at least partly because of the high equipage rate of operators; design of the approaches was operator initiated (FAA 2017b). RNP-AR approaches require both suitably equipped aircraft and a qualified crew before the approaches can be assigned and then cleared, meaning that fleet capability is a consideration in how often these approaches will be used. However, the equipage rate at Seattle has been diluted as new operators have begun using the airport. Many controllers explained that this is an issue in their willingness to consider assigning and clearing RNP-AR approaches, since controllers need to manage a more diverse landing sequence now compared to when the approaches were first introduced:

> *"It's like you're trying to work around the EoR aircraft instead of with it. It feels like you're cutting in line. That one approach feels like an exception. It makes the workload harder. Trying to*

work that one approach into everything else? The wind can change and when it does, it changes everything. The challenge is making it all work together in an integrated way, instead of doing it on an individual basis." (CPC103)

"It's very hard for CPCs to mix different types of approaches because the continuity is not there. You may forget, and a lot can go wrong, something can slip through the cracks. There's times when an aircraft coming from South wants the Mike approach, but if there are seven aircraft on final, I'll just say 'unable'." (CPC112)

"I use them only rarely. I like them, and I would use them more often… it's just the sequencing part is the major issue. There was a time when we offered to everyone, but most declined. Now we typically wait to request. But when they're the first guy with no-one to conflict with, then I'll offer." (CPC113)

"What has to happen for this to work is no mixed fleet. Right now, in any given arrival period 90 percent of aircraft cannot do an RNP approach, that needs to be reversed." (CTR107)

The diversity of arrival sequences is associated with controller working memory, processing capacity and comfort levels. Research suggests that controllers have a capacity of approximately 7+/-2 "storage bays" within working memory (e.g. Garland, Stein & Muller, 1999). Where successive approaches in an approach sequence are of the same "type" (such as all heavy jets, or all on EoR approaches), they may be regarded as a single chunk, and will occupy one storage bay. Where a sequence contains many alternating or switching approach types, controllers need to use more storage bays. At these times, controllers may report being aware that their workload is higher, and/or that they have less capacity to deal with the unexpected.

f. Operational Complexity

Operational complexity is used here to describe the suite of factors that make each facility unique. Apart from the noise abatement constraints, much of the operational complexity at Seattle is driven by runway availability and the interactions with nearby airfields – Boeing Field and Paine Field. Runway availability through 2015 and 2016 was limited due to construction work, which added significant complexity around the time that EoR was introduced.

The runway use plan is a pre-determined agreement that specifies how runways will be shared between approach controllers (for arrivals) and tower controllers (for departures). Sharing the "limited pavement" at Seattle-Tacoma is an acknowledged source of frustration, as reported by this manager:

"The runway use plan has always been a point of frustration on both sides, largely because the TRACON feels as though they should be able to put more aircraft on the inboard runway than we're allowed. The tower uses the inboard for departures. The largest problem with the runway use plan is that we're not allowed to land on the center runway and we want to use the inboard more, but the tower won't let us because they use it for departures. It's like the Hatfields and the McCoys in West Virginia - new controllers who come to the facilities get "brainwashed" into thinking the other people are 'bad', without ever meeting them or knowing them." (MGR114)

"The runway use plan discourages the use of EoR. We have a runway use plan that says we should put everyone on the right runway (34R), unless the final is full, when it's a thirteen or fifteen mile final. You are way past the turning point at the bay with guys all lined up before you can put someone on the left. You need to review the runway use plan before you spend time and money designing these approaches." (CPC105)

It may be that changing the runway use plan is a less onerous undertaking than re-designing the RNP-AR approaches. It is not known if the tower controllers were consulted in the initial design of the Greener Skies approaches, and as indicated in the GAO (2013) report, the engagement and expertise of tower controllers can make a difference in the way these procedures are designed and implemented.

A related constraint discussed by controllers was the need to "shoot the gap", a term which refers to the need to cross an active runway. Figure 7 shows the runway configuration at Seattle-Tacoma International Airport, and as can be seen:

"We joke about taking 34C out altogether, then you wouldn't have to cross the runways! The third runway was completed in 2008. Controllers are shooting gaps in arrivals to get their departures on the right runway. To get the departures to the correct runway you need to taxi across. It's the same on the South flow, but not as bad." (CTR107)

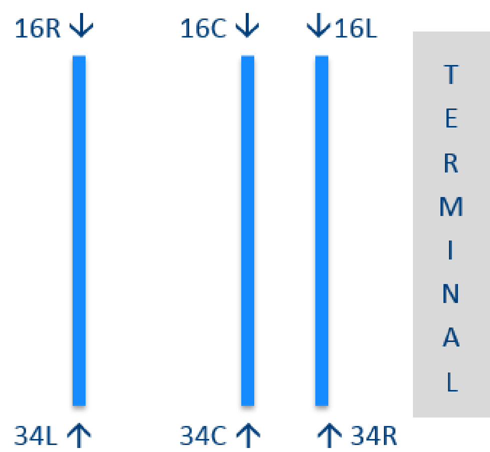

Figure 8: Runways at Seattle-Tacoma International Airport (operations run in the North configuration on runways 34L, 34C, 34R, or in the South configuration on 16R, 16C, 16L).

Every facility has its own complexity factors, which is part of what makes each air traffic control facility unique. At Seattle, adjacent airfields as well as available runways color the complexity picture:

"There's the airspace complexity, and the interaction with Boeing Field. With traffic volume and complexity, when there's drama, conflict or high traffic, our first reaction is to ditch the Mikes and go for vectoring. You've got to consider the Paine Field interactions too. We're talking all kinds of hiccups." (CPC109)

"We're not supposed to do it with traffic on the Boeing North final and there's pretty much always traffic on it. I hear it works well at other places with independent runways, but everything here is so congested that it's tricky." (CPC110)

This is interesting because one of the reasons Seattle was selected as a site for NextGen concept validation was because it had complex, but not saturated, airspace – yet traffic has increased continuously since these approaches were first introduced (FAA, 2017b).

g. Time & Opportunity

As a success factor, time and opportunity refers to factors associated with helping controllers to find or create "space" to use EoR. This can refer to literal space, in the sense of creating a "gap" within a planned landing sequence. It can also refer more generally to controllers feeling that they have the time and scope within their controlling practice to safely use the technique.

The RNP-AR (Mike) approaches at Seattle were introduced as "specials", meaning that they were not publicly available approaches, and were are developed by air carrier operators for operator use. When they were first introduced there was some discussion at the TRACON about how to support controllers in finding opportunities to assign and clear aircraft for EoR. This work was apparently initiated by the facility; no-one mentioned external support and resources being made available to the facility on a proactive basis. The possibility of creating a local adaptation to the Converging Runway Display Aid (CRDA), to provide a decision support tool to controllers in determining whether or not there would be space in the sequence for an EoR approach, was only learned about by chance:

"CRDA didn't come to us, we were surviving, and we needed something, then I heard about the CRDA adaptation through the grapevine and called an engineer at the OSF. You've got to establish trust with controllers…. CRDA was going to be great, but then came the problems with the glitches and patches. There was so much trial and error. It came down to me and the OSF engineer to figure out how CRDA was going to look. I thought 'I can't believe they're counting on me to do this'." (CPC109)

"We presented three tools to the workforce to brainstorm ways to anticipate the position of aircraft, CRDA, dash marks along the finals representing distances, and tie-points on the video maps. People preferred CRDA because the visual reference is nice… CRDA was a brilliant idea and it was initially successful, but then we discovered limitations." (CPC115)

The idea of using an adaptation to CRDA to support EoR operations was initially developed at Denver OSF (see section 7.2.g.). The OSF covering Seattle TRACON is located at Fort Worth Texas, meaning that on-site support for user testing, controller feedback and software adjustments was not available at Seattle. On the ground in Seattle, one controller was working almost single-handedly, valiantly trying to support the entire CRDA adaptation.

Seattle TRACON also did not have the benefit of some of the lessons learned from Denver OSF, in terms of using macros to switch the adaptation on and off from the Traffic Management Unit (TMU) or increasing the number of “Runway Pair Configurations” (RPCs) to allow closer alignment with the curved approach[9]. There was no test group of controllers to refine the local version of the adaptation – so many of these issues were experienced by controllers on the operations floor, resulting in a loss of confidence in the CRDA adaption as a decision support tool:

> *“We have some internal problems. I’ve seen that sitting on final, when you combine one position with another position it turns off the ghost targets… you have to go through the process of how to turn it on. Since we don’t do it often we have to take time to turn it on, figure out how to do it. It’s very annoying that the target doesn’t stay on.” (CPC105)*

> *“The hardest part about CRDA is turning it on, I forget the commands and I have to ask someone. You have to turn it on position, you can’t leave it on.” (CPC104)*

The loss of confidence in CRDA was widespread, but not unanimous. There were accounts within the interviews that gave a cautious sense of optimism about CRDA being used:

> *“We use the ghost for any RNP approach when there is traffic, otherwise you’ll make a hole bigger than it needs to be. It helps with sequencing general RNP approaches. But about half a mile to a mile off, the target makes a jump, and it doesn’t follow the curve exactly.” (CPC105)*

Controllers at Seattle who had experience of sequencing both with and without CRDA were asked to provide a rating of sequencing ease both with and without CRDA. They were asked to do this using a five-point scale, where 1 was very difficult and 5 was very easy. The mean rating prior to CRDA being introduced was 1.70, while the mean sequencing ease rating after CRDA was introduced was 3.80[10]. This indicated that CRDA significantly increased the ease of sequencing, albeit that some challenges remained:

> *“I think if we can get the CRDA tool working correctly, if it predicted the exact slot on final and knowing what speeds the plane will be at… That sort of tool would be very helpful.” (CPC102)*

> *“It’s easy to get tunnel vision on CRDA and get sucked into building a specific hole for the EoR. That means you’re not focusing on the sequence as a whole, so you can end up missing something. It takes a lot of focus.” (CPC103)*

> *“Matching speeds is a major challenge. Maintaining half a mile separation difference while gauging the ghost target – which is moving at the wrong speed - is difficult. You’re busy, it’s counterproductive to get CRDA to work when it’s much easier taking them into the downwind. I still like doing them, I just don’t get many of them.” (CPC105)*

> *“I think it would nice if CRDA started a little earlier. As final I don’t look out as far out, but as a feeder you look at the whole airspace, maybe 40 or 50 miles out.” (CPC103)*

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[9] There was also a glitch with one of the radar feeds used to create the CRDA projected path at Seattle. This radar feed was removed from the CRDA adaptation, but by then controllers had already experienced the inaccuracy.

[10] A repeated measures t-test indicated that the results were statistically significant, suggesting that the difference did not arise by chance ($t=-5.64$, $df=10$, $p<0.05$).

h. Individual Factors

Individual factors include subjective factors that influence the way controllers control traffic. Different controllers have different styles and preferences, based on the methods and techniques that best help them meet their operational goals. Motivation, training/experience and workload are all factors that may fall into this category, and most of these items were evident within the Seattle data.

In terms of motivation, many controllers reported that their willingness to assign or clear RNP/EoR approaches was dependent on the position that they were working, and who was on the preceding and/or following position. Consideration of co-worker preferences is a fundamental aspect of team work in air traffic control:

> *"As the feeder you don't know what the exact sequence is, or what the final controller has in mind. It depends on which downwind they're coming in, the base turn in. You never know. You don't want to throw them under a bus if you can avoid it. So, I put off the decision as a feeder and let the final controller decide whether they can do it. It can affect other parts of the sequence." (CPC103)*

> *"I'm cautious when using them. As a feeder if I'm not sure that it will work, I'll say we'll set up for it, but it might not work and you might have to break off, because I don't know what the final controller is thinking. They might be more conservative." (CPC104)*

Another quote illustrated that motivation to assign these approaches may be influenced by perceptions of control:

> *"It's about lack of control. With this, the pilots are in control not the controllers. And we like being in control." (CPC115)*

Training and experience were also factors that came into play when deciding whether to assign and/or clear RNP approaches:

> *"At Portland, we got simulations on just what it would look like on the EoR approach, CRDA. It takes practice to do and get comfortable with it. In Seattle, they had already implemented them when I got here so I got individual training, but it wasn't focused on EoR approaches." (CPC104)*

> *"The only way to get controllers comfortable is for them to see it a bunch of times. Adding RNP to the inboard runway might be helpful too. Labs go only so far because it's not real. The best probably would be replays on FALCON or something that shows it in action, that would probably be a better route. Start slow, practice with visuals and use it in low volume traffic. If you could land all Mikes on a separate runway on VFR then I wouldn't even worry about it. In IMC it's not ideal unless you have time under your belt." (CPC116)*

> *"When I got here a year ago the take on it was no one uses it because it didn't work. But I think if we used it more it would probably be easier to use. I think it's a cool idea and I wish it worked better than it does, but nobody using it makes it harder for others to use it." (CPC103)*

Related to this is the concept of workload, since it is important that controllers can choose when to use these approaches, based on their planned sequencing and their assessment of the situation:

> *"We'd get some pressure from management during busy times, saying 'You have to do this'." (CPC115)*

It is not acceptable to require controllers to use a given method or technique unless they have been provided with all necessary support, training and tools to do so competently, and confidently.

6.3. Seattle-Tacoma International Airport Operator Interviews

Following the Seattle TRACON site visit, the research team wished to gain additional insights into the human factors aspects of EoR approaches from the flight deck perspective. To supplement the data collection interviews undertaken with personnel at Seattle TRACON, two interviews were conducted with three trial pilots and/or fleet captains with two airlines operating from Seattle-Tacoma International Airport. Noting that not all points were made by all individuals or operators, the main themes that emerged from these interviews were as follows:

- During the design phase of the RNP-AR approaches, there was collaboration between the airlines, the Federal Aviation Administration, NATCA, and four controllers. One interviewee said: *"The procedures look like what everyone wanted them to look like. At this point it's an equipage issue."* It appears that the airline representatives and air traffic controllers who participated in this research had markedly different perspectives on the level of collaboration during the procedure design phase.

- The terminology is different between the flight deck and air traffic control. Airline representatives reported that most pilots do not know what "EoR" means, since the separation benefits of EoR are not relevant to the flight deck. Pilots know these approaches as RNP-AR approaches, requiring certain equipage and crew training to be considered "authorized" to fly them.

- It would be an idea to advertise when the RNP-AR approaches are available at Seattle using the Automated Terminal information System (ATIS). This is done at some locations but is not currently the case at Seattle.

- Pilots in general do not request RNP-AR at Seattle since the response from air traffic control is often "*Unable*". It's not helpful when controllers ask, *"Would you like the RNP?"* It would be more helpful for pilots to be able to expect the RNP, but these are seldom assigned at Seattle.

- One operator reported that their pilots do not ask for the RNP because air traffic control reserves the right to take them off it. Changing the approach so close to the airport creates an issue for the flight crew because it takes more than the available time to reprogram the FMS. Hence, pilots have learned not to ask for these approaches at Seattle.

- Portland TRACON uses a significant number of RNP approaches, and CRDA is available to controllers, albeit that EoR is not available. There may be value in taking an "appreciative inquiry" approach and visiting the facility to find out why RNP approaches are so well accepted and well used at that airport.

- For one operator, Seattle has the highest number of unstable approaches of all airports they operate into: *“I will tell you that we fly to Los Angeles and San Francisco, yet we are managed much more dynamically and much more closely in at Seattle than we are anywhere else we operate into. Seattle is by far the most unpredictable place we operate in.”*

7. EoR Approaches at Denver

7.1. Denver TRACON Site Visit

The visit to Denver TRACON (D01) was conducted between October 2 and October 5, 2017. A human factors specialist and an assisting systems engineer spent three days on site. This included time spent observing operations on the TRACON floor and monitoring transmissions on a finals position; and time spent interviewing managers, Certified Professional Controllers and operational support engineers. The team also visited the Operational Support Facility to view laboratory control positions and discuss adaptations to the Converging Runway Display Aid (CRDA) that is used to support controllers making EoR approach decisions at the Denver TRACON. As with the Seattle site visit, the interviews were conducted in accordance with a pre-approved protocol (Thomas & Kirby, 2017a), and the key areas of interest were:

- EoR planning and implementation (facility preparation);
- EoR impact on workload, controlling style and practices;
- Automation, trust and confidence;
- Operational challenges/benefits of EoR (facility specific);
- Training considerations (expected or emergent);
- Supervision/management considerations and leadership support;
- Lessons learned and suggestions for improvement.

Interviews lasted in the region of 30-50 minutes and were again conducted in an office close to the operational floor. To allow for a more meaningful analysis of data, questions asked of Certified Professional Controllers in both site visits were very similar. At Denver TRACON, the human factors specialist led the interviews and took notes focusing on pertinent quotations and operational human factors issues, while the systems engineer took additional notes. Interviews at Denver involved those being interviewed and the research team; no other observers were present. Again, all interview data are non-attributable; the codes following each quotation do not relate to interviewee names.

The Denver Operational Support Facility (OSF) is adjacent to the Denver TRACON. Engineers within the OSF provided bespoke on-site support to Denver TRACON personnel by adapting the Converging Runway Display Aid (CRDA) for use within Denver's EoR operations. These engineers created an innovative adaptation to existing CRDA software by working closely with controllers, identifying their requirements and incorporating their feedback. The adaptation provides CPCs with a ghost target that moves along the "straight-in" extended runway centerline so that controllers can more easily identify sequences and spacing opportunities for simultaneous EoR approaches. The research team visited the OSF facility, saw a demonstration of the CRDA software on the laboratory positions, and asked additional questions of the engineers involved.

7.2. Denver TRACON Interview Results

A summary report describes the conduct of site visit (Thomas & Kirby, 2017b). This report focuses on the results of the visit and the analysis of interview data. In total, the following interviews were conducted:

- An interview with a former Support Manager[11]
- An interview with the current Support Manager for Airspace and Procedures
- An interview with an Operational Manager
- An interview with a Front-Line Manager
- Interviews with 14 Certified Professional Controllers (CPC)
- Interviews with two Operational Support Facility (OSF) engineers
- An interview with one OSF manager
- An interview with one contract training instructor (formerly certified at the facility)

Of the CPCs interviewed, 10 were arrival controllers and 4 were departure controllers. All CPCs at Denver TRACON work final approaches. The interviewed CPCs had between 6 and 29 years of total controlling experience, and their experience at the Denver TRACON ranged from 2-13 years. Many of these controllers had previous experience at ATCTs, ARTCCs, other TRACONs, and at military locations. The data from these interviews are discussed using the categories of the model shown in Figure 9.

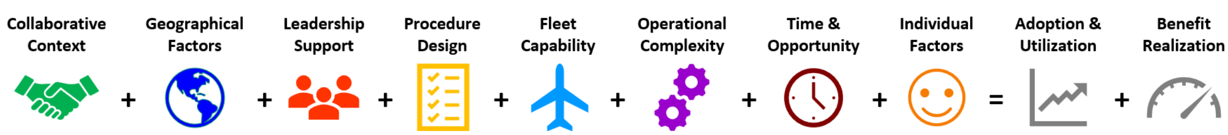

Figure 9: RNP-AR and EoR success factors for adoption, utilization and benefit realization

a. Collaborative Context

Several interviewees at Denver TRACON reported that it was an open and innovative facility, and its willingness to try new technologies is evidenced by its frequent involvement in key site testing for FAA initiatives. There appears to be a culture of open-mindedness and a willingness to try new ideas, while also accepting that it takes time to move from concept validation to operational success, and that the path does not always run smoothly:

> *"At Denver, our culture is one big team. We've all bought in and can be candid with each other. Here I know who to go to, to make things happen. It's the people… Here, you take a big breath, we're in this together, we might not get there straight away, but we will get this done." (CPC202)*

[11] This interview was conducted by telephone in advance of the site visits, since the individual was shortly due to retire from federal service.

Several key working relationships with external organizations are positive and collaborative in nature, which assists the facility in providing air traffic services and in working on mutually beneficial projects. Speaking of the initial design and implementation of the EoR approaches at Denver, one of the managers said:

> *"EoR at Denver became a ground swell - but getting there was not a ground swell. It was about overcoming resistance, it was not easy, there was a lot of work winning people over. We had to bring in carriers and pilots, we had to work at it. Controllers and pilots worked face to face – South West, United and Frontier – they all came in for joint training and joint briefings, and we all worked together." (MGR201)*

One of the controllers at Denver TRACON is the point of contact for recurrent training with one of the airlines, providing further evidence of the collaborative working relationship:

> *"He is the Frontier airlines recurrent training briefing POC. He goes to them to talk about air traffic, and he shares information on our operation. It's outreach, and it's a very good thing to support. I think it's one of the reasons we have been successful, and we wish more airlines would do that. We have great relationships - we're here for safety and our customers." (MGR205)*

Another example of collaboration at Denver TRACON is the relationship with the OSF. The OSF is co-located immediately adjacent to the TRACON on the same site, being a five or ten-minute walk door-to-door. This facilitated the collaboration between engineers and controllers on the CRDA adaptation, which grew organically and has resulted in CRDA being made available as a decision support tool at multiple sites across the NAS.

b. Geographical Factors

Geographical considerations that were mentioned at Denver included the mountains, the airport altitude, and the physical space available in terms of the number of runways. Interestingly, none of these factors were discussed in the context of being an impediment to EoR. One of the factors mentioned in relation to the success of EoR was the involvement of the tower controllers and the flexibility of the tower in terms of runway use:

> *"All parties have to be flexible… The tower has to be flexible letting us use of an overflow runway, and we just went from there." (MGR203)*

This is a markedly different situation to what was reported within the Seattle TRACON data, and indeed one of the Denver interviewees commented on the Seattle situation:

> *"At Seattle, they only have 2 runways to use, and no option of an overflow runway. Seattle's problem is that their controllers need to use both runways, all the time. At Denver, controllers ran to two runways routinely, putting EoRs on the third when they could. At Denver, the EoRs had no competition – they could land without disturbing the straight ins. That meant that our controllers could run a few and see if they liked it…. controllers could "experiment" a little and see what they thought and whether they worked. Then, they could start using them on the other runways." (MGR201)*

It seems that "pavement availability" and the ability to segregate the EoR operation, at least initially, is a key geographical factor supporting acceptance of a new procedure.

c. Leadership Support

Leadership support is a significant factor in implementing any significant change. Without supervisory and management support to provide leadership and reinforcement, the change is unlikely to be sustained over a prolonged period. The interviews at Denver TRACON included time with several managers. Some of the insights from these individuals are as follows:

> *"When we implemented this, we put a 'big focus' on it. Without CRDA, EoR can be difficult to do, because you have to go 'old school' and count the miles. At that point, it becomes a numbers game. Ultimately, we don't want to guess at separation. CRDA takes the numbers and the guessing away." (MGR205)*

The workload issue is also relevant to operational management. Traffic volume and complexity drives staffing, and since EoR reduces transmissions, this could potentially allow a controller to handle a busier piece of airspace, and/or free up controllers for other parts of the operation (e.g. final monitoring).

> *"From an FLM's perspective, a lot depends on the controller, who I know who can cope with what. I will try to recommend or suggest RNP approaches when I can. There are times when we can choose, when there are lots of RNPs, when we have lots of people and lower workload, we have more flexibility." (MGR205)*

With regards to providing advice for other facilities, one manager commented:

> *"With a new facility, which does not have the ability to segregate the EoR operation, CRDA would be invaluable. The downwind approaches are counter-intuitive to a controller so CRDA helps." (MGR203)*

> *"In terms of understanding the CPC perspective, they don't like trying to use new things when they are busy. You need to give them time to "play" with the approaches, check that they are doing it and make it easier for them to try it. We also had to get them to start sequencing with these approaches when they were mixing them into a sequence for another runway." (MGR203)*

One manager also provided some insights into working at a facility that is willing to try new technologies. In these instances, it may take supporting policies and analyses some time to "catch up" with what is happening on the operational floor:

> *"With these RNP approaches, as with lots of new technology, the orders and the procedures take a while to catch up. We're constantly learning. But headquarters and senior management are sometimes slow to respond to change, sometimes it takes a while for them to understand, and time for them be able to see it from a controller's perspective. Headquarters don't always get that seeing something on paper is not the same as seeing it in the operation." (MGR205)*

And finally, persistence was also shown to be an important element of leadership support:

> *"The other thing you need to know is that we had to encourage the pilots to use them. We went through that phase, the TMU will tell you all about it – we had to use baby steps." (MGR203)*

"We knew that pilots would have the same 'vectors are better' bias as controllers, just because that's what they know, they prefer visuals and vectors. So, we had to do joint training. Pilots will say 'we'll just take the visual' - controllers must be SO persistent to overcome this. It takes a lot to keep offering that approach, to just keep trying and keep reinforcing with pilots. That's what we are asking controllers to do. So we have to prepare controllers, let them know that pilots will turn it down, and say 'please keep trying'." (MGR201)

d. Procedure Design

There are FAA national orders that govern the design, development and implementation of PBN procedures FAA (2016b, 2016c). Procedure design is an important factor in RNP adoption and utilization, since without an acceptable design there would be little advantage in adopting and utilizing these approaches, and therefore benefit realization would be expected to be low. The theme identified in the Salgueiro and Hansman (2017) research, where a successful RNP approach was one that "overlaid" or "mimicked" a visual approach, was also evident within the Denver site data. For example, consider the following extracts from a discussion about approach design.

"Success is about two things. 51% of the success is about procedural design, whether you have the right design. And 49% of the success is about implementation. You cannot implement without a plan and hope that EoR will be 'adopted' by the operation. You need to convince controllers to give it a try, and if the approaches are better, they will continue to use them. But, your plan cannot be 'just give them a try' – that won't work. You need a plan that management and labor relations can get behind." (MGR 201)

Hence, the "approach to beat" with an RNP design is a visual approach:

"The approach designers won't know why you want to replace a visual in good weather, but that's really what you need to do". (MGR201)

This might seem counter-intuitive, but from an implementation perspective it makes sense. Giving controllers a direct visual comparison shows it is unlikely they could achieve better by vectoring. This will increase the probability that they will assign and clear these approaches, when appropriate to do so:

"The design must be better than what a controller can achieve by vectoring. It cannot be as good, because that won't be good enough. And it cannot be worse – because for them to assign it, you need to overcome their beliefs that vectoring is better." (MGR201)

"If you can be more efficient with a vector, then your design is not effective. It needs to be tight and still meet all the requirements – at Denver, ours are as tight as they can be. I cannot vector the way the RNP does, it's a good descent." (MGR203)

"It has to better than we can vector. If you think you can vector inside that arc, then you won't use the approach." (CPC205)

The design of the EoR approach is relevant to safety, as well as efficiency. Walls et al's (2017) safety study of Track-to-Fix EoR approaches suggested that there was a risk of wrong runway selection and indicated that this risk could be eliminated by "E*nsuring an aircraft is on a path that is unique to the intended landing runway prior to being considered established on the approach,*" (p. 98). Denver's RNP approaches were initially designed to be parsimonious, and are currently being altered to eliminate the risk of incorrect runway selection:

> *"We designed these approaches so that there would be an element of the downwind shared between approaches, to minimize workload for controllers and streamline the approaches. It's a very elegant solution from a design perspective. However, we now know that this can be late for the controller to see what has happened. We need controllers to see that they are on the correct unique path BEFORE pilots start making the turn. So, now we are switching the transitions, to change the point where the unique path becomes truly unique." (MGR202)*

Denver TRACON personnel worked in partnership with airlines, building off already strong relationships with their "customers" to design the RNP approaches:

> *"We worked with the airlines to build the approaches". (MGR203)*

The work was detailed and thorough:

> *"We started with departures, developed inputs and fixes, and designed it all the way to the ground, and we looked at the downwinds with the departures climbing off. On the FMS dial in the lowest altitude was 9,000 and we had a lot of pilot deviations, so we ended up removing 9,000 and made the lowest point 11,000. We don't like to rely on saying "that should work." (MGR203)*

Longer term, there may be a question about whether RNAV considerations become the key priority in airspace design. Because the future is trajectory based, there may be a need to review the various factors impacting on airspace design and possibly re-prioritize to ensure that the implementation of RNAV capabilities is not being unduly impeded.

Finally, one of the Denver interviewees made an observation about the design of the Seattle approaches, and the way that they were implemented:

> *"The approach design at Seattle is very good – they have close in approaches, with short downwind legs. They are very close in to the airport, as they must be to be effective. However, Seattle didn't limit initial implementation to visual approaches, running the RNPs next to the visuals is a good start." (MGR201)*

e. Fleet Capability

RNP-AR approaches require both suitably equipped aircraft and a qualified crew before the approaches can be assigned/cleared. The RNP approaches at Denver use Radius-to-Fix turns, and there is a lower equipage rate for approaches that use RF Turns, compared to the alternative (Track-to-Fix). This means that fleet capability is a key consideration. Until the fleet is 100% authorized for these approaches, controllers will be managing a mixed landing sequence. This was one of the key challenges in EoR operations identified at Denver. Some controllers minimized their use of EoR when the base leg was busy:

"For me, I use them sporadically, it's hit and miss. It depends on my base leg traffic, I avoid CRDA and Zulu approaches if the base leg is busy." (CPC209)

Others mentioned that they preferred the separation of these approaches from other traffic. EoR approaches at Denver were initially introduced on 34R (North configuration) and 17R (South configuration) only. These runways were regarded as "overflow" runways, and they allowed the segregation of EoR traffic. This technique was still preferred by a minority of controllers:

"I think it should be like a HOV lane, with no blending of the other traffic. The blending is the hardest. It doesn't matter how veteran you are, especially without CRDA – the eyeballing is a challenge." (CPC213)

The same controller did not believe that the design of the RNP approaches offered significant advantages; although it must be noted that this was a minority view:

"I can run a tighter finals operation myself with vectors, than I can with RNAV Zulus. I can get it tighter. A Zulu[12] is great for picking a sequence at 30 or 40 miles out, but it will never replace vectoring to final. When you have 10 aircraft coming in from the same fix it's easy, all moderate and nicely spaced. But EoR introduces complexity into a mixed bag of traffic." (CPC213)

This controller believed that the RNP-AR approach, even used within an EoR operation, did not offer any advantage over manual and tactical control. Contrast this with a view from another controller, who appeared to be a key advocate of RNP approaches and EoR within the facility:

"You can make any sequence work if you're 30 miles out. I can sequence 60 miles out, so what's the issue?" (CPC205)

Again, this was a minority view. Most controllers interviewed were between these two extremes, acknowledging that the main challenge in EoR operations with a mixed fleet was sequencing, while also being willing to try and make these approaches work when conditions, and their workload, allowed.

"If they come alongside, and I have an aircraft on the base leg, the mixed nature is the workload challenge. If you have nose to tail RNPs that will work, because they are all in trail. If the compression looks good, you're away. But of course, it's not always possible to do it. It's mixing the base legs with the Zulus that's hard, it depends so much on the traffic." (CPC203)

As noted within the Seattle TRACON data, controllers develop considerable expertise at managing the sequence in a way that optimizes their available processing capacity (typically 7+/2 "chunks" of information, in accordance with Garland, Stein & Muller, 1999). Where successive flights are not of the same "type", they will be processed individually as smaller "chunks", and a greater number of memory storage bays are required to work the same number of aircraft. The controller may report feeling less comfortable or confident that they have the capacity to deal with anything unexpected that occurs.

[12] EoR approaches are known within the Denver operation as "Zulus".

f. Operational Complexity

This category of factors includes operational complexity related factors that impact how controllers make decisions, and how they use RNP approaches within the EoR operation. Every facility has a unique pattern of complexity factors, and at Denver the situation is no different:

> *"We're a complex operation! We have the weather, the winds, the mountains, the runways, the tailwinds. Really, it's all complex." (MGR205)*

One factor is the availability of runways. Denver received a waiver authorizing EoR on for simultaneous independent EoR approaches on 34L/35L, 34L/35R, 34R/35R, 16L/17L, 16R/17R, and 16R/17L (Mayer, 2016, see Figure 8). Only 34R and 17R were used for these approaches initially, with the runways serving as "overflow" runways that functionally segregated EoR traffic. This incremental introduction meant that the sequencing challenges of working with a mixed fleet were not an immediate issue. Had they been, then it is probable that adoption and utilization at Denver would have been inhibited. Initial use of EoR operations was also restricted to visual conditions (VMC).

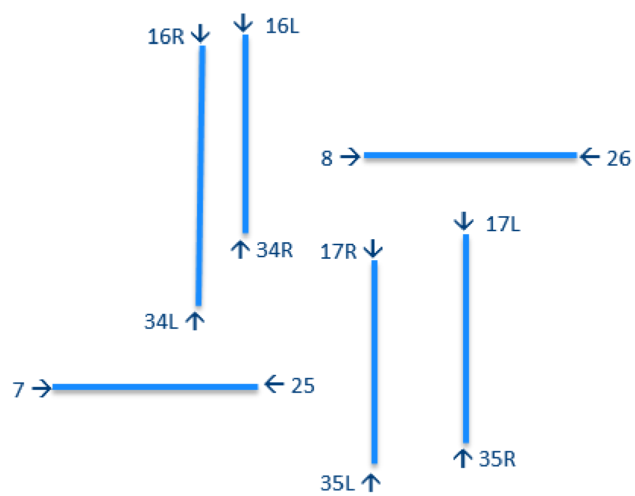

Figure 10: Runways at Denver International Airport. EoR was initially implemented on 34R (landing North configuration) and 17R (landing South configuration) only, simplifying the way that the concept was operationalized.

> *"It was incremental, we did one runway at a time, then outboards only, and ideally CRDA would all be up and running first. Without the CRDA at this facility, we were unsure about using EoR, we really only did the obvious ones." (CPC212)*

Another complexity factor cited was compression, which is associated with changing wind speeds and wind direction on finals, and the contingent need for speed control. This was particularly an issue for successive Zulu approaches:

> *"With successive Zulus, there is significant compression, so I use less than 170 and lock them in on 150. You do have to be proactive on speed control. If the approach plate gives 210, then I use*

190, and you can drop to 150 on a 6 or 7 mile final. You can get him to 150 before establishing him. He can be 20 knots slower at each transition point." (CPC205)

"You see the string, and you think 'I don't think this is going to work'". Arrivals will assign it, and you think 'will this work? How can I make it work? Can I adjust his speed?' I don't adjust speed on the first RNAV Zulu approaches, only on successive approaches. Then, it's five miles tight one after the other, and you really need a bigger buffer for successive RNP-Zulu approaches." (CPC206)

At the time of the initial introduction, it appears there was a lack of clarity concerning whether speed control was permissible on an RNP approach. For the first few months it seems that both controllers and pilots were not clear whether a controller could assign a different speed to that which had been published:

"We were first told that we would not touch their speed. That lasted about six months. Even the pilots were not sure if we could touch their speed." (CPC209)

However, most of those interviewed - and especially those who enjoyed using RNP approaches – suggested that speed control was necessary to be able to use EoR successfully:

"If it's a high wind or high compression day, and you're wrong about it - it it's not good! You've got to be confident in your pattern. I know from 18 years' experience what that will look like on finals. CRDA does a good job representing where the air craft would be, but other things can affect its performance. There's the wind, meteorological zones, the atmosphere, the pilot slowing down. The CRDA gives a prediction – it is not reality. So, speed control is important, especially if you don't know what they are doing, like if it's the first one of the day." (CPC204)

"You have to use speed control – if there's a tail wind on the turn, you have to account for that before passing it, so you give them a little more space. If you're going to be good at this, then you have to use speed control." (CPC211)

"Clear everything early – and then use speed control to make it work. If you clear to close to the initial fix, the flight crew won't have it loaded and they cannot capture the initial fix in time. Clear them early. Using CRDA, you can make those decisions earlier." (CPC203)

The opportunity to use proactive speed control appears to be a factor in determining how willing a controller is to assign and/or clear RNP approaches when complexity and traffic levels ramp up. There appeared to be an association with confidence in "old school" controlling methods - such as "eyeballing", "tie-breaking" and "mile-counting" – and confidence in using RNP:

"Speed control is all about miles, if you match speed, the one further away will come in later. Trust your flying miles, break the ties. I learned how to do this on my own, by counting miles, before we even had CRDA." (CPC205)

Perhaps for these controllers, CRDA is simply another tool in the toolkit. Generally, the controllers who preferred not to use speed control also tended to be more cautious in their trust of CRDA:

"CRDA is a spacing tool, and not a spacing guarantee. The ghost is not real. I cannot speed control the Zulu approach, and I can't be sure the straight in will be exactly 3 miles behind. The Zulu is constantly descending, and I would never slow a straight in that early. Even with the

CRDA adaptation, blending is a challenge. The aircraft must make a tight turn, and some aircraft reduce their speed at the top of the approach, and some aircraft do it partway, and others drop as late as they can." (CPC213)

This highlights an issue that was also reported in the work on flight deck human factors conducted by Chandra and Markunas (2016, 2017). Their pilot interviews revealed differences in the on-board automation that meant aircraft performance characteristics did not always meet pilot expectations. Perhaps the simple conclusion is that both pilots and controllers should expect that there will be times when aircraft are less responsive than might be ideal, and that "Unable" is a useful transmission for both the pilots and the controllers.

While it is true that airlines might prefer RNP approaches to remain on the published speeds, this is not always an option from an operational perspective. Those controllers who reported using speed control proactively for Zulu approaches tended to be able to make more use of EoR and tended to have fewer reservations assigning and clearing. It must also be noted that some of this difference may be due to the way the operation is staffed. Since January 2012, controllers have been certified either on Arrivals & Finals positions, or on the Departures & Finals positions. This means while all controllers have experience of issuing RNP clearances, only arrivals controllers who work the feeder positions also have experience of assigning RNP approaches.

g. Time and Opportunity

In any change initiative, having insufficient time and opportunity to try something new is considered a potential barrier to success. At Denver, a local adaptation to the CRDA helped controllers to identify situations where they would be able to safely and expeditiously assign and clear an EoR approach. The availability of this local adaptation is a remarkable tale that blends persistence with genius and serendipity with service, creating a superb example of engineering innovation in action.

The tale began with a current Denver TRACON controller, who previously worked at New York TRACON (N90). Within the JFK area at N90, CRDA was available on a "spare" operational position; controllers could glance over to refer to the tool on a different scope. On arrival at Denver, the controller's knowledge was dormant until the RNP approaches were introduced. At this point, the controller realized the potential use and value of the CRDA tool. The controller approached the Airspace and Procedures Office to suggest that CRDA might be useful in assisting controllers with identifying opportunities to use EoR. On the third visit to the office to try and persuade the team how this might be useful, the conversation was overheard by a manager who was a champion of RNP and EoR, and who was keen to explore the idea.

Fortunately, Denver TRACON is co-located immediately adjacent to the regional OSF. The OSF is an organization of air traffic controllers, engineers and technicians responsible for deploying, supporting and maintaining all terminal software and automation. The aforementioned manager approached one of the OSF engineers with the suggestion that an adaptation to CRDA might support controllers in identifying opportunities to use EoR approaches. The engineer was familiar with CRDA and knew that the way it worked might lend itself to this application, although some adjustments would need to be made. The engineer provided an elegant and innovative solution that required creating "fake" airports and runways within CRDA. He used a series of straight lines to replicate the EoR curved approaches, in much the same way that track-to-fix sections "simulate" a curved approach. CRDA had never been used in this way previously; this was an entirely new application of existing software.

This creative solution was totally operationally focused, in that the engineer worked closely with a small team of operational controllers to understand their needs, and to create a tool that provided the information they were looking for. This team (the Finals Working Group) had already been formed at the TRACON with the aim of managing the different controlling styles within the finals operation and improving consistency. The working group proved to be a sound "test-bed" for ideas and solutions, meaning that bugs and blips in early versions of CRDA were confined to the working group, and were resolved before CRDA was released operationally. This helped increase and maintain controller confidence in the automation, since the adaption was fully functional and met the key requirements before it was introduced to the rest of the controllers and used "live" during operations.

The adaptation to CRDA generated a "ghost" target that appears on an extended runway centerline, allowing controllers to see the position of an aircraft on an EoR approach "as if" it were flying a straight in approach (Garcia & Goodlin, 2016). This was possible because the route of an RNP approach is highly predictable and consistent. The speed of the ghost target matches the speed of the aircraft on the EoR approach but does not take the wind into account. Following the initial adaptation, further refinements were made to the Denver CRDA adaptation. These included adding further runways to the decision support tool (via the addition of extra RPCs), simplification of the macro used to turn on the tool at each position, and the ability to switch the ghost to a different runway when there is change to the runway assignment. A timeline of key CRDA adaptation activities within the EoR operation at Denver is shown in Figure 9.

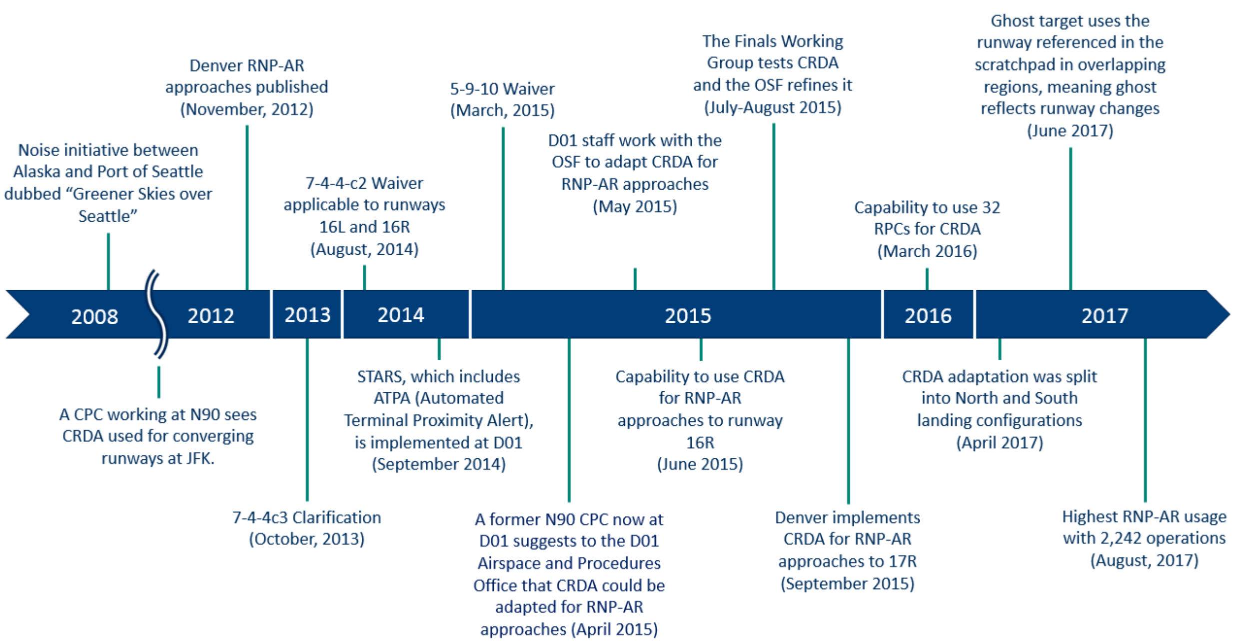

Figure 11: Timeline of key CRDA adaptation activities within the EoR operation at Denver TRACON.

It must be noted that CRDA is not the only decision support tool available to controllers at Denver; controllers also reported using SPLAT-T and range rings to support their EoR-related decision-making. However, CRDA has had a significant positive impact supporting controllers in making sequencing decisions related to EoR approaches. Controllers at Denver who had experience of using EoR both before and after CRDA was introduced were asked to provide a rating of sequencing ease, on a five-point scale where 1 was very difficult and 5 was very easy. The mean rating prior to CRDA being introduced was 2.86, while the mean sequencing ease rating after CRDA was introduced was 4.82[13].

As to how CRDA works, controllers who used CRDA almost unanimously reported that it provided them with additional time, since it helped to identify EoR opportunities earlier, when aircraft are further out:

> *"CRDA helps make the assessment more consistent, now I can tell earlier if I can make it work. It's the time window. The feeders use it too – they can see 35 miles out, so it's much more predictable." (CPC203)*
>
> *"CRDA is an innovative tool. People are looking and saying, 'I'll get 10 miles there for sure,' so now you can run it like a normal approach." (CPC207)*
>
> *"CRDA takes a lot of the work out, you know in advance if they will be a fit, or if they will be a tie." (CPC208)*
>
> *"The ghost looks faster than it would normally be, and normally an aircraft on straight in would be slower at that point, so you have to get comfortable with this." (CPC203)*

Using local adaptations to CRDA to support RNP and EoR operations has generated significant value for the FAA. Although it is difficult to put a dollar value on this innovation, it is possible to look at the benefits in terms of "ripples in a pond", using a value creation model described by Wenger, Trayner and de Laat (2011). From the original idea, to the user-testing conducted within the Finals Working Group, through the segregated EoR operation that led to successful implementation at Denver, multiple sites within the NAS are using local CRDA adaptations to support controller decision making. This is illustrated in Figure 12.

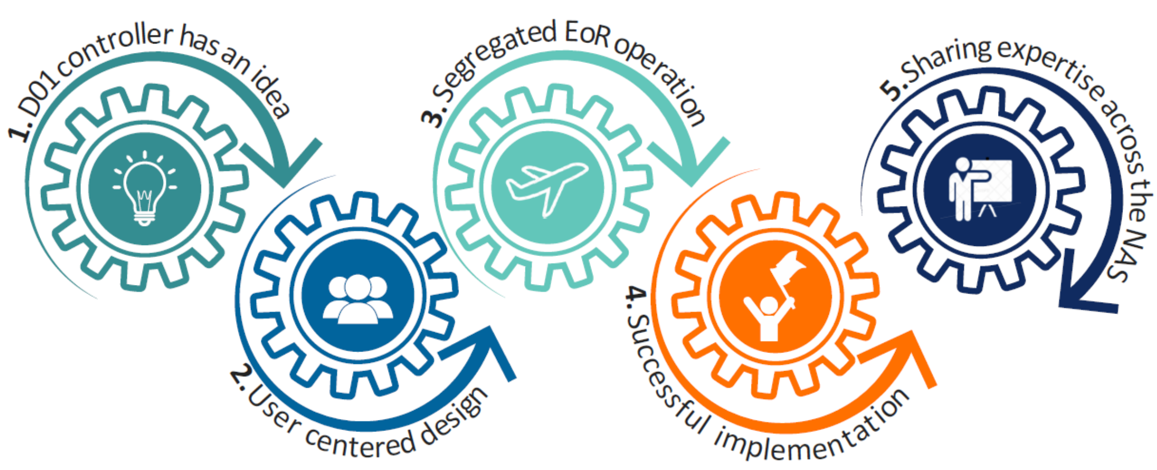

Figure 12: The value created from Denver's CRDA adaptation to support controller decision making

[13] A repeated measures t-test indicated that the results were statistically significant, suggesting that the difference did not arise by chance ($t=-5.64$, $df=10$, $p<0.05$).

h. Individual Factors

Individual factors include subjective factors that influence the way controllers achieve their operational aims. The data included consideration of three main factors: motivation, training/experience, and workload. In terms of motivation, the controllers interviewed represented a wide spectrum of views on RNP approaches. It was evident that a few controllers had enjoyed working with Zulu approaches from the start, while others had come to use these approaches as they become more widely accepted, and as the functionality of the CRDA decision support tool evolved.

It was also evident from the data that controllers control their traffic in accordance with their own preferences and style, and often consider the next controller in the flow when making control decisions. This is in accordance with previous research and reflects the team-based nature of air traffic control. No-one interviewed voiced extremely strong opinions against RNP approaches; this may reflect sampling bias or may reflect an openness to different controlling preferences within the facility.

The controllers interviewed had different motivations for assigning and/or clearing RNP approaches. The following quotes extracted from interview notes illustrate this range:

> *"My driver, why I use them, is to reduce carbon emissions. I know that's rare… out of the 80 folks I work with, 2 or 3 might think that carbon emissions are an issue for us as a species, for our planet."* (CPC205)

> *"There's a sense of fairness, of not wanting to fudge the sequence because it feels like you are moving number 2 to number 1. But the reality is you are not delaying number 1. You are just 'cartwheeling'*[14] *an RNP in the gap. This is an 'aha' moment for people, when they see this."* (CPC202)

> *"I don't like to delay base traffic because I have a Zulu. What won me over was – hey, this makes my workload easier. If I can slow this dude to 20 knots slower than published, I can fit him in and I'll get a 60% reduction in my transmissions."* (CPC205)

> *"I'll do all I can to make it work. The feeder controller does have to be proactive on speed control. We do have to work to make it work, and some folks are not on a self-improvement trajectory, they might be a little stagnant."* (CPC211)

> *"I am in the 1%, I like a challenge. This spices up what I have been doing for 5 years. Every guy we shoot on a Zulu is one less to get established on the 30° before we can lose separation. There are less deals, less worry about the 30° rule for me."* (CPC205)

[14] "Cartwheeling" is a term used at Denver TRACON to communicate the idea that clearing an EoR approach does not necessarily mean delaying traffic on the base leg, which some controllers regard as "queue-jumping" Cartwheeling refers to using an available space in the sequence for an aircraft on the downwind approach – the fact that this has been given a name is indicative of the acceptance of CRDA and EoR at the facility.

There were also some observations on training and workload within the data. Training is included as an individual factor within the context of change management, because an individual who does not feel confident with RNP will be less inclined to assign and clear these approaches.

> *"The apprehension comes from the visuals. A controller will have done those maybe 100,000 times. But the RNP-ARs, maybe 100 times. They don't have the same familiarity with it. With younger and newer controllers, they are using CRDA already and have no apprehension – they only have to see it five times to know that it works." (CPC204)*

At Denver, it was not possible to simulate the RF turns in the laboratory. When Zulus were introduced, generic RNAV simulations were available, but this was not done specifically for the introduction of Zulus or for CRDA. Training for the Zulu approaches is now integrated into the facility classroom and simulator-based training. At the time of implementation, CRDA was trained by crew briefings, supported by video demonstrations.

Workload is also an individual factor. Controllers who perceive that issuing RNP approaches will increase their workload unacceptably will generally avoid RNP in future similar circumstances, unless they can use other mitigations. Conversely, in situations where RNP is perceived to reduce a controller's workload, that controller will be likely to use RNP again in future similar circumstances, because the reduction in workload provides them with increased mental capacity:

> *"Cleared visual approach runway 27 left" may be more efficient for the airline, but not for the controller. If I vector, I might give heading three five zero, or turn right eighty degrees…. And there can be a huge delay depending on how fast the response is. With the volume of our traffic and the closeness of our runways, this is AWESOME! I am a huge fan. It takes me 4-5 transmissions on a regular approach. With Zulus, it saves frequency time. It's predictable. And I can see exactly where they will be." (CPC211)*

7.3. Denver International Airport Operator Interviews

Following the Denver TRACON site visit, the research team wished to gain additional insights into the human factors aspects of EoR approaches from the flight deck perspective. To supplement the data collection interviews undertaken with personnel at Denver TRACON, three interviews were conducted with three trial pilots and/or fleet managers with three operators. Noting that not all points were made by all individuals or operators, the main themes that emerged from these interviews were as follows:

- The main challenges for pilots with changed approaches (such as expecting the RNP-AR and then being switched to the ILS) are associated with programing changes into the aircraft's FMS. Programming challenges are exacerbated with procedure designs that do not have linked transitions. When this occurs, pilots need to manually link the route elements, and this can take considerable time – controllers should plan on this needing at least 10 miles.

- If controllers do need to take an aircraft off an RNP-AR approach, it is not helpful to assign an ILS because that will take significant time to program. If a controller takes an aircraft off the RNP-AR approach, then it is preferable to give headings and vectors because pilots cannot easily revert to the STAR waypoints.

- The interface on the FMS may not be intuitive to use and may not list approaches prioritized by frequency of use. Runway selection may require pilots to scroll through all available approaches for a given airport, and this is associated with a risk of human error. Having unique paths to each runway potentially allows controllers to identify runway selection errors earlier, further out from the airport. This gives both pilots and controllers additional time to remedy the situation.

- The FMS can vary across each operators' fleet, based on the aircraft manufacturer and the supplier of the FMS, so it is challenging to give controllers specific guidance on how long it might take pilots in different aircraft types to make changes. The best rule of thumb is for controllers to advise pilots to expect the RNP-AR with as much notice as possible, and to avoid changes to the approach or runway assignment except in extraordinary circumstances.

- Modern avionics mean that some aircraft have what might be regarded as "slippery" characteristics when viewed "on the glass" from the controllers' perspective. It may not be possible for pilots to control the lateral track, the vertical track and speed at the same time. Hence, it may also take additional time for controllers to see the result of their ATC instruction on their screens.

- Having a shared understanding between different operators and air traffic controllers is important. This type of "perspective sharing" can be built through shared training, joint communications forums, and other activities. Shared meetings to design RNP procedures are a mechanism for doing this, and that also assists with implementation of the procedures. Another valuable outcome from this type of initiative is a recognition that different terms are used in different ways between the flight deck and air traffic control[15].

- In designing these procedures, there needs to be a recognition that as many stakeholders as possible should be involved. It is not sufficient to consider only the major operator, since what works well for the dominant carrier might not work for everyone. Ideally, identifying more immediate (or at least short term) gains for all operators (including the not-yet-equipped) helps to create more of a win-win situation, and enhance buy in to make the investment necessary to support change.

- Using speed control may cost an operator a little efficiency, since this is a deviation from the published approach. It is easier for pilot to comply with a speed control request in level flight, so approaches that are designed with a level leg make energy management easier for flight crews. Ideally, an approach procedure would be designed with an inbuilt level segment connecting the STAR to the approach; that would provide some flexibility for speed adjustment as needed.

[15] Differences in terminology in performance-based navigation have been discussed in several reports, including Barhydt & Adams (2006a) and GAO (2013).

8. Conclusions

8.1. An Unintentional Experiment

In some ways, the introduction of EoR approaches at Seattle and Denver was an “unintentional experiment” in the design of RNP-AR approaches and the operational implementation of EoR. This is because the contrast between the two sites, while not planned, revealed useful and unique lessons about the operational implementation of EoR.

Retrospectively, it is possible to identify several factors that contributed to the challenges at Seattle, and which it would be advisable to avoid elsewhere as far as possible:

- Levels of stakeholder involvement are determinants of success. Involve all interested parties, including operators and tower and TRACON controllers, to minimize the risk that procedures will need to be redesigned in the future.

- Develop a structured implementation or change management plan at the facility, that must include a phased or graduated approach, and must factor in the timing of other changes such as runway construction work. Even where traffic levels are high, complex and/or constant, there may be an option to trial procedures in visual conditions to allow controllers to gain familiarity and confidence before using them in more demanding contexts, and to supplement this exposure with laboratory/simulation training, replays and videos.

- Resource the implementation or change management plan, to deliver the communication and training necessary to prepare controllers for the change. This should include any resources to make software adaptations and to staff a contained user group to support testing of tools-in-development. This group will be charged with ironing out bug and glitches before operational controllers test the tool (and potentially lose confidence). Resources to create visual communications (such as videos and FALCON replays) also need to be planned and provided.

Retrospectively, it is also possible to identify several factors that contributed to success at Denver:

- The configuration of the airport allowed a third runway, normally used for “overflow” traffic, to be dedicated to RNP approaches using EoR. These approaches were initially used in VMC conditions, in low to moderate traffic. These factors allowed controllers to gain familiarity and experience under relatively independent and relatively “mild” conditions, when compared to peak periods, complex movements, and high traffic volume.

- The adaptation to CRDA was initially suggested by a controller who had seen “conventional” CRDA used at a different TRACON. The idea was supported by an Airspace and Procedures manager who believed in the value of RNP and EoR. The adaptation was developed by an engineer and a team of dedicated specialists who provided operational, engineering, software and management support, at no additional cost to the government. The co-location of the TRACON and the OSF allowed convenient, close and regular collaboration between all team members. This factor is not unique to Denver but is unusual – only eight TRACONs in the U.S. have an adjacent or co-located OSF.

- A Finals Working Group had already been established at the facility before the CRDA adaptation idea was formulated. This collaborative group was formed with the support of NATCA and FAA management, and shows the facility’s pre-existing commitment to improving its operations. The Finals Working Group provided requirements to the OSF engineering team, tested CRDA adaptation versions, and provided immensely valuable user feedback on many issues. This meant that many bugs and glitches in early versions of the adaptation could be eliminated before the adaptation was seen by most operational controllers, resulting in increased confidence in the decision support tool.

Some of these factors were unique to Denver and may be difficult to replicate elsewhere. Others are in alignment with best practices in change management and the introduction of new technology, and could be replicated, at least in part, at other facilities within the NAS.

8.2. Human Factors Considerations in Procedure Design

The literature review and the results of interviews at air traffic control facilities and with operators suggested an initial set of human factors guidance principles that may be useful in the <u>design</u> of RNP approaches. These are as follows:

1. A simple baseline for designing a sound RNP approach is to overlay a visual approach. Another option is to attempt to improve the efficiency of an ILS approach. It is also possible to design an innovative approach based on operational feedback, ideas and suggestions. To maximize use of RNP approaches, it helps to enable the controller to make a comparison between the efficiency of the visual/ILS approach, and the RNP approach.

2. In designing RNP approaches, stakeholder involvement is paramount. This will ideally include engaging all parties with interests, and formally considering/analyzing the different motivations between them. As well as the intended use of the approach, “anticipated under-use” might also need to be considered. For example, at some airports pilots may prefer to land at runways closer to the terminal, and this may impact requests for runways and approaches. Differences between operator business models also need to be considered - what works for the dominant carrier might not work for all operators. Successful design initiatives are likely to be those that include some short-term wins for all operators, including those not yet fully equipped to fly an RNP approach.

3. Some safety systems provide advisories, alerts and/or alarms that notify pilots and/or air traffic controllers of potentially critical situations or conditions that may require attention or action. If a system triggers an advisory, alert or alarm inappropriately, users may lose confidence in those communications.

In designing RNP approaches, there is a need to analyze impacts on advisories, alerts and/or alarms, and to make provision for monitoring advisories, alerts and/or alarms once the procedure is implemented.

4. In designing RNP approach procedures, there is a need to consider what a controller may be able to achieve by vectoring. For a controller to assign/clear an EoR approach, the controller needs to believe that at that time, this is the best option available. The design must be sufficiently effective to overcome some common controller beliefs, habits and preferences. These might include perceptions such as “you can’t beat a straight-in,” “vectoring is best,” and “I can run finals tighter myself.” RNP provides repeatability and predictability, with stabilized approaches and fewer go-arounds. These are some wider benefits of using RNP approaches.

5. The approach design should be “error-resistant” as far as possible and should consider the flight-deck aspects of performance as well as the controller perspective. Note that both pilot and controller errors are likely to be more frequent when the procedure is first introduced, and then may be expected to dip off slightly. Pilot and controller errors are then likely to rise again as users become more familiar and comfortable with the newly-implemented procedure.

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8.3. Human Factors Considerations for Operational Implementation

The literature review and the results of interviews at air traffic control facilities and with operators also suggested an initial set of human factors guidance principles that may be useful in <u>implementing</u> RNP approach procedures. These are as follows:

1. Plan a stepped or phased implementation – start simple, and work progressively upwards. For example, this may include:
    - Operating initially in visual meteorological conditions (VMC)
    - Operating initially in lower complexity/traffic levels
    - Segregating EoR operations onto a different runway (if possible)

2. Use dynamic audio-visual aids to support briefing, training, and familiarization for controllers:
    - Depending on the design of the procedure, these approaches can seem counter-intuitive. It’s difficult for controllers to know that these approaches will work until they see them.
    - Using, videos, radar replays and simulations helps controllers to understand how implementing EoR approaches works “on the glass.”

3. Find collaborative and creative ways to build shared controller/pilot understanding of RNP approaches and EoR operations, particularly with regards to:
    - Encouraging joint facility/airline involvement in approach design, training, and implementation meetings, including both operational controllers and line pilots.
    - Providing opportunities to discuss differences in terminology. Controllers often refer to EoR approaches using the relevant approach “label” (such as “Mike” at Seattle and “Zulu” at Denver), and understandably tend to focus on the separation aspects of these approaches. Pilots and operators tend to refer to these as RNP-AR approaches, and tend to be more focused on early assignments and the predictability and stability of the approach.

- Support mechanisms and initiatives that help controllers and pilots understand the limitations of EoR operations (such as the availability of a space within the sequence), and the constraints of flight deck automation (such as the time it takes to reprogram).

4. Provide decision support tools for controllers in merging traffic on the RNP approach with traffic on the base leg:
   - Adapting the Converging Runway Display Aid (CRDA) to support RNP operations is a brilliant engineering innovation, and adaptations have made sequencing significantly easier at both Seattle and Denver TRACONs. However, CRDA does not include all relevant information that may be helpful to a controller (e.g. wind), and it may not be as useful in all types of EoR operations. All local adaptations of CRDA need to be tailored to the specific application.
   - Where the full functionality of the Denver CRDA adaptation is not available or appropriate for other facilities, SPLAT-T, range rings and tie-point markers may also provide useful decision support information to controllers.

5. Encourage proactive speed control and defensive controlling techniques:
   - Controllers who most successfully integrate EoR approaches into their controlling repertoire seem to be those who proactively manage the sequence with speed control.
   - Controllers remain responsible for monitoring aircraft on RNP-AR approaches to ensure that they do not deviate from the intended path. Although RNP technology provides high precision tracking on the approach, rare events may still require controller intervention.

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