F Denver Metroplex Study Team Final Report

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Study Team Final Report

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Denver Metroplex Study Team

Table of Contents

1 Background **1**

2 Purpose of the Metroplex Study Team **2**

3 Denver Metroplex Study Team Analysis Process **3**

3.1 Five Step Process 3

3.2 Denver MST Process and Schedule 4

3.3 Denver Study Area Scope 5

3.4 Assumptions and Constraints 5

3.5 Assessment Methodology 5

3.5.1 Track Data Selected for Analysis 6

3.5.2 Analysis and Design Tools 7

3.5.3 Determining the Number of Operations and Modeled Fleet Mix 8

3.5.4 Determining Percent of RNAV Capable Operations by Airport 9

3.5.5 Profile Analyses 9

3.5.6 Cost to Carry (CTC) 10

3.5.7 Benefit Metrics 10

3.6 Key Considerations for Evaluation of Impacts and Risks 11

4 Identified Issues and Proposed Solutions **13**

4.1 Design Concepts 13

4.2 D01/ZDV Arrival Airspace 15

4.3 DEN Procedures 16

4.3.1 DEN Arrivals 17

4.3.2 DEN Departures 38

4.3.3 Denver Satellite Airport Arrival Issues 53

4.3.4 Denver Satellite Airport Departures Issues 54

4.3.5 D01 and ZDV Airspace Change Considerations 55

4.4 Industry Concerns 57

4.5 Out of Scope Issues 57

4.6 ASIAS Safety Issues 57

4.7 Q-Routes and T-Routes 58

4.8 Additional D&I Considerations 59

5 Summary of Benefits **60**

5.1 Qualitative Benefits 60
5.1.1 Near-Term Impacts 60
5.1.2 Long-Term Impacts to Industry 60
5.2 Quantitative Benefits 61
Appendix A: Acronyms 63
Appendix B: Examples of Integrated Airspace and PBN Toolbox 66

List of Figures

Figure 1. Sample Analysis - Lateral Baselines 11
Figure 2. Proposed Departure Procedure Benefits, Impacts, and Risks 14
Figure 3. Proposed Arrival Procedure Benefits, Impacts, and Risks 15
Figure 4. MST Proposed Arrival Airspace Extensions 16
Figure 5. Current ANCHR/KIPPR STARs and Proposed NE 1 STAR (en route) 18
Figure 6. Current ANCHR/KIPPR STARs and Proposed NE 1 STAR (terminal) 18
Figure 7. Current KOHOE/WAHUU STARs and Proposed NE 2 STAR (en route) 20
Figure 8. Current KOHOE/WAHUU STARs and Proposed NE 2 STAR (terminal) 20
Figure 9. Current JAGGR/PURRL STARs and Proposed SE 1 STAR (en route) 22
Figure 10. Current JAGGR/PURRL STARs and Proposed SE 1 STAR (terminal) 23
Figure 11. Current ZPLYN/BOSSS STARs and Proposed SE 2 STAR (en route) 24
Figure 12. Current ZPLYN/BOSSS STARs and Proposed SE 2 STAR (terminal) 25
Figure 13. Current PEEKK/LDORA STARs and Proposed SW 1 STAR (en route) 27
Figure 14. Current PEEKK/LDORA STARs and Proposed SW 1 STAR (terminal) 27
Figure 15. Current CREDE/TELLR STARs and Proposed SW 2 STAR (en route) 29
Figure 16. Current CREDE/TELLR STARs and Proposed SW 2 STAR (terminal) 29
Figure 17. Current FRNCH/KAILE STARs and Proposed NW 1 STAR (en route) 31
Figure 18. Current FRNCH/KAILE STARs and Proposed NW 1 STAR (terminal) 32
Figure 19. Current MOLTN/TSHNR STARs and Proposed NW 2 STAR (en route) 33
Figure 20. Current MOLTN/TSHNR STARs and Proposed NW 2 STAR (terminal) 34
Figure 21. Proposed Weather Re-Route STAR 36
Figure 22. Current and Proposed DEN YAMMI, RIKKK, BRYCC, and YOKES SIDs (terminal) 39
Figure 23. Current and Proposed DEN YAMMI, RIKKK, BRYCC, and YOKES SIDs (en route) 40
Figure 24. Current and Proposed DEN EEONS, EMMYS, EXTAN, and EPKEE SIDs (terminal) 42
Figure 25. Current and Proposed DEN EEONS, EMMYS, EXTAN, and EPKEE SIDs 42
Figure 26. Current and Proposed DEN STAKR, SPAZZ (E/W), and SOLAR SIDs (terminal) 44
Figure 27. Current and Proposed DEN STAKR, SPAZZ (E/W), and SOLAR SIDs 45
Figure 28. DEN NEPS Points 47
Figure 29. Current and Proposed DEN West SIDs with NEPS Points 47
Figure 30. Current and Proposed DEN BAYLR, CONNR, COORZ, and FOOOT SIDs (terminal) 48
Figure 31. Current and Proposed DEN BAYLR, CONNR, COORZ, and FOOOT SIDs 49
Figure 32. Current and Proposed JMPRS SID 51
Figure 33. Current and Proposed NE and NW Satellite STARs 53
Figure 34. Proposed West PNA Satellite SID 55

Figure 35. DEN and Satellite STARs Low Airspace Adjustments 56
Figure 36. DEN STAR High/Ultra-High Airspace Adjustments 56

List of Tables

Table 1. Observed Traffic Days 7
Table 2. DEN Modeled Fleet Mix 8
Table 3. DEN Primary Runway Configurations 9
Table 4. RNAV Equipage by Airport 9
Table 5. Issues Disposition Summary 13
Table 6. All Proposed DEN NE STARs Annual Benefits 21
Table 7. All Proposed DEN SE STARs Annual Benefits 25
Table 8. All Proposed DEN SW STARs Annual Benefits 30
Table 9. All Proposed DEN NW STARs Annual Benefits 35
Table 10. All Proposed DEN STARs Annual Benefits 37
Table 11. Proposed DEN YAMMI, RIKKK, BRYCC, and YOKES SIDs Annual Benefits 41
Table 12. Proposed DEN EEONS, EMMYS, EXTAN, and EPKEE SIDs Annual Benefits 43
Table 13. Proposed DEN STAKR, SPAZZ (E/W), and SOLAR SIDs Annual Benefits 46
Table 14. Proposed DEN BAYLR, CONNR, COORZ, and FOOOT SIDs Annual Benefits 50
Table 15. All Proposed DEN SIDs Annual Benefits 52
Table 16. Denver MST Total Annual Benefits 62

1 Background

In September 2009, the Federal Aviation Administration (FAA) received the final report from the Radio Technical Commission for Aeronautics (RTCA) Task Force 5. This report, entitled *NextGen Mid-Term Implementation Task Force Report* contains top priorities for the implementation of NextGen initiatives. These initiatives include the formation of teams leveraging FAA and Industry Performance-Based Navigation (PBN) expertise to expedite the implementation of optimized airspace and procedures.

Metroplex was developed in direct response to the recommendations of Task Force 5 to provide a systematic, integrated, and expedited approach to implementing PBN procedures and associated airspace changes. This process focuses on a geographic area, rather than a single airport and from planning to post-implementation, has an expedited life-cycle of approximately three years.

Metroplex projects are centered on two types of collaborative teams:

- Metroplex Study Teams (MST) provide a comprehensive, front-end strategic look at each major metroplex.
- Using the results of the MST, Design and Implementation (D&I) Teams provide a systematic, effective approach to the design, evaluation, and implementation of PBN-optimized airspace and procedures.

2 Purpose of the Metroplex Study Team

The principle objective of the MST is to identify operational issues effecting local air traffic facilities as well as industry users, and in response to the identified issues, propose PBN procedures and/or airspace modifications to ultimately optimize operations within the study area. These efficiencies include utilizing existing aircraft equipage by adding Area Navigation (RNAV) procedures, optimizing descent and climb profiles to eliminate or reduce level-offs, and adding more direct RNAV routing in both the en route and terminal environments. The deliverables of the MST will be used to scope future detailed design efforts in the D&I phase of Metroplex.

3 Denver Metroplex Study Team Analysis Process

3.1 Five Step Process

The Denver MST followed a five step analysis process:

1. Collaboratively identified and characterized existing issues:
   a) Reviewed current operations
   b) Solicited input to obtain an understanding of the broad view of operational challenges in the metroplex
2. Proposed notional procedure designs that address the issues and will optimize the operation:
   a) Used an Integrated Airspace and PBN Toolbox (Appendix B)
   b) Obtained technical input from operational stakeholders
   c) Explored potential solutions to the identified issues
3. Quantitatively and qualitatively identified the expected benefits of the notional designs:
   a) Assessed the Rough Order of Magnitude (ROM) impacts of notional designs
   b) Used objective and quantitative assessments as required
4. Identified considerations and risks associated with the proposed changes:
   a) Described high-level considerations (e.g., if additional feasibility assessments are needed)
   b) Assessed risks (e.g., if waivers may be needed)
5. Documented results

Steps one and two were worked collaboratively with local facilities and operators through a series of outreach meetings. Step three was supported by the Metroplex National Analysis Team (NAT). The methodology used for the quantitative analysis is described in Section 3.5. The NAT is a centralized analysis and modeling resource that is responsible for data collection, visualization, analysis, simulation, and modeling. Step four was conducted with the support of the Metroplex Specialized Experts. The Specialized Experts provided on-call expertise from multiple FAA lines of business, including environmental, safety, airports, and specific programs like Time-Based Flow Management (TBFM).

3.2 Denver MST Process and Schedule

- Administrative Week:
  - August 18-22, 2014
  - Reviewed Denver Metroplex airports and current procedures
  - Reviewed initial issues provided by local facilities and industry operators
- Kickoff Meeting:
  - August 27, 2014 at Denver Air Route Traffic Control Center (ARTCC)
  - Discussed concepts and proposed schedules
  - Established facility points of contact
- First Outreach Meetings: Existing Operations and Planning
  - Industry Stakeholders: August 27, 2014 at Denver ARTCC
  - FAA Facilities: August 28, 2014 at Denver ARTCC
- MST worked on Issue Matrix and initial notional design development:
  - September 2-19, 2014
- Second Outreach Meetings: Enhancement Opportunities
  - FAA Facilities: September 23-24, 2014 at Denver ARTCC
  - Industry Stakeholders: September 25, 2014 at Denver ARTCC
- MST focused on final solutions, costs, and benefits:
  - September 29 – October 24, 2014
- Final Outreach Meetings: Summary of Recommendations
  - FAA Facilities: October 28, 2014 at Denver ARTCC
  - Industry Stakeholders: November 6, 2014 at Denver ARTCC
- Documentation: Final Report, Final Briefing, and Study Team package
  - MST completed all documentation: October 29 - November 14, 2014
  - Final deliverables due November 21, 2014

There were three rounds of outreach meetings with local facilities, industry, and other stakeholders, including the Department of Defense, business and general aviation, airports, and others. The First Outreach focused on issue identification, the Second Outreach on notional solutions, and the Final Outreach on summarizing the analyses of benefits, impacts, and risks. Assessments at this stage in the metroplex process are expected to be high-level. More detailed analyses of benefits, impacts, costs, and risks are expected after the D&I phase has been completed.

3.3 Denver Study Area Scope

The Denver Metroplex consists of those facilities and airspace that contain the primary flows of traffic serving the Denver International Airport (DEN), respective satellite airports, and adjacent facilities that interact with DEN primary traffic flows. The principal Air Traffic Control (ATC) facilities serving the Denver Metroplex are the Denver Air Traffic Control Tower (DEN ATCT), Denver Terminal Radar Approach Control (D01), and Denver ARTCC (ZDV).

Denver Metroplex Airports:

- Denver International Airport (DEN)
- Centennial Airport (APA)
- Rocky Mountain Metropolitan Airport (BJC)
- Front Range Airport (FTG)
- Fort Collins - Loveland Municipal Airport (FNL)
- Greeley-Weld County Airport (GXY)
- Vance Brand (Longmont) Airport (LMO)
- Buckley Air Force Base (BKF)

3.4 Assumptions and Constraints

Metroplex is an optimized approach to integrated airspace and procedures projects; thus, the proposed solutions center on PBN procedures and airspace redesign. The MST is expected to document those issues that cannot or should not be addressed by airspace and procedures solutions. These issues are described in Section 4 of this report.

The expedited timeline of the Denver Metroplex and focused scope bound airspace and procedures solutions to those that can be achieved without requiring an Environmental Impact Statement (EIS) e.g., only requiring an Environmental Assessment (EA) within current infrastructure and operating criteria. The MST may also identify airspace and procedure solutions that do not fit within the environmental and criteria boundaries of a Metroplex project. These other recommendations then become candidates for other integrated airspace and procedures efforts.

3.5 Assessment Methodology

Both qualitative and quantitative assessments were made to gauge the potential benefits of proposed solutions. The qualitative assessments are those benefits and improvements that the MST could not measure, but which would result from the implementation of the proposed solutions. These assessments included:

- Impact on ATC task complexity
- Ability to laterally and/or vertically segregate flows

- Impact of flow segregation to/from adjacent facilities
- Ability to enhance safety
- Improved connectivity to en route structure
- Reduction in pilot-controller transmissions minimizing frequency congestion
- Improved track predictability and repeatability
- More efficient fuel planning
- Reduced reliance on ground-based navigational aids (NAVAID)
- Increased systemic efficiencies

An example of qualitative assessment is task complexity, which can be lessened through the application of structured PBN procedures versus the use of radar vectors, but quantifying that impact is difficult. Reduced communications between pilot and controller, as well as reduced potential for operational errors are examples of metrics associated with controller task complexity that cannot be quantified.

For the quantitative assessments, the MST identified changes in track lengths, flight times, time in level flight, and fuel burn. Potential benefits were measured by comparing current flights to the MST proposed procedures using a Markov Chain Monte Carlo method[1] to approximate aircraft behavior based on distributions from historic radar tracks. Fuel burn for these aircraft was calculated from The MITRE Corporation's (MITRE) validated implementation of the European Organization for the Safety of Air Navigation (EUROCONTROL) Base of Aircraft Data and Total Energy Model (BADA+TEM). The quantitative analyses compared the use of current procedures and shortcuts under baseline conditions with full-time use of the procedures proposed by the MST.

3.5.1 Track Data Selected for Analysis

During the study process, a representative set of radar traffic data was utilized in order to maintain a standardized operational reference point. For determining the number, length, and location of level-offs for the baseline of operational traffic, radar track data from 21 high-volume days under mostly visual meteorological conditions (VMC) were utilized. Operational counts and weather data from Airport Specific Performance Metrics (ASPM) and Performance Data and Analysis Reporting System (PDARS) were used to select seven days from the months of January, June, and July 2014. Table 1 shows the analysis days utilized by the DEN MST.

[1] Markov Chain Monte Carlo methods are a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results.

Table 1. Observed Traffic Days

January		June		July	
Date	Ops	Date	Ops	Date	Ops
01/02/14	1,630	06/03/14	1,602	07/10/14	1,674
01/03/14	1,607	06/06/14	1,652	07/15/14	1,679
01/09/14	1,517	06/17/14	1,629	07/16/14	1,708
01/10/14	1,521	06/24/14	1,612	07/17/14	1,725
01/17/14	1,536	06/25/14	1,598	07/20/14	1,673
01/20/14	1,526	06/26/14	1,614	07/28/14	1,701
01/31/14	1,484	06/27/14	1,553	07/30/14	1,748

The historical radar track data was used to visualize the flows and identify where short-cuts were routinely applied, as well as where flight planned routes were more rigorously followed. The track data was used as a baseline for the development of notional solutions, including PBN routes and procedures. In many cases, the MST overlaid the historical radar tracks with PBN routes or procedures to minimize the risk of significant noise impacts and an associated EIS. Lastly, the 21 days of radar track data was used for modeling of benefits.

3.5.2 Analysis and Design Tools

The following tools were employed by the MST and the NAT in the process of collecting and analyzing flight track data for designing notional procedures within the Denver Metroplex:

- PDARS
  - Historical traffic flow analysis using merged datasets to analyze multi-facility operations
  - Customized reports to measure performance and air traffic operations (i.e., fix loading, hourly breakdowns, origin-destination counts, etc.)
  - Identification and analysis of level flight segments
  - Graphical replays to understand and visualize air traffic operations
- Terminal Area Route Generation Evaluation and Traffic Simulation (TARGETS)
  - Comparison of actual flown routes to proposed routes when developing cost/benefit estimates
  - Notional airspace and procedure designs
- Air Traffic Airspace Lab (ATALAB) National Offload Program (NOP) data queries
  - Quantification of traffic demand over time for specific segments of airspace

- ASPM
  - Identification of runway usage
- National Traffic Management Log (NTML)
  - Identification of occurrence and magnitude of Traffic Management Initiatives (TMI)
- Traffic Flow Management System (TFMS)[2]
  - Traffic counts by aircraft group categories for annualizing benefits
  - Examination of filed flight plans to determine impact of significant re-routes
- Flight Pattern Distribution Generator (FPDG)
  - Builds arrival and departure distributions
  - Determines fuel burn

3.5.3 Determining the Number of Operations and Modeled Fleet Mix

Due to the compressed schedule of the MST, there was not sufficient time to model the entire fleet mix for each airport. A representative fleet mix was developed for each traffic flow at DEN, based on the most common aircraft types on that flow, excluding prop and turboprop flights. The airport-wide modeled fleet mix is shown in Table 2.

Table 2. DEN Modeled Fleet Mix[3]

Aircraft Type	Weighted Distribution
B73x	34%
A319, A32x	27%
CRJx	26%
E14x	8%
B75x	5%

To determine the number of aircraft on each flow, three weeks of ZDV/D01 merged PDARS track data was analyzed. The annual counts of aircraft on each flow were then estimated by

2 TFMS was previously known as Enhanced Traffic Management System (ETMS).

3 The PBN Dashboard, an online tool that reports these percentages through analysis of two sources: the equipment suffix from TFMS and the percentage of PBN-equipped aircraft by type from a Part 121 avionics database. Due to the incomplete nature of the data sources used, the percentages of RNAV-equipped operations are assumed to be conservative.

taking the total counts for the three weeks and multiplying by 17.4. The percentage of time in each runway configuration for the modeled airport was determined by analyzing a year's worth of data, and is shown in Table 3.

Table 3. DEN Primary Runway Configurations[4]

North	South	Other
48%	41%	11%

3.5.4 Determining Percent of RNAV Capable Operations by Airport

The principle objective of the Denver MST was to identify and address operational issues and propose PBN procedures and airspace modifications. The PBN Dashboard was used to determine the percent of operations at each airport that would benefit from these new procedures.

Table 4 lists the Instrument Flight Rules (IFR) RNAV equipage percentages analyzed for the Denver airports based of the NAT Site Package created using 2013 data.

Table 4. RNAV Equipage by Airport[5]

Airport	% of RNAV-Equipped IFR Operations
DEN	92%
BJC	90%
FTG	78%
APA	89%
BKF	21%
FNL	90%
GXY	85%
LMO	76%

3.5.5 Profile Analyses

To determine the current level-offs of arrivals and departures in the Denver Metroplex, the MST examined three weeks of ZDV/D01 merged track data. The Denver RNAV Program has minimized level-offs for DEN Standard Terminal Arrival Routes (STARs). The MST also used

4 Source: ASPM and PDARS, August 1, 2013- July 31, 2014

5 The PBN Dashboard, an online tool that reports these percentages through analysis of two sources: the equipment suffix from TFMS and the percentage of PBN-equipped aircraft by type from a Part 121 avionics database. Due to the incomplete nature of the data sources used, the percentages of RNAV-equipped operations are assumed to be conservative.

TARGETS to calculate the length of the current published routes and actual flown tracks. Baseline routes were constructed based on these traffic characteristics and compared to the proposed routes. Any reduction in level-offs and distance savings were then converted into fuel savings by using the FPDG BADA total energy model, taking into account the modeled aircraft fleet mix at DEN. The fuel savings were then annualized, assuming a fuel price per gallon of $3.01 based on fuel costs for YTD 2014 from Research and Innovative Technology Administration (RITA) Bureau of Transportation Statistics.

3.5.6 Cost to Carry (CTC)

Aircraft fuel loading is based on the planned flight distance and known level-offs. Furthermore, airlines must carry extra fuel to compensate for the weight of the total fuel required to fly a route. This extra fuel is known as the Cost to Carry (CTC). For this analysis, based on feedback from the MST industry representative, CTC was assumed to be 10% for DEN. This means that for every 100 gallons of fuel loaded, CTC is 10 gallons for DEN.[6]

3.5.7 Benefit Metrics

The benefits metrics were generated using the following process:

1. The radar track data from the days mentioned previously was parsed by flows into and out of DEN. These flows were then analyzed to determine geographic location, altitude, and length of level-offs in the airspace. The average overall track flow length was also estimated.
2. Baseline routes were developed that mimic the average vertical and lateral path of the tracks in the flows.
3. Proposed notional routes were designed by the MST.
4. The impacts of the proposed notional routes were estimated as compared to the current published procedures for the flow, if any, and the baseline routes.
   a) Vertical savings: The baseline vertical paths and its associated level-offs were compared with the proposed MST vertical paths.
   b) Lateral distance savings: The baseline published procedures were compared to the length of the proposed MST procedures.
5. The fuel and cost savings were then estimated based on the above impacts. Both lateral and vertical savings are based on both fuel savings and CTC savings.

Figure 1 shows current, baseline, and proposed routes for a flow with the comparisons for lateral savings highlighted in magenta.

[6] This figure was chosen based on the fact that most of the aircraft flown in the study area are narrow-body; for heavy aircraft, international flights, or long-haul flights, the number could be significantly greater.

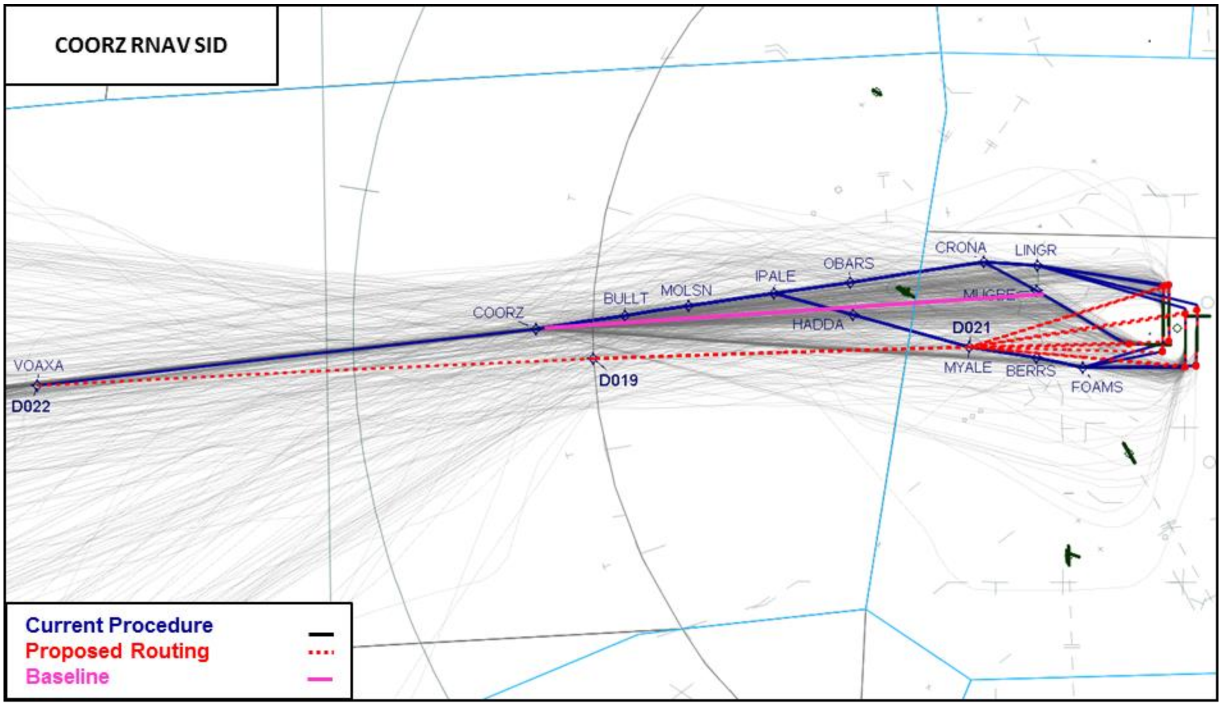

Figure 1. Sample Analysis - Lateral Baselines

3.6 Key Considerations for Evaluation of Impacts and Risks

In addition to the quantitative and qualitative benefit assessments described in Section 3.4, the Denver MST was tasked with identifying the impacts and risks from the FAA's operational and safety perspective, as well as from the airspace user's perspective. For each individual issue and proposed solution throughout Section 4 of this report, specific impacts and risks are identified; however, there are a number of impacts and risks that generally apply to many of the proposed solutions, as described below:

- Controller and pilot training: With the increased focus on PBN and the proposed changes in airspace and procedures, controller and pilot training will be a key consideration for nearly all proposals.
- "Descend via" procedure issues: The proposed use of "descend via" clearances will similarly require controller and pilot training, and an agreement must be reached during D&I on exactly how procedures will be requested, assigned, and utilized from both the FAA and user perspectives.
- Aircraft equipage: There are challenges with working in a mixed equipage environment and these risks must be considered during D&I. While procedures have been designed to take advantage of PBN efficiencies, procedures and processes must be developed for conventional operations as well.

- Safety Risk Management (SRM): Safety is always the primary concern and all of the proposed solutions will require an SRM assessment, which will occur during the Operational and Environmental Review of the D&I Phase.
- Environmental issues: All proposed solutions are subject to environmental review and the Metroplex schedule limits that review to an EA rather than an EIS. The MST worked with environmental specialists to determine whether any of the proposed solutions have the potential for significant environmental impacts, and developed mitigation alternatives if necessary.

4 Identified Issues and Proposed Solutions

This section presents the findings and results of the Denver MST analysis. It reviews identified issues, proposed solutions, benefits/impacts/risks, and analysis results.

Ninety issues were submitted to the MST. Similar issues raised by all involved parties were consolidated and categorized by the MST to determine potential solutions. Some issues required additional coordination and input and could not be addressed within the time constraints of the MST process and were deferred to D&I for further consideration. The remaining issues were deemed out of scope by the MST. Table 5 depicts the issues count summary.

Table 5. Issues Disposition Summary

ATC Facility	Submitted Issues	Out of Scope	Deferred to D&I	TBFM	Issues Worked
DEN ATCT	14	6	4	0	4
D01	35	10	5	3	17
ZDV	36	4	6	11	15
Industry	5	3	0	0	2

4.1 Design Concepts

The primary goal of the Denver MST was to create procedures utilizing RNAV everywhere and Required Navigation Performance (RNP) where beneficial. The use of PBN procedures will allow efficiency gains through optimized profile climbs/descents and enhanced lateral paths not reliant on ground based navigation, while allowing predictability and repeatability, reducing ATC task complexity, and frequency congestion. The MST removed unused transitions to reduce chart clutter and the potential for improper flight planning. Runway transitions were used on all DEN notional designs, while limiting potential environmental risks. The MST recommends the use of transitional separation (3 nautical miles [NM] increasing to 5 NM) which will increase airspace efficiencies for departures.

Currently, controllers rely on an assortment of conventional and RNAV departure procedures. The facilities use both vectors and route structure where necessary to maintain separation and expedite aircraft climbs into en route airspace.

The proposed departure procedures attempt to maintain unrestricted climbs as much as possible, while providing procedural segregation where practical from other Standard Instrument Departures (SIDs) and STARs. It is fully expected that ATC will continue to tactically enable shorter routings and remove climb restrictions. Additionally, the use of transitional separation between terminal and en route facilities will increase airspace efficiency. Airspace modifications that enable procedural efficiencies need to be considered during D&I.

RNAV SIDs with flow dependent transitions were designed for repeatable, predictable paths. The MST recognizes that RNAV off-the-ground procedures may create a dis-benefit in track miles flown in certain circumstances. The D&I Team may elect to further evaluate the combination of radar vectors and RNAV off-the-ground SIDs to determine the most beneficial solution(s) for DEN departures.

With respect to the notional departure proposals, Figure 2 depicts benefits, impacts, and risks for the FAA and airspace users, as well as environmental considerations.

FAA Operational/Safety

Benefits	Impacts/Risks
• Reduced communications • Multiple runway transitions • Reduced vectoring • Ability to procedurally segregate from STARs • Increased procedure conformance	• Runway transitions • LOA/SOP revisions • Training • Sectorization • Frequency Licensing

Airspace User

Benefits	Impacts/Risks
• Reduced track miles • Reduced level segments • Reduced cost to carry • Reduced fuel burn and carbon emissions	• Runway assignment • Training

Environmental Considerations

- Noise screening/analysis
- Emissions analysis

Figure 2. Proposed Departure Procedure Benefits, Impacts, and Risks

In general, the issues associated with the current arrival procedures to DEN were related to inefficient lateral and vertical paths, conflicts with departure traffic, underutilized en route transitions, and ATC/pilot complexity.

In addition to optimizing vertical profiles, lateral paths were shortened, routes segregated, unused en route transitions removed, the number of STARs reduced, and flow dependent transitions proposed. Arrival procedures for several satellite airports in the Denver Metroplex were created. Where possible, these new STARs were procedurally segregated from DEN SIDs and STARs. The D&I Team will need to assess the location of additional waypoints with possible restrictions and en route transitions associated with the STARs. Further D&I considerations include airspace modifications that enable procedural efficiencies, modifications to current conventional (non-RNAV) STARs, and holding pattern locations and requirements.

The MST recommends that RNP Standard Instrument Approach Procedures at DEN be reviewed during the D&I phase for optimized downwind alignment and reduction in arc length.

With respect to the notional arrival proposals, Figure 3 depicts benefits, impacts, and risks for the FAA and airspace users, as well as environmental considerations.

FAA Operational/Safety	
Benefits	**Impacts/Risks**
• Reduced communications • Multiple runway transitions • Reduced vectoring • Increased procedure conformance	• Runway transitions • LOA/SOP revisions • Training • Sectorization • Frequency Licensing

Airspace User	
Benefits	**Impacts/Risks**
• Reduced track miles • Reduced level segments • Reduced cost to carry • Reduced fuel burn and carbon emissions	• Preferred runway assignment • Training

Environmental Considerations
• Noise screening/analysis • Emissions analysis

Figure 3. Proposed Arrival Procedure Benefits, Impacts, and Risks

4.2 D01/ZDV Arrival Airspace

- Issues
  - Sixteen directional STARs create increased workload issues for both pilots and controllers due to the multiple configuration changes at DEN, generating re-route clearances for ZDV and flight path management complexities for pilots.
  - Bidirectional STARs require that controllers issue a runway assignment at least 10 NM prior to the end of the common route. Additional airspace is required for D01 to accomplish this requirement.
- Notional Solutions
  - The MST designed airspace extensions to all four corner posts that are approximately 10 NM and delegated from ZDV to D01. The D&I Team should further analyze the exact size of the arrival extensions required to accommodate runway transitions.
  - Common routes will allow D01 to assign runway transitions in a timely manner.
  - ZDV will be required to issue the landing direction.

Figure 4 depicts the MST proposed airspace arrival extensions.

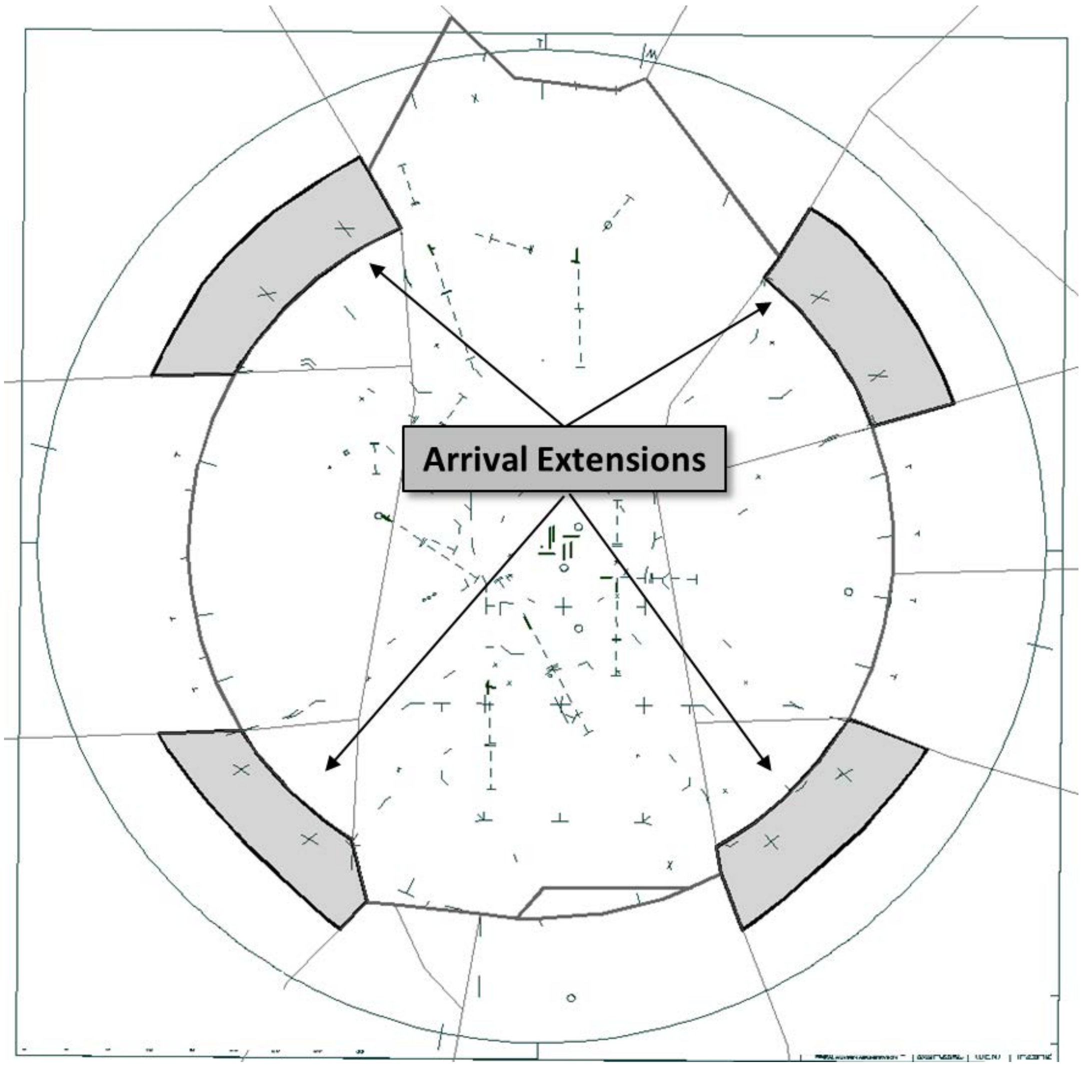

Figure 4. MST Proposed Arrival Airspace Extensions

4.3 DEN Procedures

DEN is the busiest airport within D01 terminal airspace with 1,629 daily operations on average in 2013, of which 99% being either air carrier or air taxi flights. APA and BJC are the primary satellite airports. D01 airspace extends from the surface to 23,000 feet mean sea level (MSL). Adjacent terminal facility airspace to D01 includes COS ATCT to the south. D01 also provides approach control services for Grand Junction Regional (GJT) and Pueblo Memorial (PUB). ZDV airspace overlies D01 airspace. DEN has multiple runway configurations with north being predominant at 48% followed by the south configuration at 41% and other configurations at 11%.

4.3.1 DEN Arrivals

This section describes the operational issues, notional solutions, and expected benefits the MST has identified for arrivals to DEN.

Arrival issues for DEN include inefficient lateral paths, underutilized vertical profiles (level segments), excessive vectoring, and frequent STAR clearance changes. Multiple runway configuration changes in conjunction with directional STARs has led to the submission of numerous Air Traffic Safety Action Program (ATSAP) reports by controllers as well as numerous Aviation Safety Action Program (ASAP) reports by industry. Short side operations hamper controllers with limited time and/or distance to sequence arrivals. Efficiency is also degraded where arrivals to satellite airports are mixed with arrivals to DEN.

4.3.1.1 DEN NE STARs

This section describes all proposed DEN NE STARs. The NE gate accounts for approximately 26% of all DEN jet arrivals.

4.3.1.1.1 DEN NE 1 STAR

The current DEN ANCHR/KIPPR STARs account for approximately 13% of all DEN jet arrivals.

- Issues
  - Two STARs for north/south runway configurations create pilot and controller task complexity due to multiple configuration changes at DEN.
  - No dedicated RNAV runway transitions to Runways 7 or 26, which creates additional pilot and controller task complexity.
  - Actual flight tracks do not follow current arrival procedures.
- Notional Solutions
  - RNAV Optimized Profile Descent (OPD) STAR created with runway transitions for north, south, east, and west flows, resulting in optimized lateral paths to reduce flight track miles.
  - STAR was shortened for operational flexibility, unused en route transitions were removed, and an en route crossover transition was created, which will be ATC assigned only.
  - Modified en route and terminal merge points for increased sequencing time where feasible and created runway transitions which merge with RNPs (long side) and instrument landing system (ILS)/RNP (short side) procedures.
  - Created an altitude window of 17,000-FL230 at the beginning of the common route.
  - Segregated from the proposed notional northeast APA arrival referenced in Section 4.3.3.

Figures 5 and 6 depict the en route and terminal views of current and proposed notional STARs with current flight tracks and ATC only crossover.

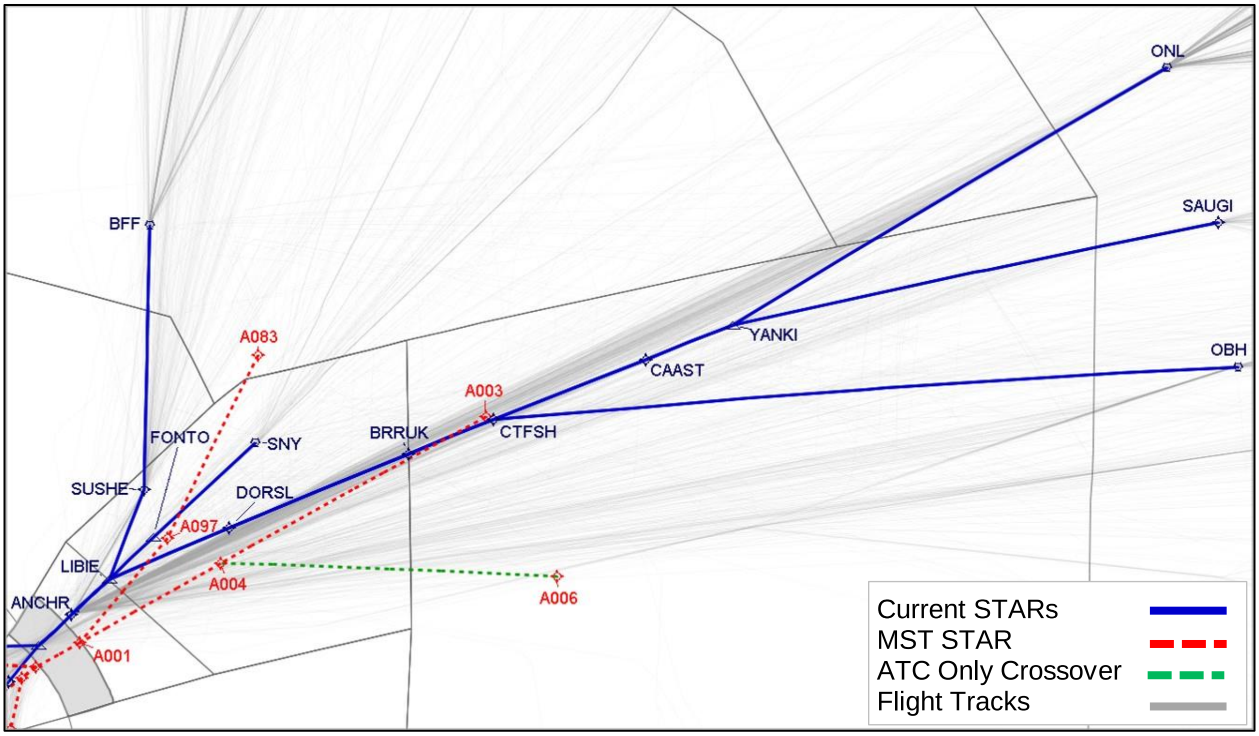

Figure 5. Current ANCHR/KIPPR STARs and Proposed NE 1 STAR (en route)

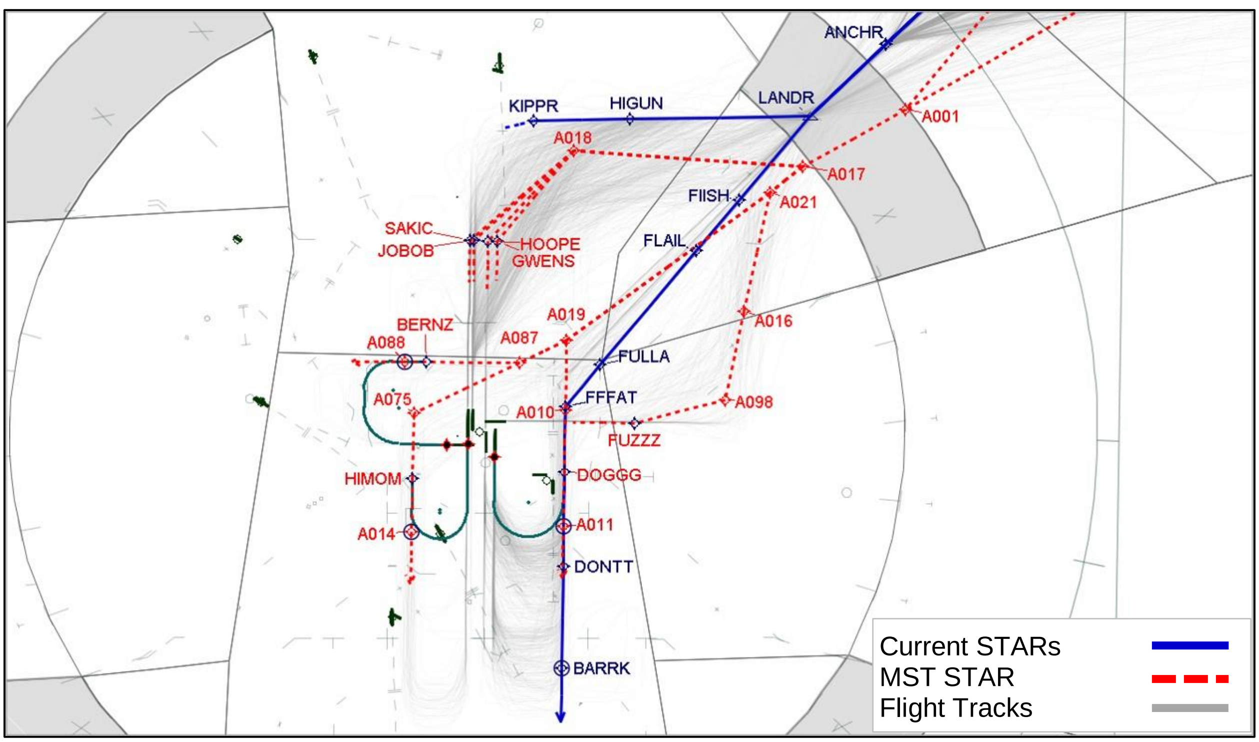

Figure 6. Current ANCHR/KIPPR STARs and Proposed NE 1 STAR (terminal)

4.3.1.1.2 DEN NE 2 STAR

The current DEN KOHOE/WAHUU STARs account for approximately 13% of all DEN jet arrivals.

- Issues
  - Two STARs for north/south runway configurations create pilot and controller task complexity due to multiple configuration changes at DEN.
  - No dedicated RNAV runway transitions to Runways 7 or 26, which creates additional pilot and controller task complexity.
  - Actual flight tracks do not follow current arrival procedures.
  - The APA PUFFR STAR underlies the KOHOE/WAHUU STARs and its current location restricts OPD utilization for DEN arrivals.
- Notional Solutions
  - RNAV OPD STAR created with runway transitions for north, south, east, and west flows resulting in optimized lateral paths to reduce flight track miles.
  - STAR was shortened for operational flexibility, unused en route transitions were removed, and an en route crossover transition was created, which will be ATC assigned only.
  - Modified en route and terminal merge points for increased sequencing time where feasible and created runway transitions which merge with RNPs (long side) and ILS/RNP (short side) procedures.
  - Created an altitude window of 17,000-FL230 at the beginning of the common route.
  - Segregated from the proposed notional northeast APA arrival referenced in Section 4.3.3.

Figures 7 and 8 depict the en route and terminal views of current and proposed notional STARs with current flight tracks and ATC only crossover.

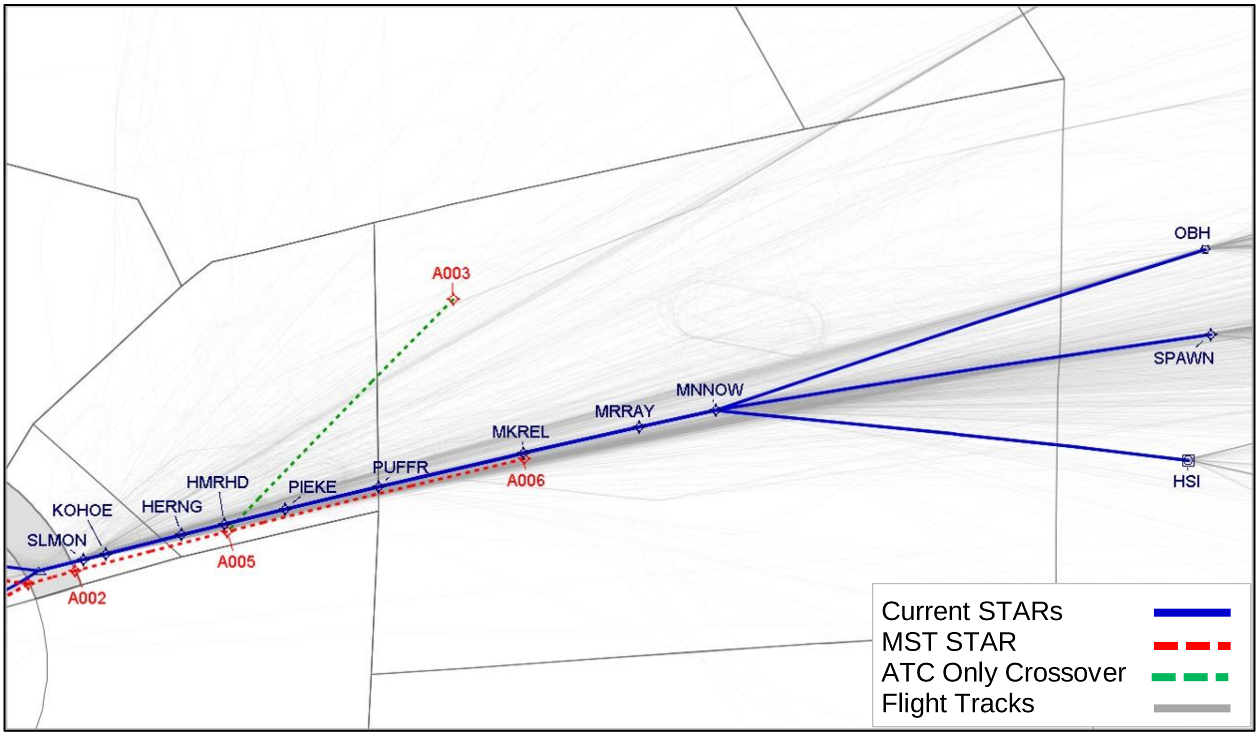

Figure 7. Current KOHOE/WAHUU STARs and Proposed NE 2 STAR (en route)

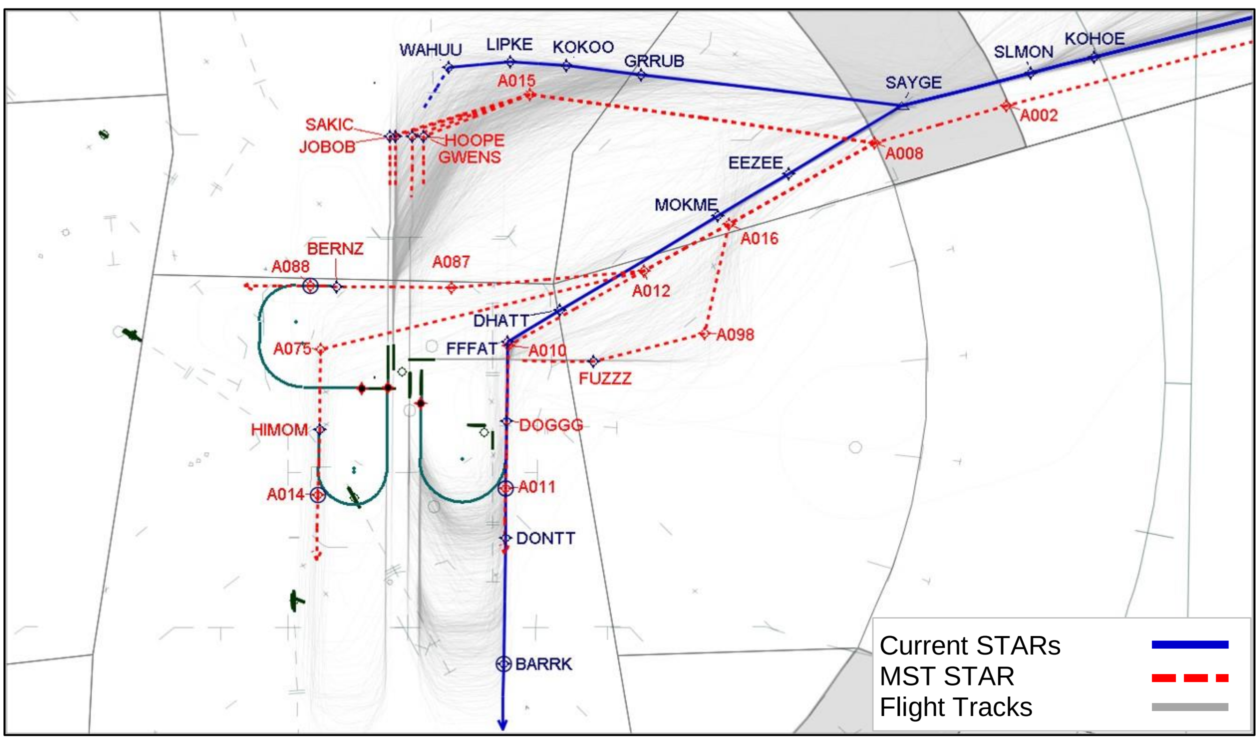

Figure 8. Current KOHOE/WAHUU STARs and Proposed NE 2 STAR (terminal)

4.3.1.1.3 All DEN NE STARs Cost Benefit Analysis

Projected annual savings for the proposed DEN NE STARs are estimated in Table 6. Total estimated savings are rounded to the nearest whole figure.

Table 6. All Proposed DEN NE STARs Annual Benefits

Estimated Annual Fuel Savings (Dollars)	Fuel Burn (Distance and Profile)	$196K
	Cost to Carry	$27K
Total Estimated Annual Fuel Savings (Dollars)		$223K
Total Estimated Annual Fuel Savings (Gallons)		65K
Total Estimated Annual Carbon Savings (Metric Tons)		600

4.3.1.2 All DEN SE STARs

This section describes all proposed DEN SE STARs. The SE gate accounts for approximately 29% of all DEN jet arrivals.

4.3.1.2.1 DEN SE 1 STAR

The current DEN JAGGR/PURRL STARs account for approximately 13% of all DEN jet arrivals.

- Issues
  - Two STARs for north/south runway configurations create pilot and controller task complexity due to multiple configuration changes at DEN.
  - No dedicated RNAV runway transitions to Runways 7 or 26, which creates additional pilot and controller task complexity.
  - Actual flight tracks do not follow current arrival procedures.
- Notional Solutions
  - RNAV OPD STAR created with runway transitions for north, south, east, and west flows resulting in optimized lateral paths to reduce flight track miles.

- STAR was shortened for operational flexibility, unused en route transitions were removed, and an en route crossover transition was created, which will be ATC assigned only.
- Modified en route and terminal merge points for increased sequencing time where feasible and created runway transitions which merge with RNPs (long side) and ILS/RNP (short side) procedures.
- Created an altitude window of 17,000-FL230 at the beginning of the common route.
- The MST recommends that the D&I Team further review the OATHE (A086) transition for additional efficiency gains. This may result in the need for airspace modifications.

Figures 9 and 10 depict the en route and terminal views of current and proposed notional STARs with current flight tracks and ATC only crossover.

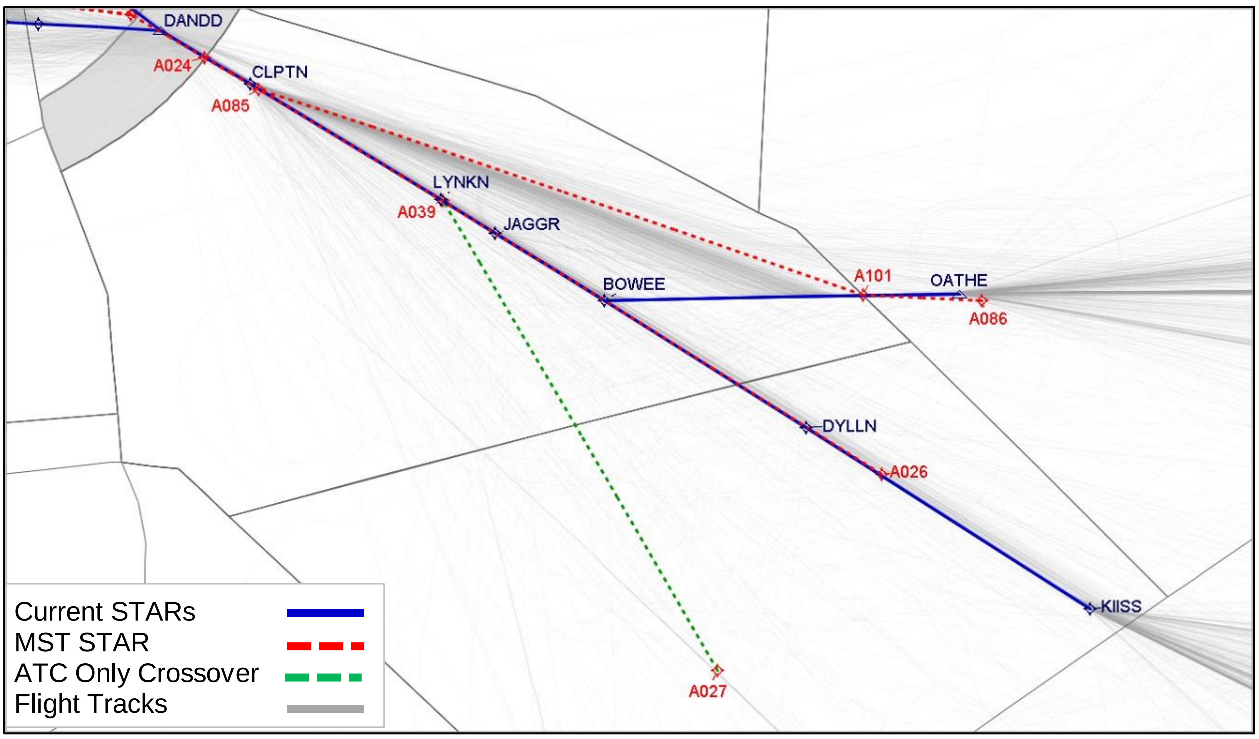

Figure 9. Current JAGGR/PURRL STARs and Proposed SE 1 STAR (en route)

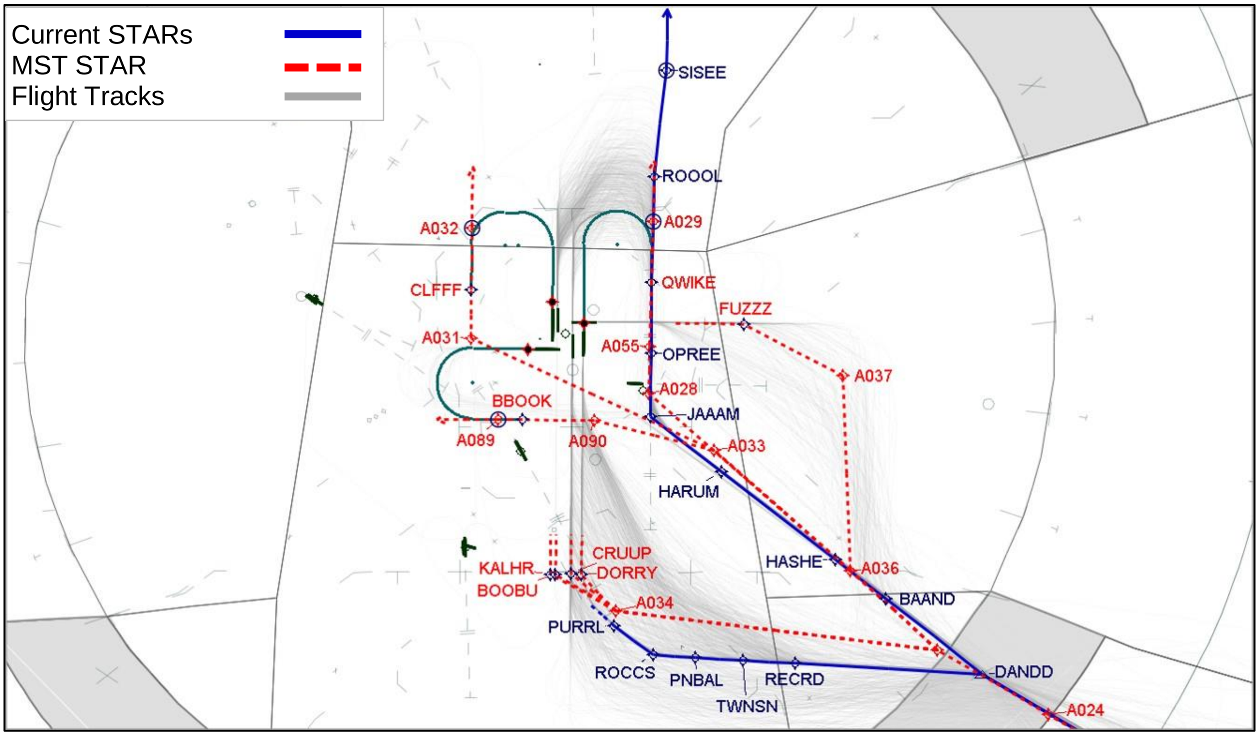

Figure 10. Current JAGGR/PURRL STARs and Proposed SE 1 STAR (terminal)

4.3.1.2.2 DEN SE 2 STAR

The current DEN ZPLYN/BOSSS STARs account for approximately 16% of all DEN jet arrivals.

- Issues
  - Two STARs for north/south runway configurations create pilot and controller task complexity due to multiple configuration changes at DEN.
  - No dedicated RNAV runway transitions to Runways 7 or 26, which creates additional pilot and controller task complexity.
  - Actual flight tracks do not follow current arrival procedures.
- Notional Solutions
  - RNAV OPD STAR created with runway transitions for north, south, east, and west flows resulting in optimized lateral paths to reduce flight track miles.
  - STAR was shortened for operational flexibility, unused en route transitions were removed, and an en route crossover transition was created, which will be ATC assigned only.
  - Modified en route and terminal merge points for increased sequencing time where feasible and created runway transitions which merge with RNPs (long side) and ILS/RNP (short side) procedures.

- Created an altitude window of 17,000-FL230 at the beginning of the common route.

Figures 11 and 12 depict the en route and terminal views of current and proposed notional STARs with current flight tracks and ATC only crossover.

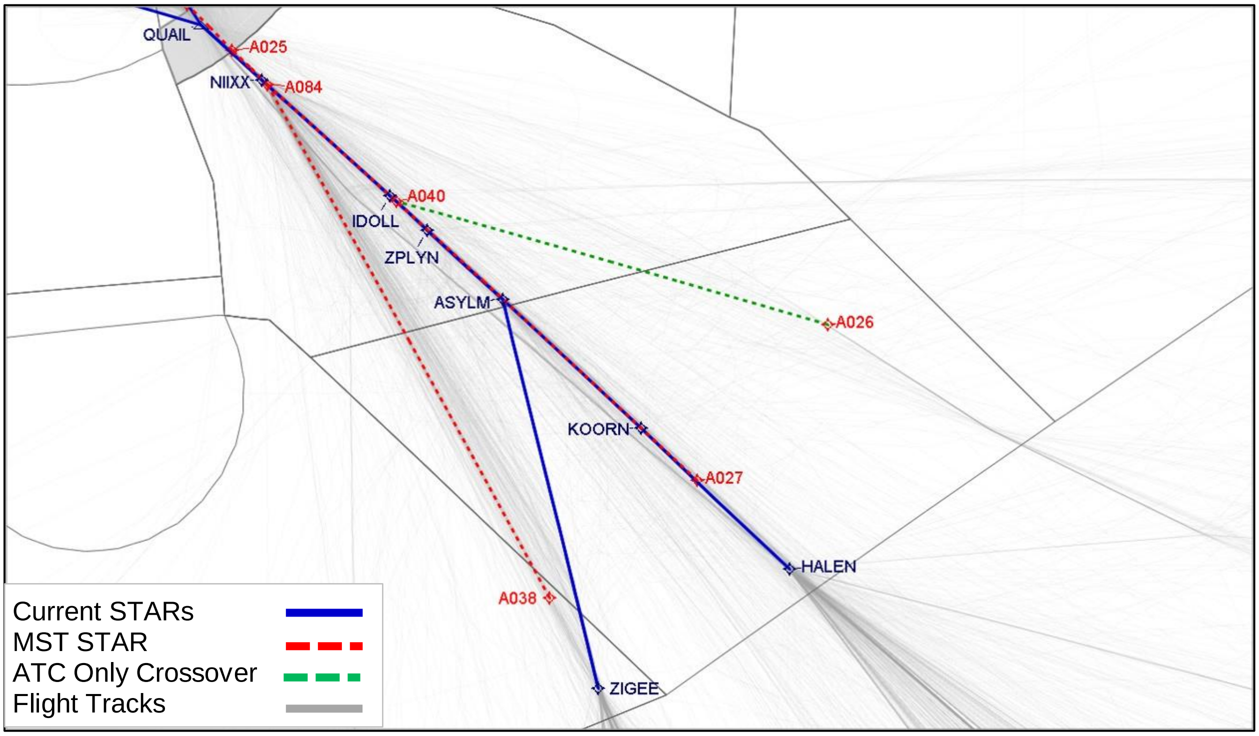

Figure 11. Current ZPLYN/BOSSS STARs and Proposed SE 2 STAR (en route)

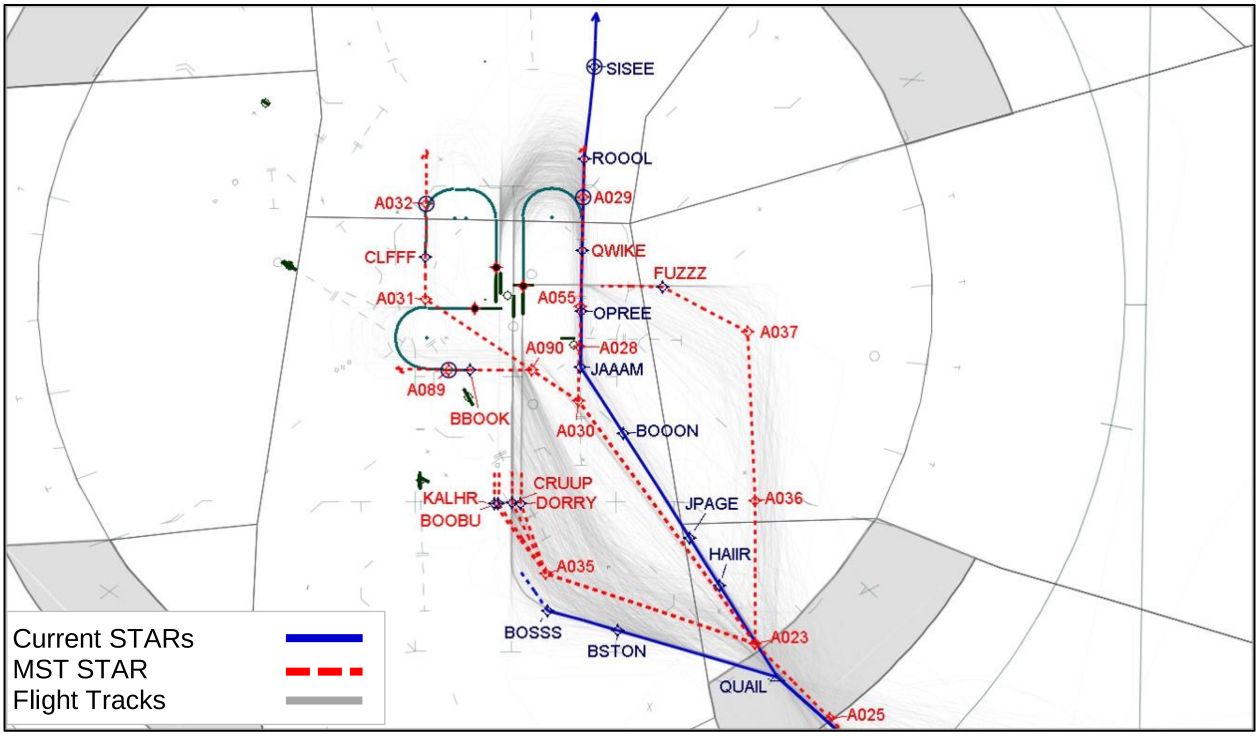

Figure 12. Current ZPLYN/BOSSS STARs and Proposed SE 2 STAR (terminal)

4.3.1.2.3 All DEN SE STARs Cost Benefit Analysis

Projected annual savings for the proposed DEN SE STARs are estimated in Table 7. Total estimated savings are rounded to the nearest whole figure.

Table 7. All Proposed DEN SE STARs Annual Benefits

Estimated Annual Fuel Savings (Dollars)	Fuel Burn (Distance and Profile)	$170K
	Cost to Carry	$96K
Total Estimated Annual Fuel Savings (Dollars)		$267K
Total Estimated Annual Fuel Savings (Gallons)		57K
Total Estimated Annual Carbon Savings (Metric Tons)		500

4.3.1.3 DEN SW STARs

This section describes all proposed DEN SW STARs. This gate accounts for approximately 22% of all DEN jet arrivals.

4.3.1.3.1 DEN SW 1 STAR

The current DEN PEEKK/LDORA STARs account for approximately 10% of all DEN jet arrivals.

- Issues
  - Two STARs for north/south runway configurations create pilot and controller task complexity due to multiple configuration changes at DEN.
  - No dedicated RNAV runway transitions to Runways 7 or 26, which creates additional pilot and controller task complexity.
  - Actual flight tracks do not follow current arrival procedures.
- Notional Solutions
  - RNAV OPD STAR created with runway transitions for north, south, east, and west flows resulting in optimized lateral paths to reduce flight track miles.
  - STAR was shortened for operational flexibility, unused en route transitions were removed, and an en route crossover transition was created, which will be ATC assigned only.
  - Modified en route and terminal merge points for increased sequencing time where feasible and created runway transitions which merge with RNPs (long side) and ILS/RNP (short side) procedures.
  - Created an altitude window of 17,000-FL230 at the beginning of the common route.
  - Proposed route may be in conflict with the ZOMBZ satellite STAR and will need review during D&I

Figures 13 and 14 depict the en route and terminal views of current and proposed notional STARs with current flight tracks and ATC only crossover.

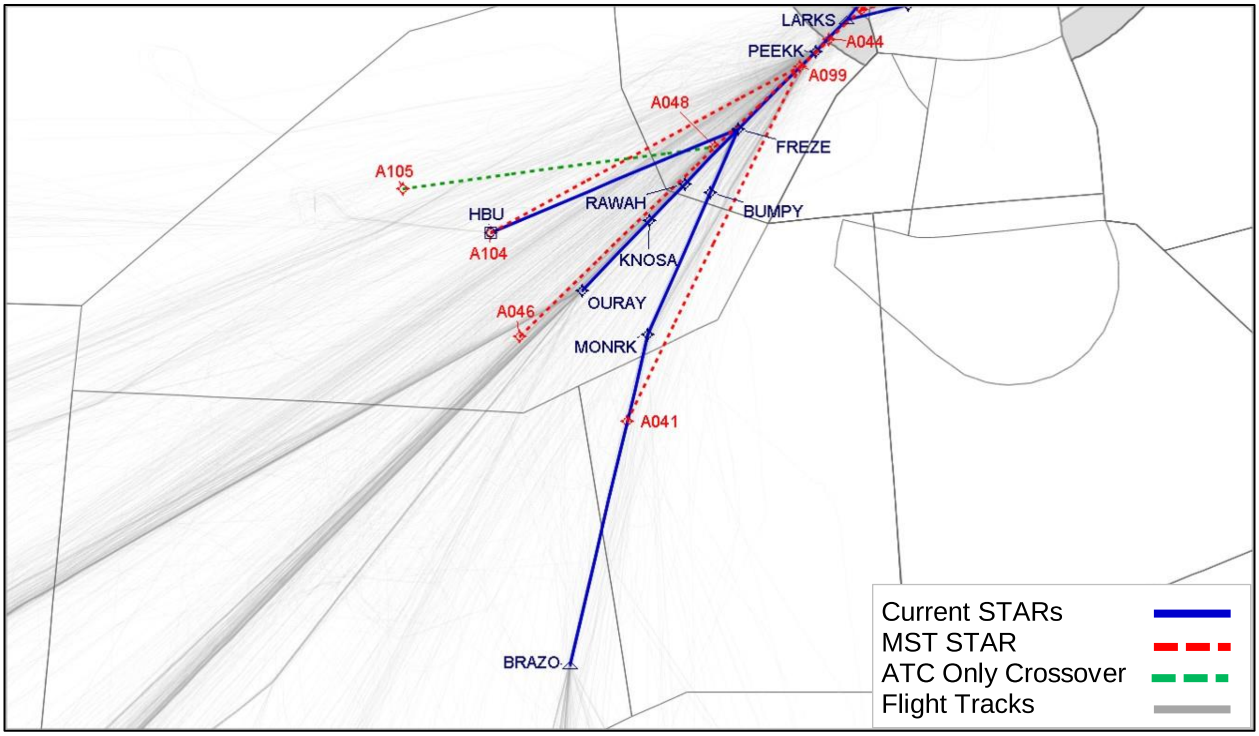

Figure 13. Current PEEKK/LDORA STARs and Proposed SW 1 STAR (en route)

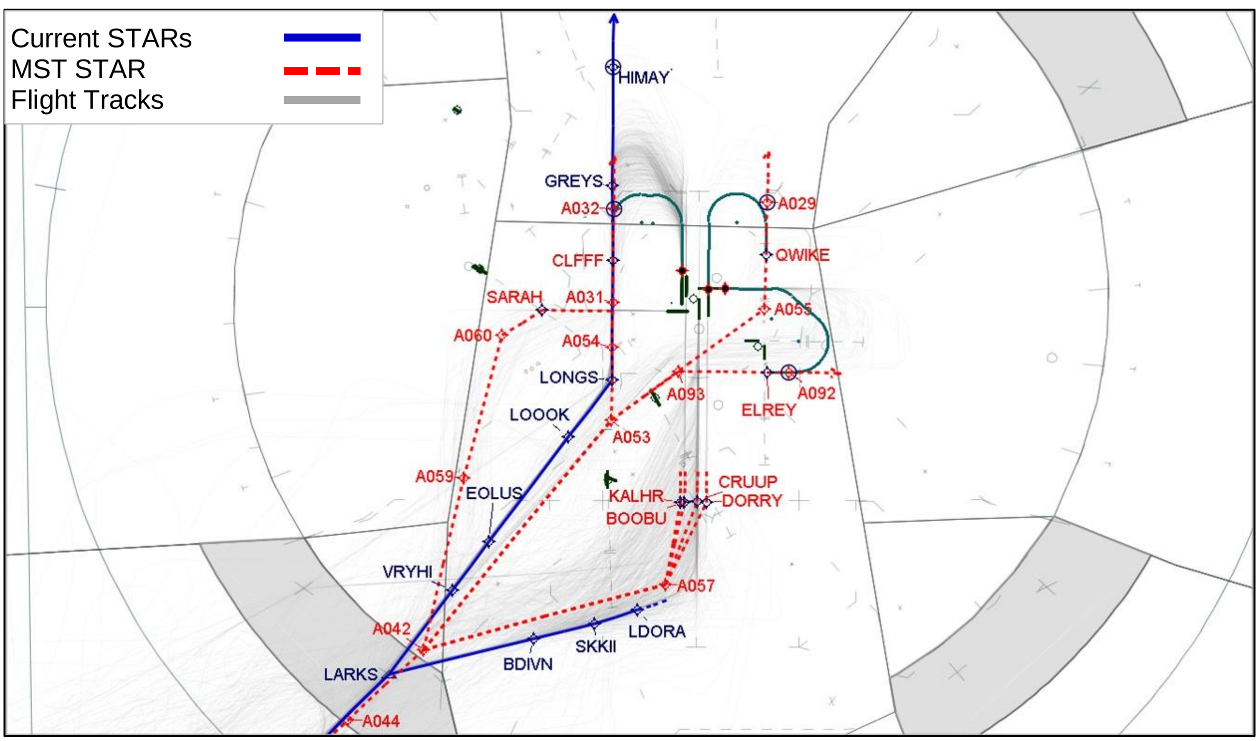

Figure 14. Current PEEKK/LDORA STARs and Proposed SW 1 STAR (terminal)

4.3.1.3.2 DEN SW 2 STAR

The current DEN CREDE/TELLR STARs account for approximately 12% of all DEN jet arrivals.

- Issues
  - Two STARs for north/south runway configurations create pilot and controller task complexity due to multiple configuration changes at DEN.
  - No dedicated RNAV runway transitions to Runways 7 or 26, which creates additional pilot and controller task complexity.
  - Actual flight tracks do not follow current arrival procedures.
- Notional Solutions
  - RNAV OPD STAR created with runway transitions for north, south, east, and west flows resulting in optimized lateral paths to reduce flight track miles.
  - STAR was shortened for operational flexibility, unused en route transitions were removed, and an en route crossover transition was created, which will be ATC assigned only.
  - Modified en route and terminal merge points for increased sequencing time where feasible and created runway transitions which merge with RNPs (long side) and ILS/RNP (short side) procedures.
  - Created an altitude window of 17,000-FL230 at the beginning of the common route.
  - The proposed JNETT (A052), HAQHY (A050) and HBU (A104) transitions are for ski airports and are restricted to at or below FL260.

Figures 15 and 16 depict the en route and terminal views of current and proposed notional STARs with current flight tracks and ATC only crossover.

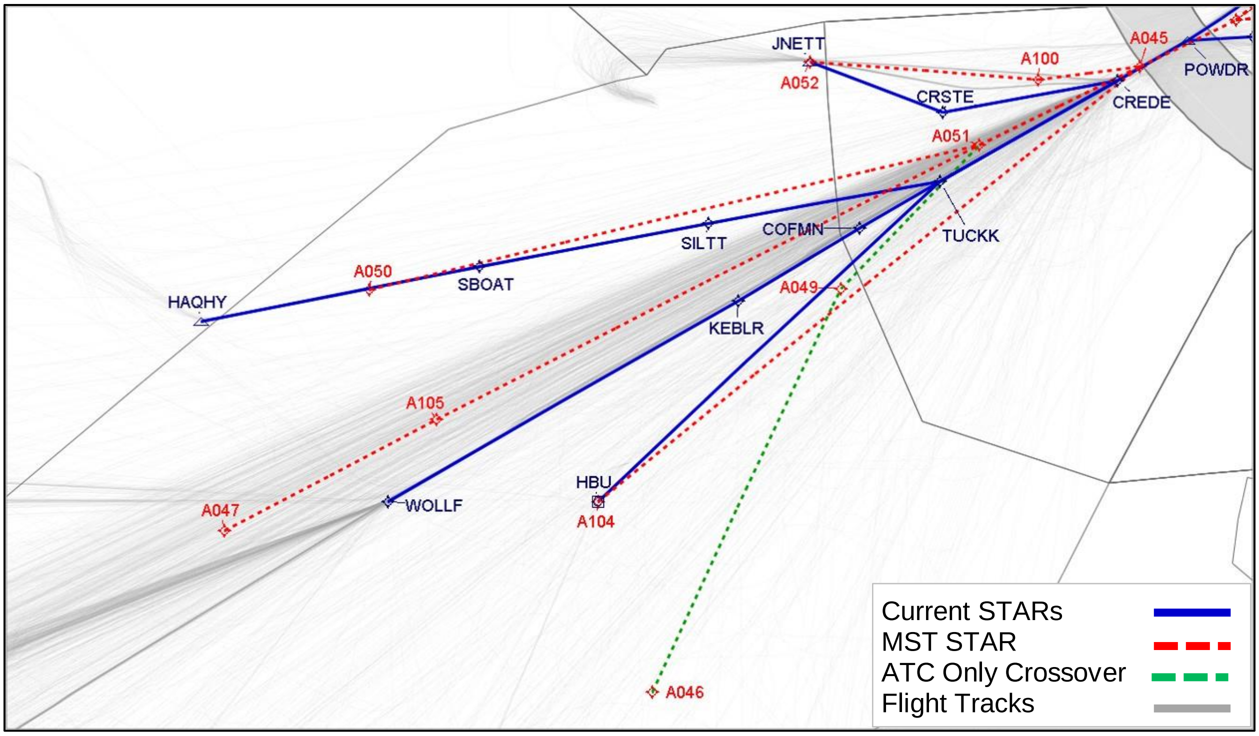

Figure 15. Current CREDE/TELLR STARs and Proposed SW 2 STAR (en route)

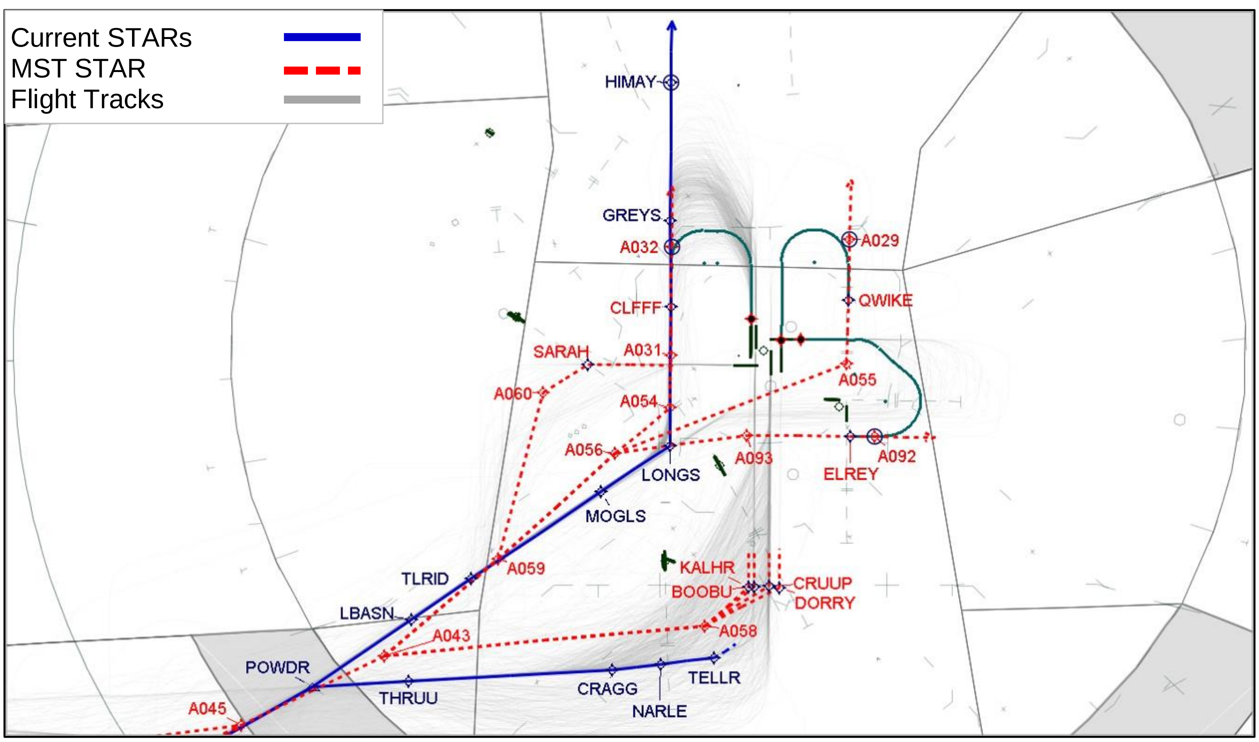

Figure 16. Current CREDE/TELLR STARs and Proposed SW 2 STAR (terminal)

4.3.1.3.3 All DEN SW STARs Cost Benefit Analysis

Projected annual savings for the DEN SW STARs are estimated in Table 8. Total estimated savings are rounded to the nearest whole figure.

Table 8. All Proposed DEN SW STARs Annual Benefits

Estimated Annual Fuel Savings (Dollars)	Fuel Burn (Distance and Profile)	$452K
	Cost to Carry	$63K
Total Estimated Annual Fuel Savings (Dollars)		$515K
Total Estimated Annual Fuel Savings (Gallons)		150K
Total Estimated Annual Carbon Savings (Metric Tons)		1,400

4.3.1.4 DEN NW STARs

This section describes all proposed DEN NW STARs. This gate accounts for approximately 23% of all DEN jet arrivals.

4.3.1.4.1 DEN NW 1 STAR

The current DEN FRNCH/KAILE STARs account for approximately 14% of all DEN jet arrivals.

- Issues
  - Two STARs for north/south runway configurations create pilot and controller task complexity due to multiple configuration changes at DEN.
  - No dedicated RNAV runway transitions to Runways 7 or 26, which creates additional pilot and controller task complexity.
  - Actual flight tracks do not follow current arrival procedures.
  - Satellite flows impact DEN STARs.
  - Arrivals are in conflict with the LMO parachute jump zone.

- Notional Solutions
    - RNAV OPD STAR created with runway transitions for north, south, east, and west flows resulting in optimized lateral paths to reduce flight track miles.
    - STAR was shortened for operational flexibility, unused en route transitions were removed, and an en route crossover transition was created, which will be ATC assigned only.
    - Modified en route and terminal merge points for increased sequencing time where feasible and created runway transitions which merge with RNPs (long side) and ILS/RNP (short side) procedures.
    - Created an altitude window of 17,000-FL230 at the beginning of the common route.
    - Satellite flows were segregated from DEN arrivals by creating two separate satellite STARs; one that serves APA, situated between the two NW DEN STARs and another, west of V4, which serves northern Denver Metroplex airports (see Section 4.3.3).
    - Adjusted STAR to avoid LMO parachute jump zone.

Figures 17 and 18 depict the en route and terminal views of current and proposed notional STARs with current flight tracks and ATC only crossover.

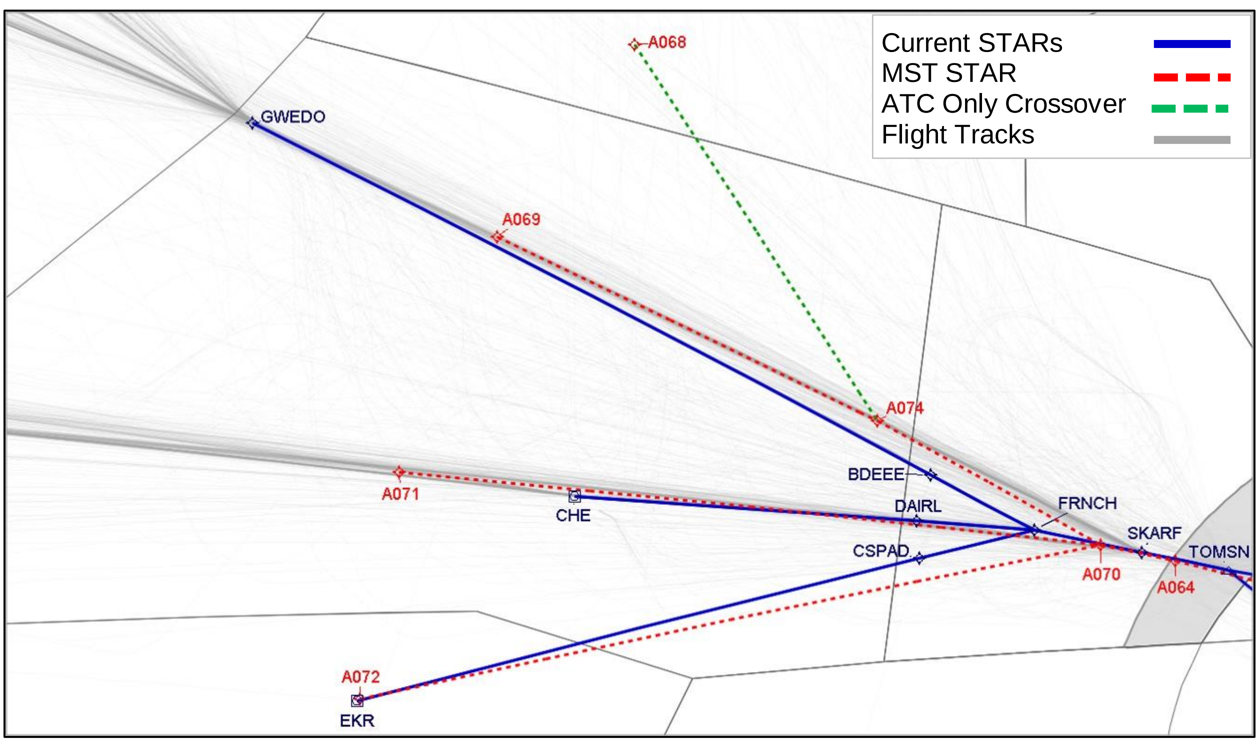

Figure 17. Current FRNCH/KAILE STARs and Proposed NW 1 STAR (en route)

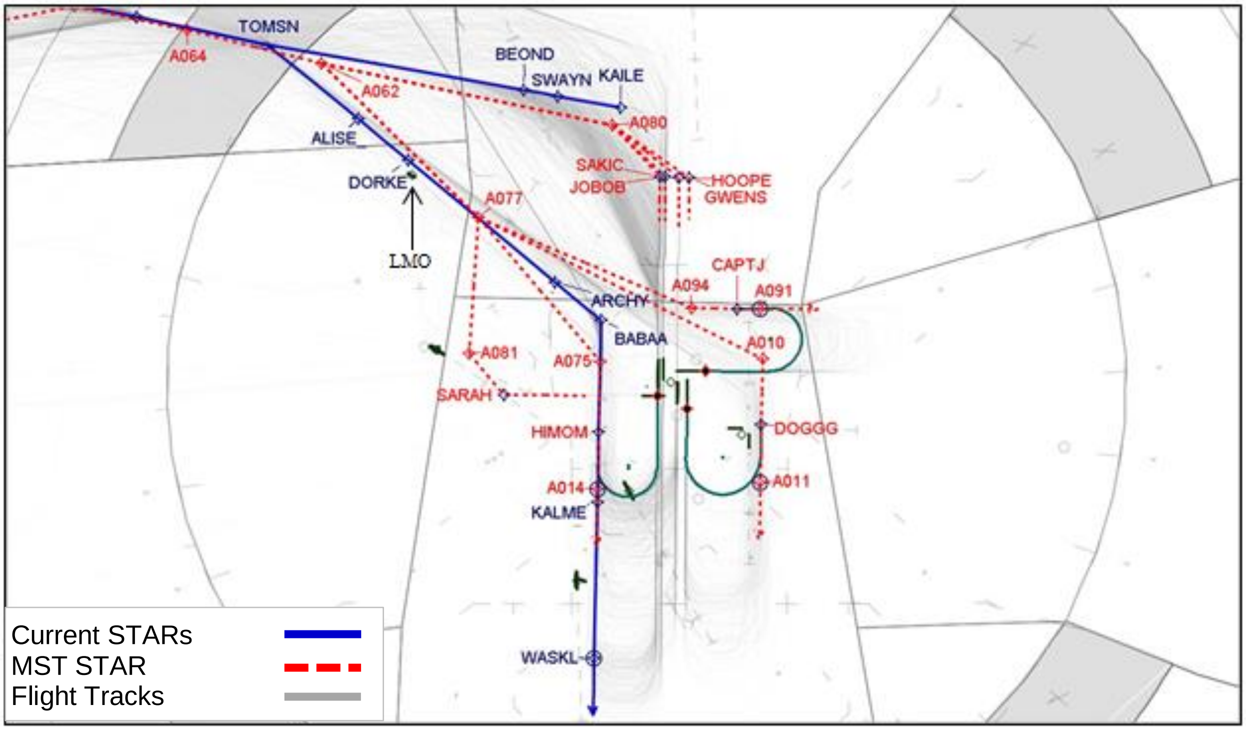

Figure 18. Current FRNCH/KAILE STARs and Proposed NW 1 STAR (terminal)

4.3.1.4.2 DEN NW 2 STAR

The current DEN MOLTN/TSHNR STARs account for approximately 9% of all DEN jet arrivals.

- Issues
  - Two STARs for north/south runway configurations create pilot and controller task complexity due to multiple configuration changes at DEN.
  - No dedicated RNAV runway transitions to Runways 7 or 26, which creates additional pilot and controller task complexity.
  - Actual flight tracks do not follow current arrival procedures.
- Notional Solutions
  - RNAV OPD STAR created with runway transitions for north, south, east, and west flows resulting in optimized lateral paths to reduce flight track miles.
  - STAR was shortened for operational flexibility, unused en route transitions were removed, and an en route crossover transition was created, which will be ATC assigned only.
  - Modified en route and terminal merge points for increased sequencing time where feasible and created runway transitions which merge with RNPs (long side) and ILS/RNP (short side) procedures.

- Created an altitude window of 17,000-FL230 at the beginning of the common route.
- Satellite flows were segregated from DEN arrivals by creating two separate satellite STARs; one that serves APA, situated between the two NW DEN STARs and another, west of V4, which serves northern Denver Metroplex airports (see Section 4.3.3).

Figures 19 and 20 depict the en route and terminal views of current and proposed notional STARs with current flight tracks and ATC only crossover.

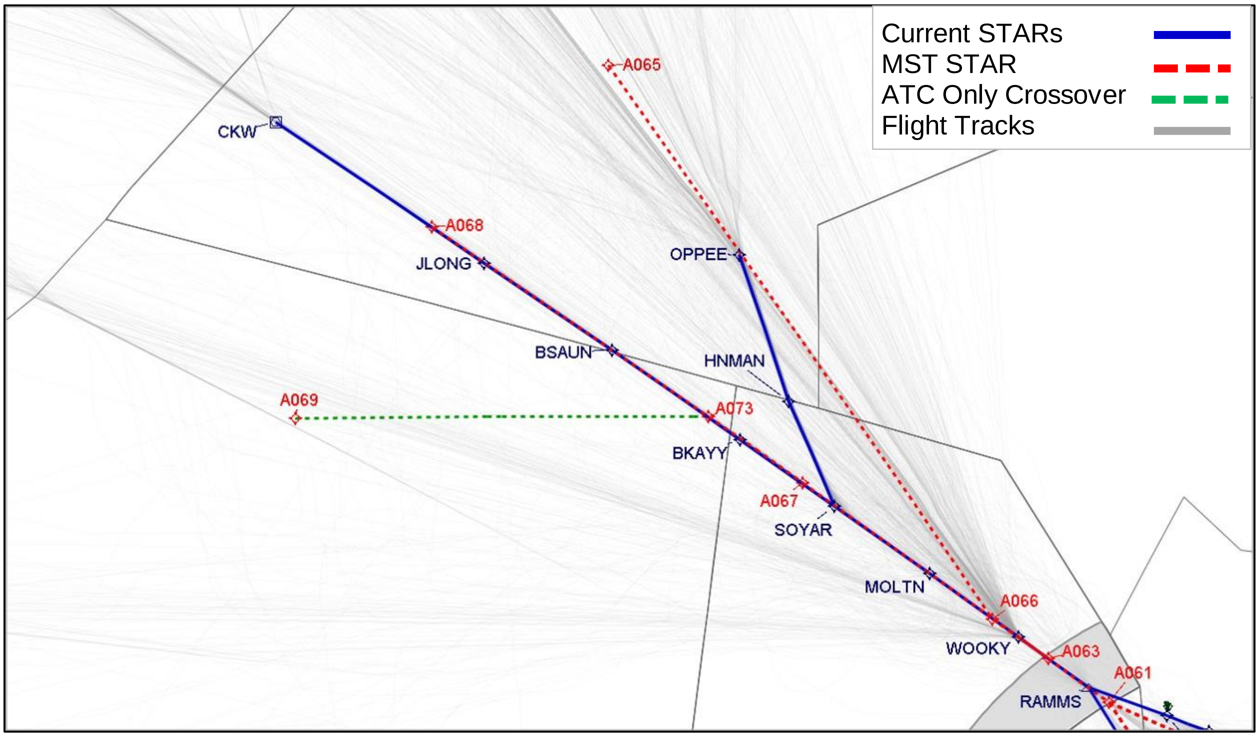

Figure 19. Current MOLTN/TSHNR STARs and Proposed NW 2 STAR (en route)

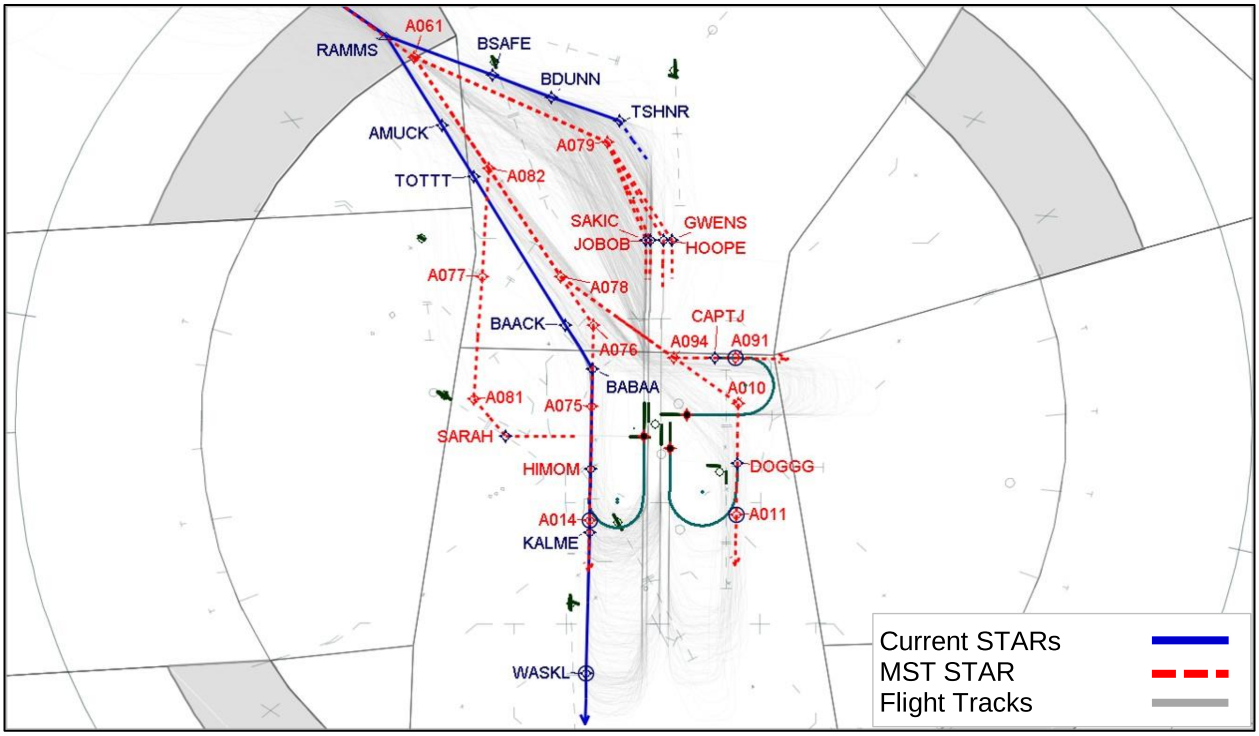

Figure 20. Current MOLTN/TSHNR STARs and Proposed NW 2 STAR (terminal)

4.3.1.4.3 All DEN NW STARs Cost Benefit Analysis

Projected annual savings for the DEN NW STARs are estimated in Table 9. Total estimated savings are rounded to the nearest whole figure.

Table 9. All Proposed DEN NW STARs Annual Benefits

Estimated Annual Fuel Savings (Dollars)	**Fuel Burn (Distance and Profile)**	**$480K**
	Cost to Carry	**$100K**
Total Estimated Annual Fuel Savings (Dollars)		**$580K**
Total Estimated Annual Fuel Savings (Gallons)		**159K**
Total Estimated Annual Carbon Savings (Metric Tons)		**1,500**

4.3.1.5 DEN Weather Re-Route STAR

- Issues
  - Lack of a published weather re-route STAR through COS ATCT to DEN.
  - Weather re-route through COS ATCT is currently a point-to-point clearance.
  - ZDV and D01 use different fixes for this route resulting in ZDV and COS ATCT issuing two different clearances.
- Notional Solutions
  - MST designed a notional weather re-route STAR through COS ATCT with four en route transitions.
  - RODDY transition is segregated from R2601.

Figures 21 depicts the MST notional weather re-route STAR with current flight tracks.

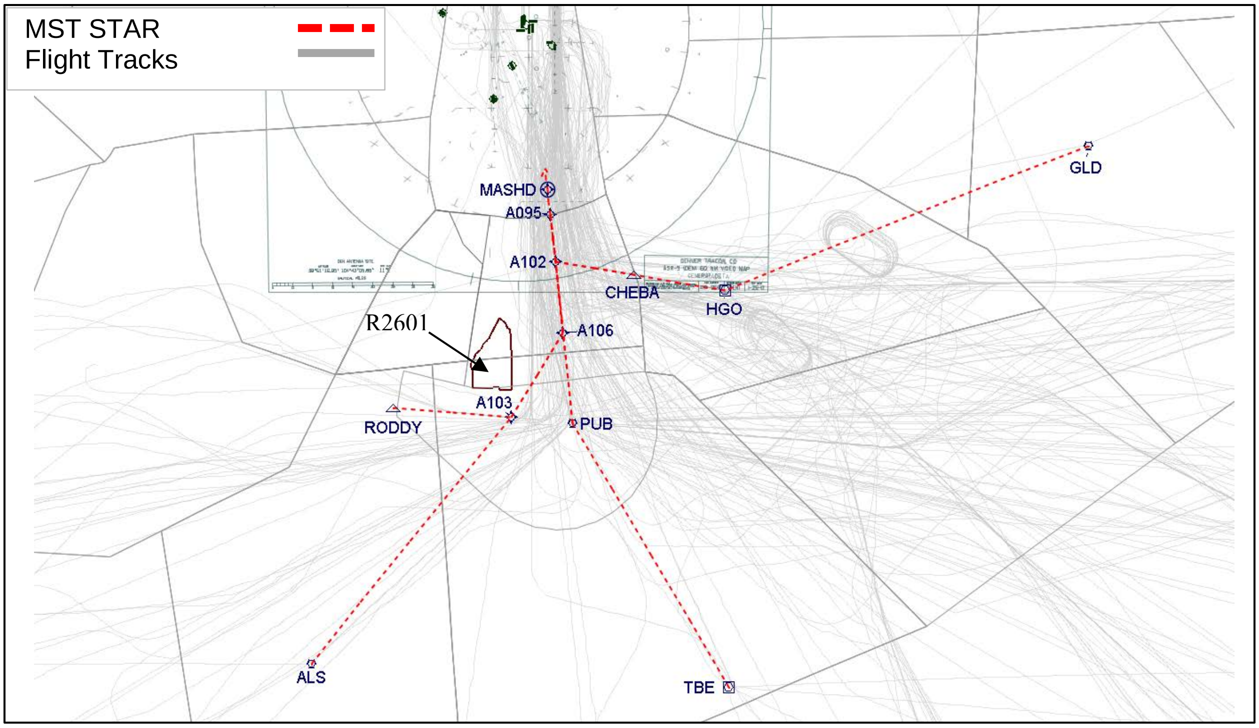

Figure 21. Proposed Weather Re-Route STAR

- Benefits
  - Cost benefit analysis was not performed for this procedure.

4.3.1.6 All DEN STARs Cost Benefit Analysis

Projected annual savings for all proposed DEN STARs are estimated in Table 10. Total estimated savings are rounded to the nearest whole figure.

Table 10. All Proposed DEN STARs Annual Benefits

	Fuel Burn Benefit ($)	Cost to Carry ($)	Overall Fuel Benefit ($)	Estimated Carbon Savings (Metric Tons)
Northeast	$196K	$27K	$223K	600
Southeast	$170K	$96K	$267K	500
Southwest	$452K	$63K	$515K	1,400
Northwest	$480K	$100K	$580K	1,500
Total Annual Savings	$1.3M	$286K	$1.6M	4,100

Total Fuel Benefit (Gal)	Total Fuel Benefit ($)
431K	$1.6M

4.3.2 DEN Departures

This section describes the operational issues, notional solutions, and expected benefits the MST has identified for DEN departures.

Currently, there are 21 SIDs serving DEN: 16 RNAV and five conventional. The MST used the existing RNAV SIDs as the starting point for procedure development. Common issues were identified by the MST, facilities, and industry as described below:

- Inefficient lateral paths
- Initial leg types do not provide the appropriate separation minima
- DEN ATCT uses a combination of RNAV off-the-ground and radar vectors
- Departure routes are in conflict with current and proposed Special Use Airspace (SUA)
- Departures are routed south or vectored north of FTG airspace
- Westbound noise issues restrict efficient procedure design
- Low conformance to the departure procedures

The MST recommends the following common notional solutions for all DEN SIDs. SID specific solutions based on departure gate are described in each notes section.

- Optimization of lateral paths to reduce flight track miles
- Segregation of RNAV SIDs from arrivals where practical
- Elimination of unused en route transition(s)
- Minimum of eight NM between all Transfer of Control Points (TCP)
- RNAV off-the-ground departure procedures
- Combination of initial RNAV legs as appropriate
- Initial altitude assignment of 10,000 feet MSL (all other altitudes are tactically assigned by ATC)
- Shortening of en route transitions for added flexibility

4.3.2.1 DEN YAMMI, RIKKK, BRYCC, and YOKES Northbound SIDs

The current north departures account for approximately 22% of all DEN jet departures.

- Northbound SID notes
  - MST routes were shortened for track mile savings and additional efficiencies.
  - MST routes for Runway 17L were designed to avoid FTG Class D airspace.

Figures 22 and 23 depict the terminal and en route views of current and proposed notional SIDs with current flight tracks.

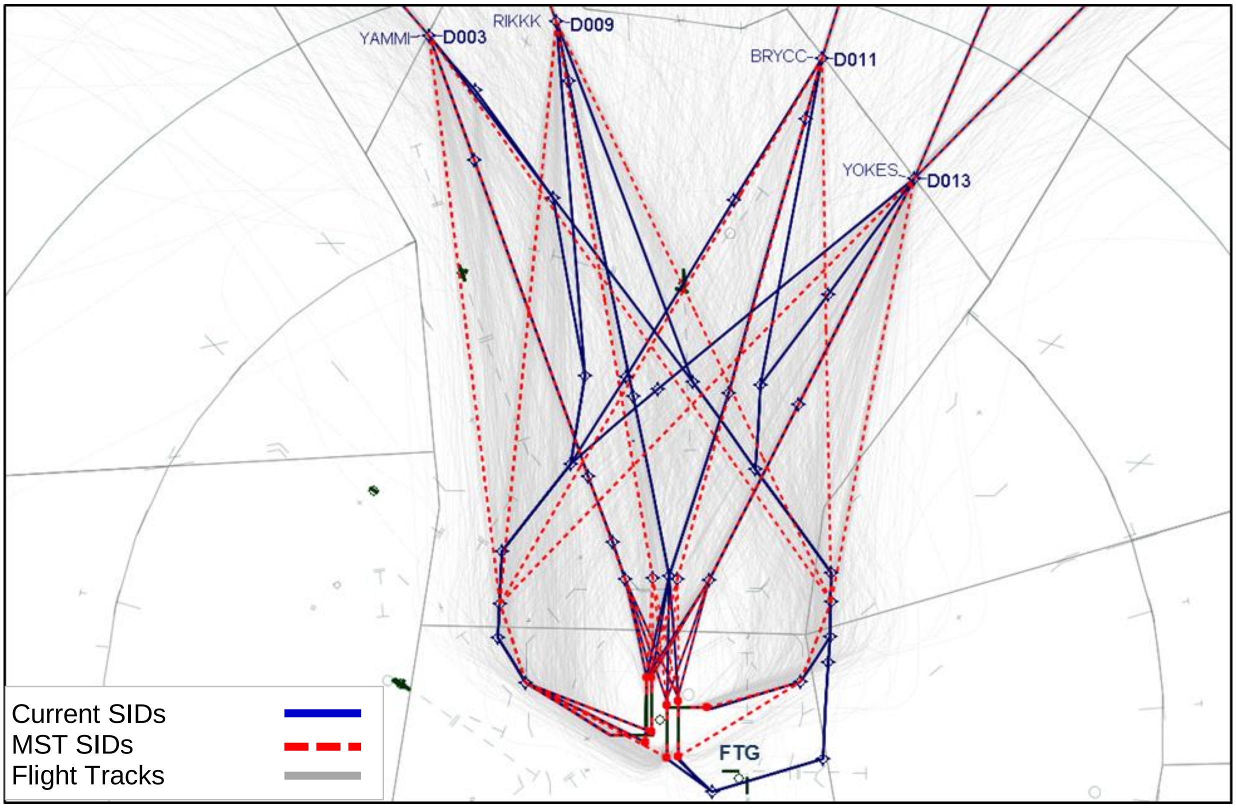

Figure 22. Current and Proposed DEN YAMMI, RIKKK, BRYCC, and YOKES SIDs (terminal)

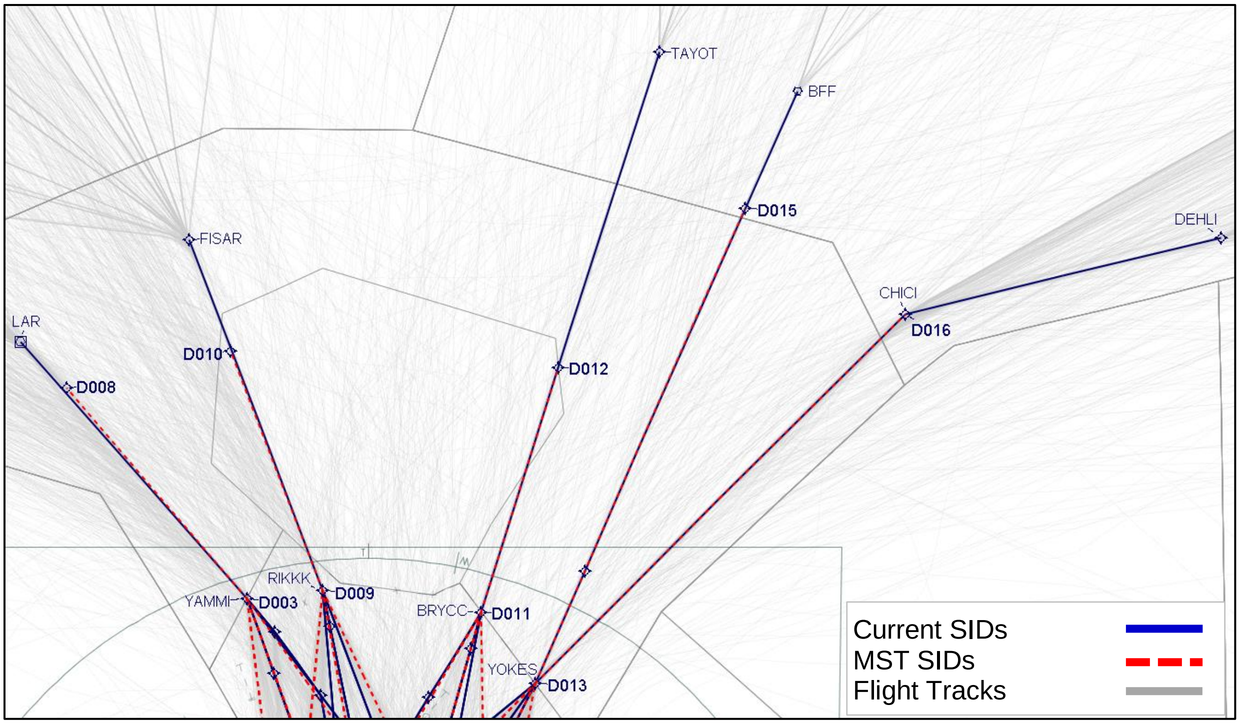

Figure 23. Current and Proposed DEN YAMMI, RIKKK, BRYCC, and YOKES SIDs (en route)

- Benefits
  - Projected annual savings for the proposed DEN YAMMI, RIKKK, BRYCC, and YOKES SIDs are estimated in Table 11. Total estimated savings are rounded to the nearest whole figure.

Table 11. Proposed DEN YAMMI, RIKKK, BRYCC, and YOKES SIDs Annual Benefits

Estimated Annual Fuel Savings (Dollars)	Fuel Burn (Distance and Profile)	$7K
	Cost to Carry	$46K
Total Estimated Annual Fuel Savings (Dollars)		$53K
Total Estimated Annual Fuel Savings (Gallons)		2K
Total Estimated Annual Carbon Savings (Metric Tons)		21

4.3.2.2 DEN EEONS, EMMYS, EXTAN, and EPKEE Eastbound SIDs

The current east departures account for approximately 36% of all DEN jet departures.

- Eastbound SID notes
  - MST routes were shortened for track mile savings and additional efficiencies.
  - MST routes were designed to avoid FTG Class D airspace on the EEONS and EMMYS SIDs.
  - A new transition was designed to avoid the proposed COUGAR Military Operations Area (MOA) for the MST EPKEE SID and will primarily be used when the MOA is active.
  - Runway 25 incorporates radar vectors for flexibility.

Figures 24 and 25 depict the terminal and en route views of current and proposed notional SIDs with current flight tracks.

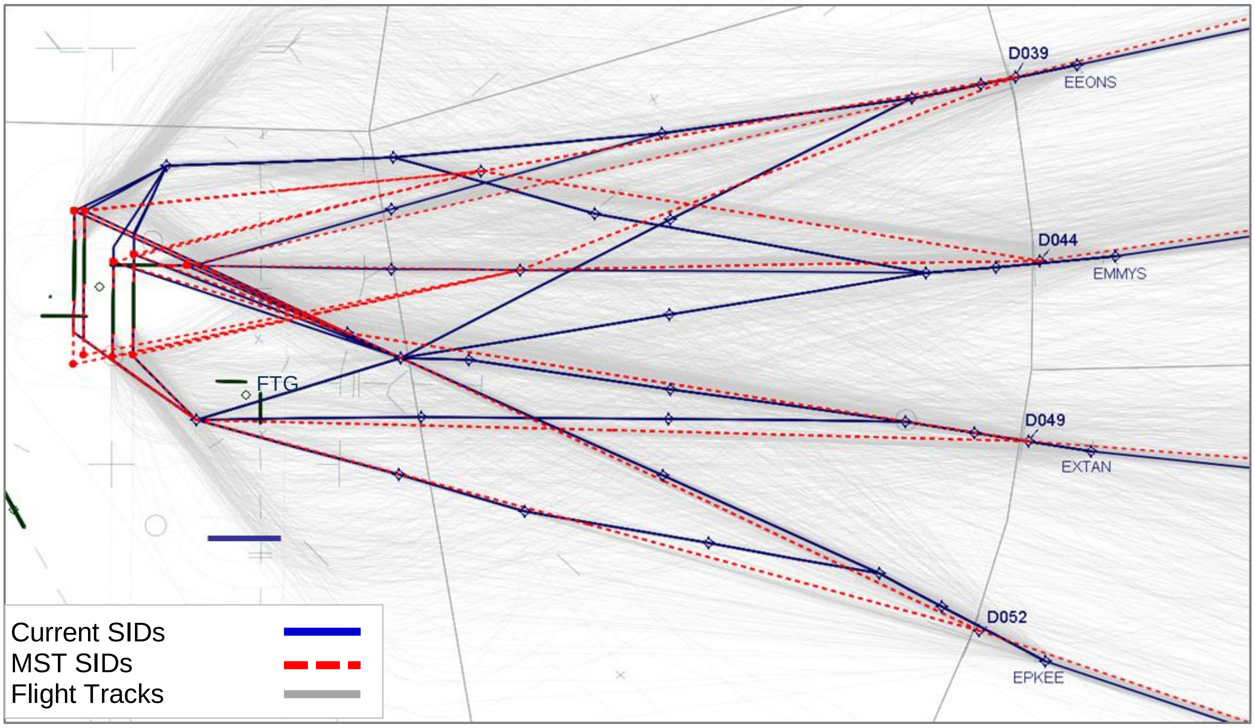

Figure 24. Current and Proposed DEN EEONS, EMMYS, EXTAN, and EPKEE SIDs (terminal)

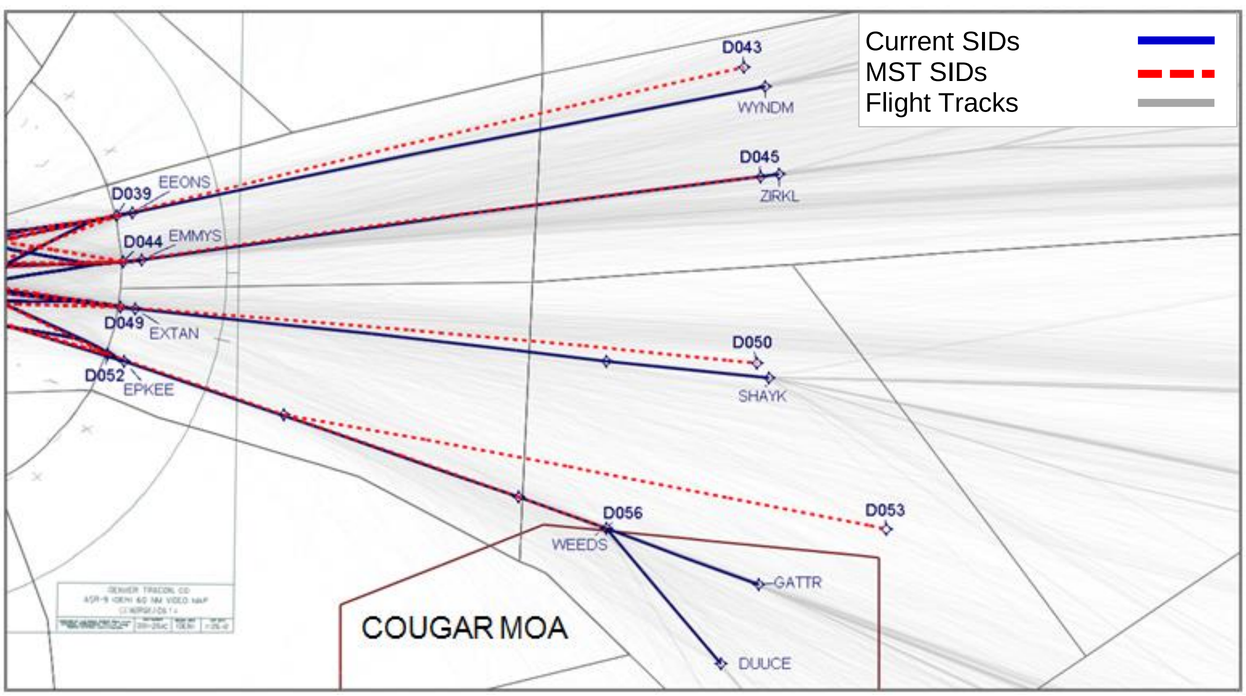

Figure 25. Current and Proposed DEN EEONS, EMMYS, EXTAN, and EPKEE SIDs (en route)

- Benefits
  - Projected annual savings for the proposed DEN EEONS, EMMYS, EXTAN, and EPKEE SIDs are estimated in Table 12. Total estimated savings are rounded to the nearest whole figure.

Table 12. Proposed DEN EEONS, EMMYS, EXTAN, and EPKEE SIDs Annual Benefits

Estimated Annual Fuel Savings (Dollars)	Fuel Burn (Distance and Profile)	$148K
	Cost to Carry	$92K
Total Estimated Annual Fuel Savings (Dollars)		$241K
Total Estimated Annual Fuel Savings (Gallons)		49K
Total Estimated Annual Carbon Savings (Metric Tons)		500

4.3.2.3 DEN STAKR, SPAZZ_E, SPAZZ_W, and SOLAR Southbound SIDs

The current south departures account for approximately 17% of all DEN jet departures.

- Southbound SID notes
  - MST routes were shortened for track mile savings and additional efficiencies.
  - Current SPAZZ SID was split into two procedures (SPAZZ_E and SPAZZ_W) which created an additional departure gate for increased flexibility and efficiencies.
  - SPAZZ_E and SPAZZ_W SIDs will avoid R2601.
  - SPAZZ_E SID avoids TWO BUTTES MOA.
  - En route transition added to the SOLAR SID for ski airports.

Figures 26 and 27 depict the terminal and en route views of current and proposed notional SIDs with current flight tracks.

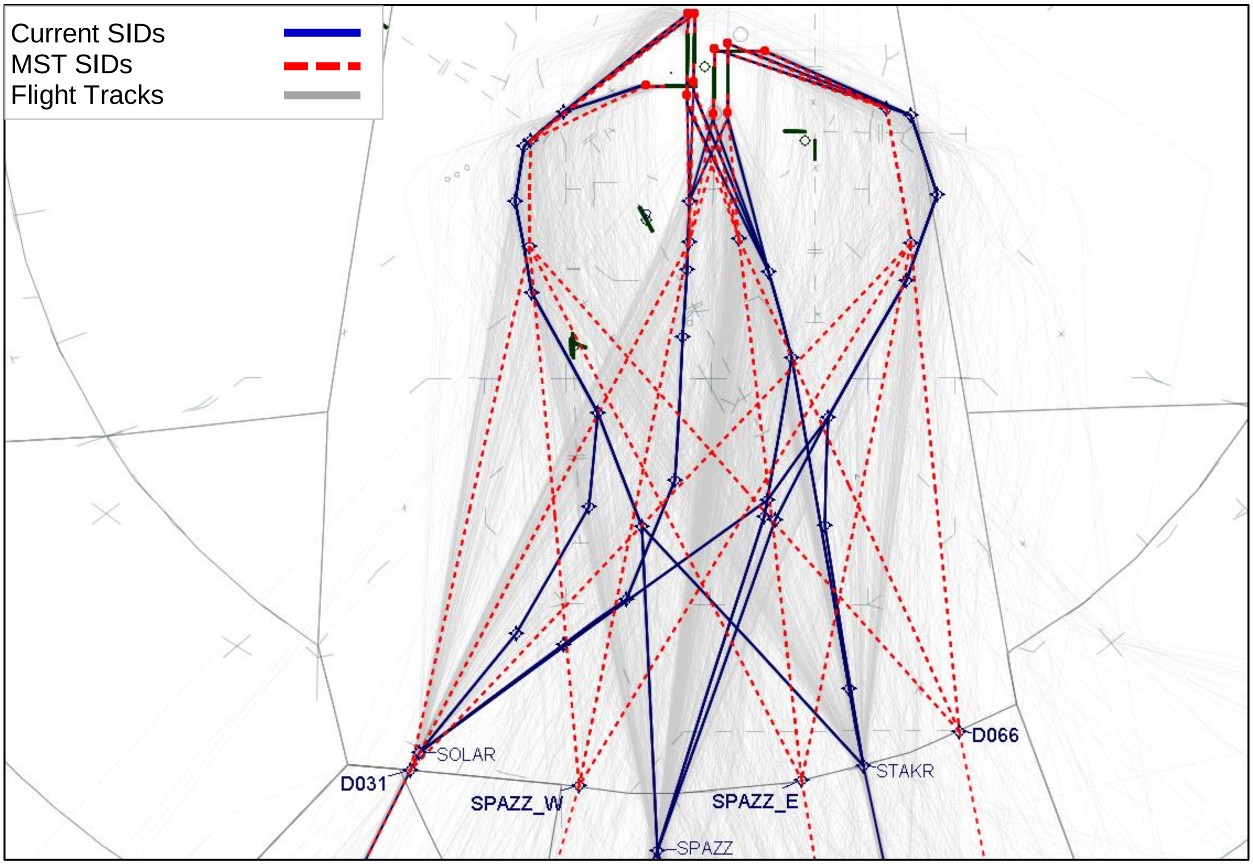

Figure 26. Current and Proposed DEN STAKR, SPAZZ (E/W), and SOLAR SIDs (terminal)

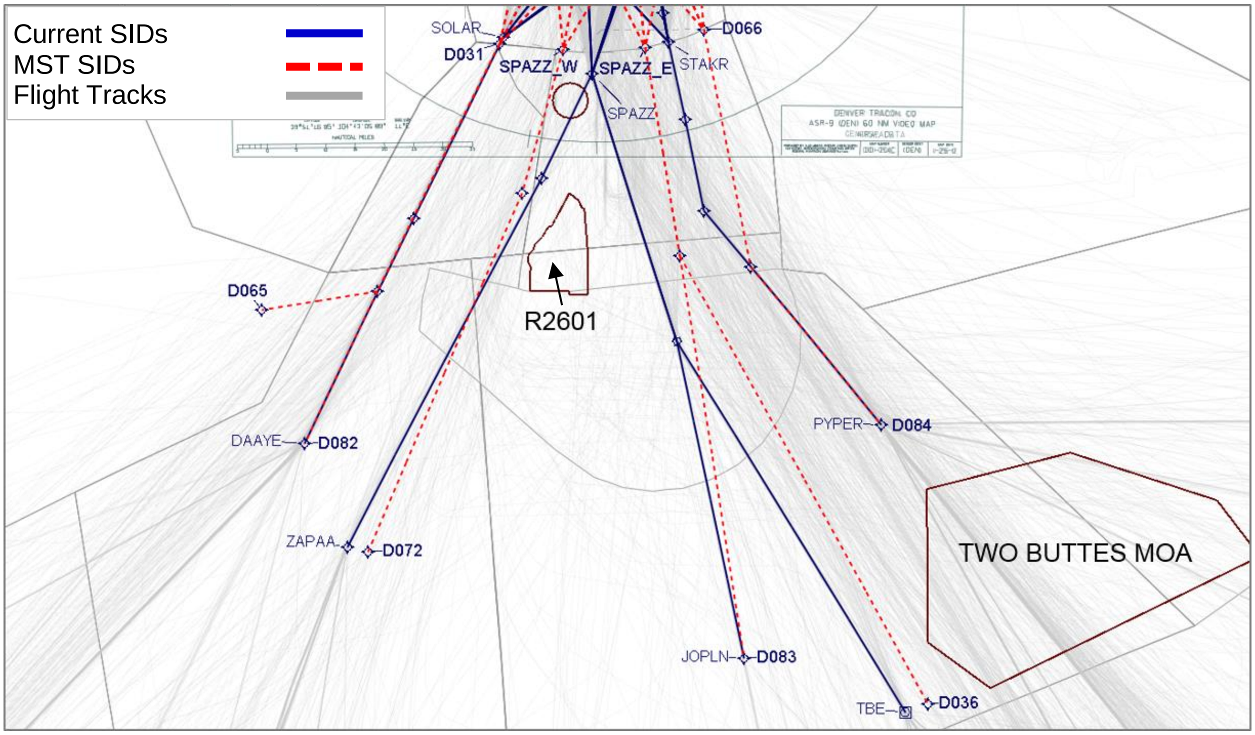

Figure 27. Current and Proposed DEN STAKR, SPAZZ (E/W), and SOLAR SIDs (en route)

- Benefits
  - Projected annual savings for the proposed DEN STAKR, SPAZZ (E/W), and SOLAR SIDs are estimated in Table 13. Total estimated savings are rounded to the nearest whole figure.

Table 13. Proposed DEN STAKR, SPAZZ (E/W), and SOLAR SIDs Annual Benefits

Estimated Annual Fuel Savings (Dollars)	Fuel Burn (Distance and Profile)	$280K
	Cost to Carry	$68K
Total Estimated Annual Fuel Savings (Dollars)		$348K
Total Estimated Annual Fuel Savings (Gallons)		93K
Total Estimated Annual Carbon Savings (Metric Tons)		900

4.3.2.4 DEN BAYLR, CONNR, COORZ, and FOOOT Westbound SIDs

The current west departures account for approximately 26% of all DEN jet departures.

- Westbound SID notes
  - MST routes were shortened for track mile savings and additional efficiencies.
  - During westbound route design, Noise Exposure Performance Standards (NEPS) sensor locations were used as a reference to attempt to minimize future noise impacts.
  - Runway 8 incorporates radar vectors for flexibility.

Figures 28 and 29 depict the DEN NEPS points and the proposed routes. Figures 30 and 31 depict the terminal and en route views of current and proposed notional SIDs with current flight tracks.

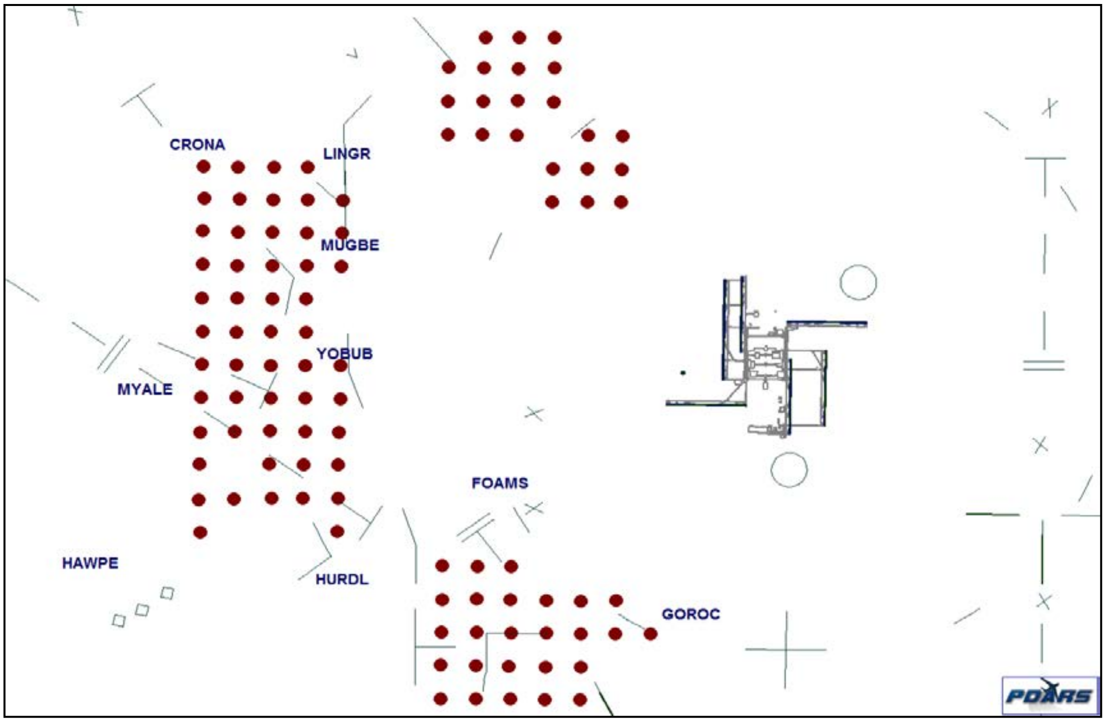

Figure 28. DEN NEPS Points

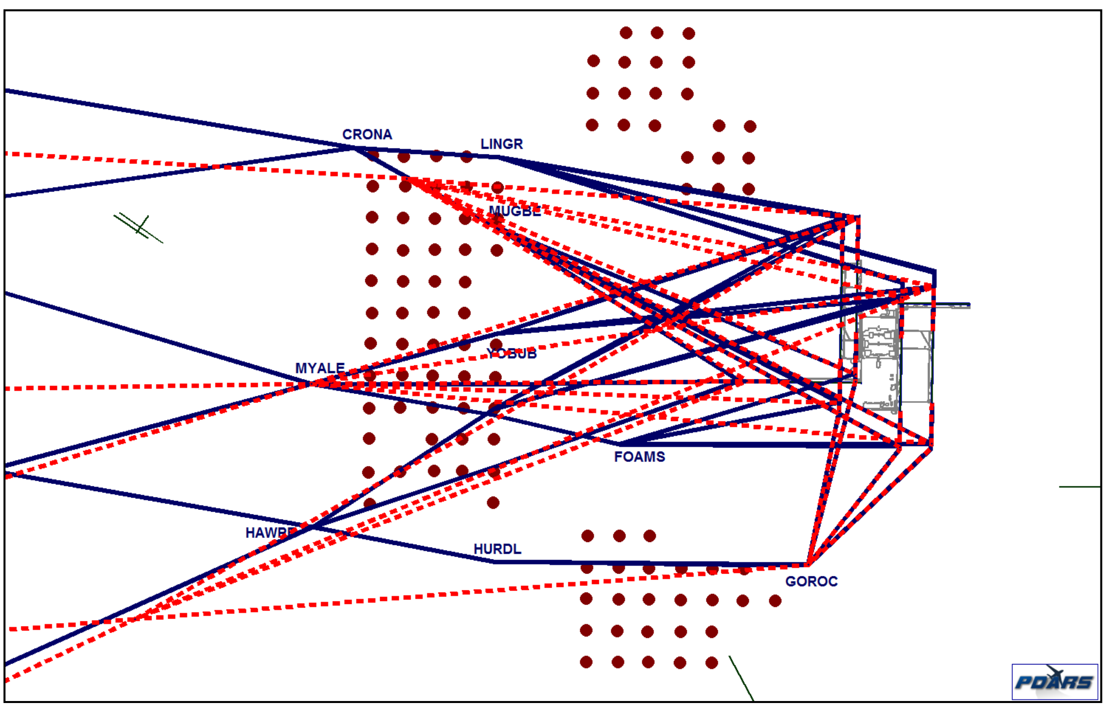

Figure 29. Current and Proposed DEN West SIDs with NEPS Points

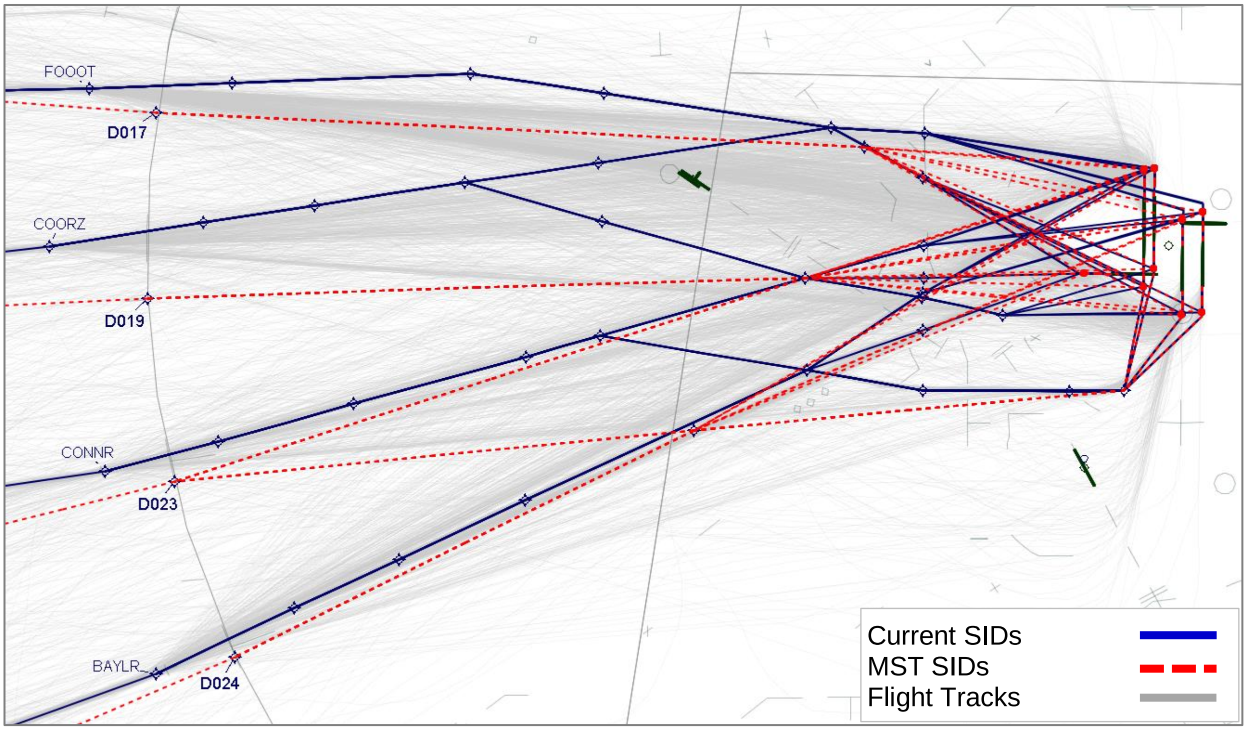

Figure 30. Current and Proposed DEN BAYLR, CONNR, COORZ, and FOOOT SIDs (terminal)

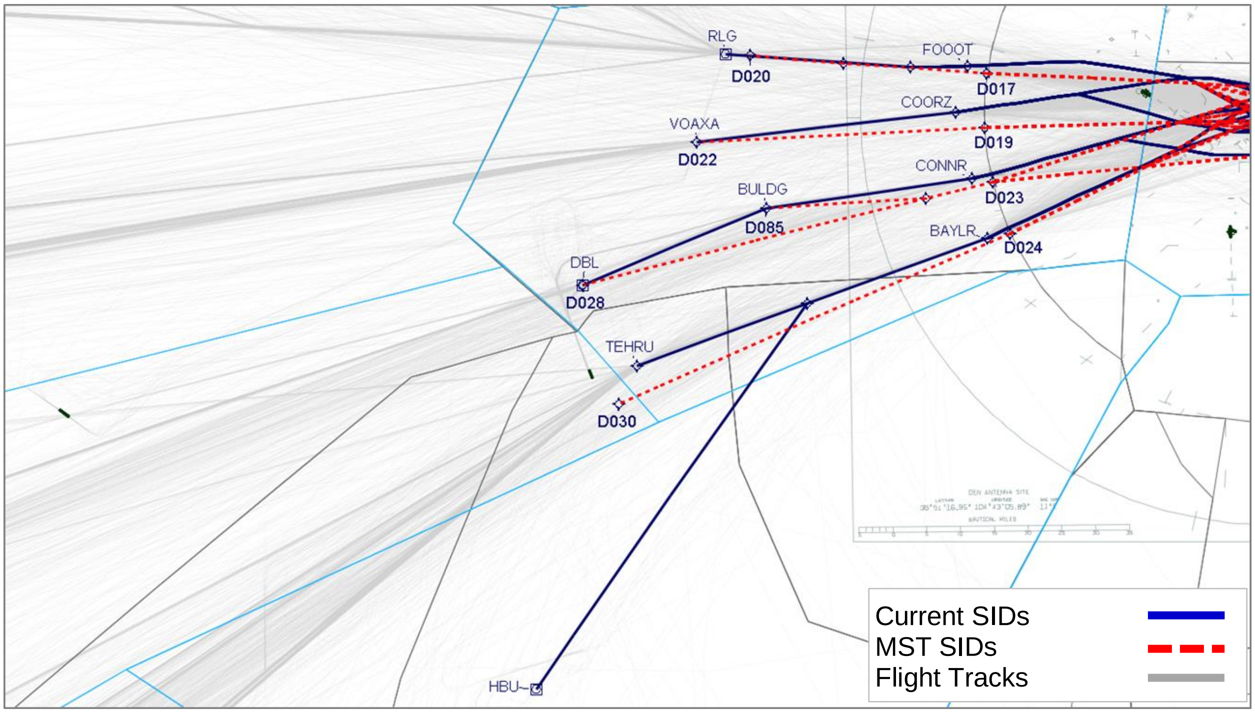

Figure 31. Current and Proposed DEN BAYLR, CONNR, COORZ, and FOOOT SIDs (en route)

- Benefits
  - Projected annual savings for the new proposed DEN BAYLR, CONNR, COORZ, and FOOOT SIDs are estimated in Table 14. Total estimated savings are rounded to the nearest whole figure.

Table 14. Proposed DEN BAYLR, CONNR, COORZ, and FOOOT SIDs Annual Benefits

Estimated Annual Fuel Savings (Dollars)	Fuel Burn (Distance and Profile)	$430K
	Cost to Carry	$105K
Total Estimated Annual Fuel Savings (Dollars)		$535K
Total Estimated Annual Fuel Savings (Gallons)		143K
Total Estimated Annual Carbon Savings (Metric Tons)		1,400

4.3.2.5 DEN JMPRS SID

- Issues
    - Current JMPRS SID not authorized by Notice to Airmen (NOTAM).
    - Procedure inefficient as currently published.
- Notional Solutions
    - Route shortened for efficiency and mimics flight tracks.
    - Notional route ends at COS ATCT boundary.
    - Further coordination with COS ATCT required.

Figure 32 depicts the current and MST notional JMPRS SID with current flight tracks.

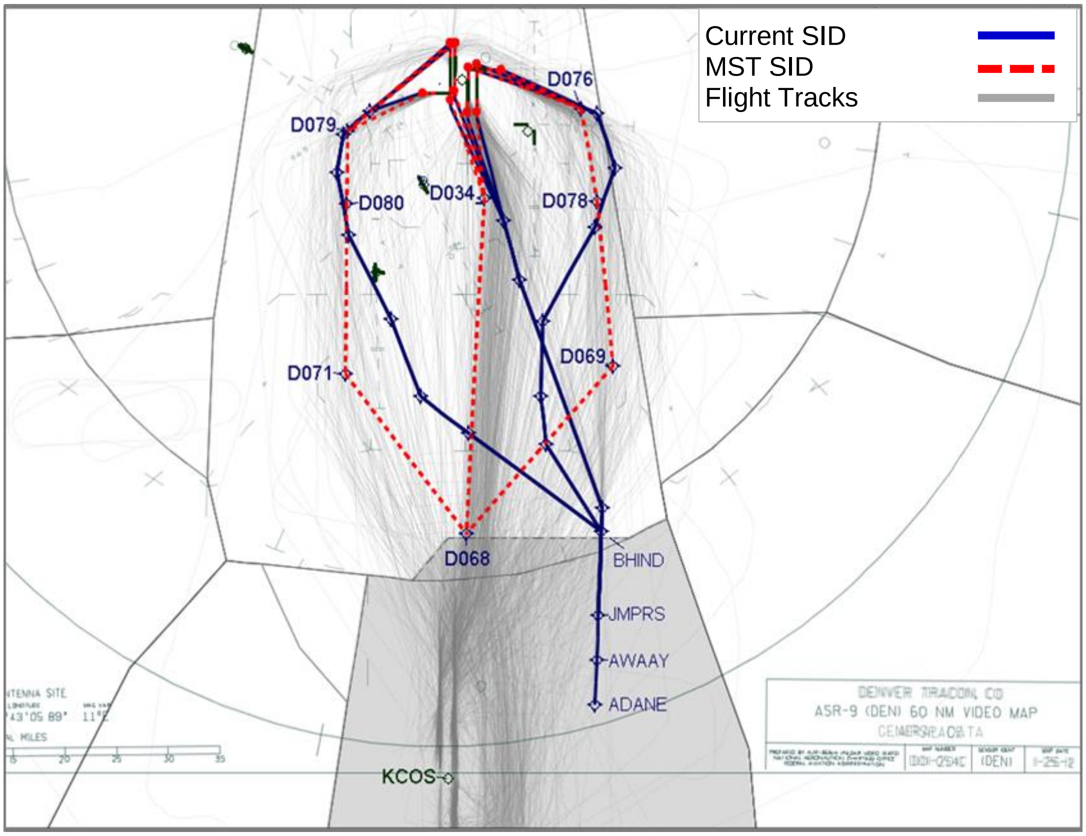

Figure 32. Current and Proposed JMPRS SID

- Benefits
  - Cost benefit analysis was not performed for this procedure.

4.3.2.6 All DEN SIDs Cost Benefit Analysis

Projected annual cost savings for the proposed DEN SIDs are estimated in Table 15.

Table 15. All Proposed DEN SIDs Annual Benefits

	Fuel Burn Benefit ($)	Cost to Carry ($)	Overall Fuel Benefit ($)	Estimated Carbon Savings (Metric Tons)
North	$7K	$46K	$53K	21
East	$148K	$92K	$241K	500
South	$280K	$68K	$348K	900
West	$430K	$105K	$535K	1,400
Total Annual Savings	$865K	$311K	$1.2M	2,821

Total Fuel Benefit (Gal)	Total Fuel Benefit ($)
287K	$1.2M

4.3.3 Denver Satellite Airport Arrival Issues

- Issues
  - APA arrival flows are not segregated from DEN arrivals and impede DEN OPDs.
  - Lack of arrival procedures for GXY, FNL, BJC, and LMO airports.
- Notional Solutions
  - Created new satellite RNAV STARs segregated from DEN STARs.
  - Satellite STARs were created for path predictability and end with radar vector legs for flexibility.
  - For the NW, satellite flows were segregated from DEN STARs by creating two separate STARs; one that serves APA, situated between the two NW DEN STARs and another, west of V4, which serves northern Denver satellite airports.
  - For the NE, satellite flows were segregated from DEN STARs by creating a separate satellite STAR north of the two DEN STARs. Additionally, a transition was created, which serves northern Denver satellite airports.

Figure 33 depicts the current (PUFFR) and proposed notional satellite STARs for the northwest and northeast only.

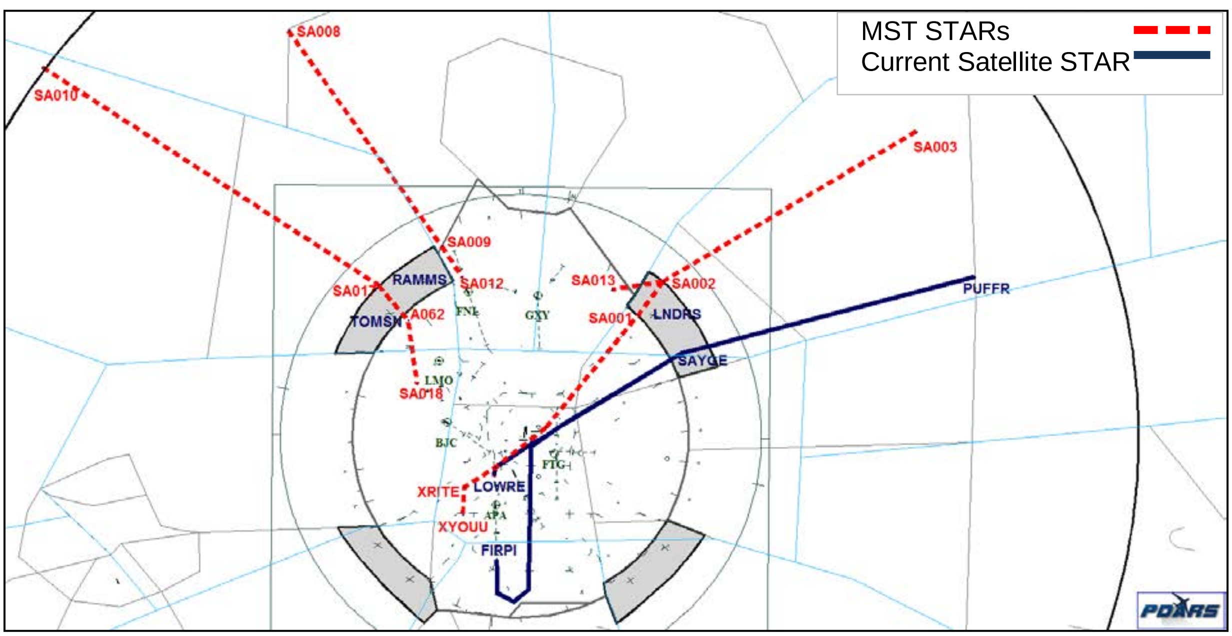

Figure 33. Current and Proposed NE and NW Satellite STARs

- Benefits
  - Cost benefit analysis was not performed for these procedures.

4.3.4 Denver Satellite Airport Departures Issues

The Denver satellite departure procedures were reviewed. Airports identified for inclusion into the Denver departure flows are:

- Centennial Airport (APA)
- Rocky Mountain Metropolitan Airport (BJC)
- Front Range Airport (FTG)
- Fort Collins - Loveland Municipal Airport (FNL)
- Greeley-Weld County Airport (GXY)
- Vance Brand (Longmont) Airport (LMO)

- Issues
  - Only four satellite airports have transitions onto DEN SIDS. GXY and LMO do not have published departure procedures that merge with DEN flows.
  - Not all satellite airports have RNAV SIDs.
  - Not all satellite airports have the same exit points as the DEN SIDs.
- Notional Solution
  - Due to time constraints, the MST opted to design one satellite Pilot Navigation Area (PNA) SID that would merge with the FOOOT DEN SID. The MST recommends that the D&I Team evaluate designing satellite SIDs that merge with all DEN SIDs or use the appropriate egress points as necessary.

Figure 34 depicts the proposed notional satellite PNA SID. The MST designed one SID as an example of what the D&I Team can expect to create during the design phase.

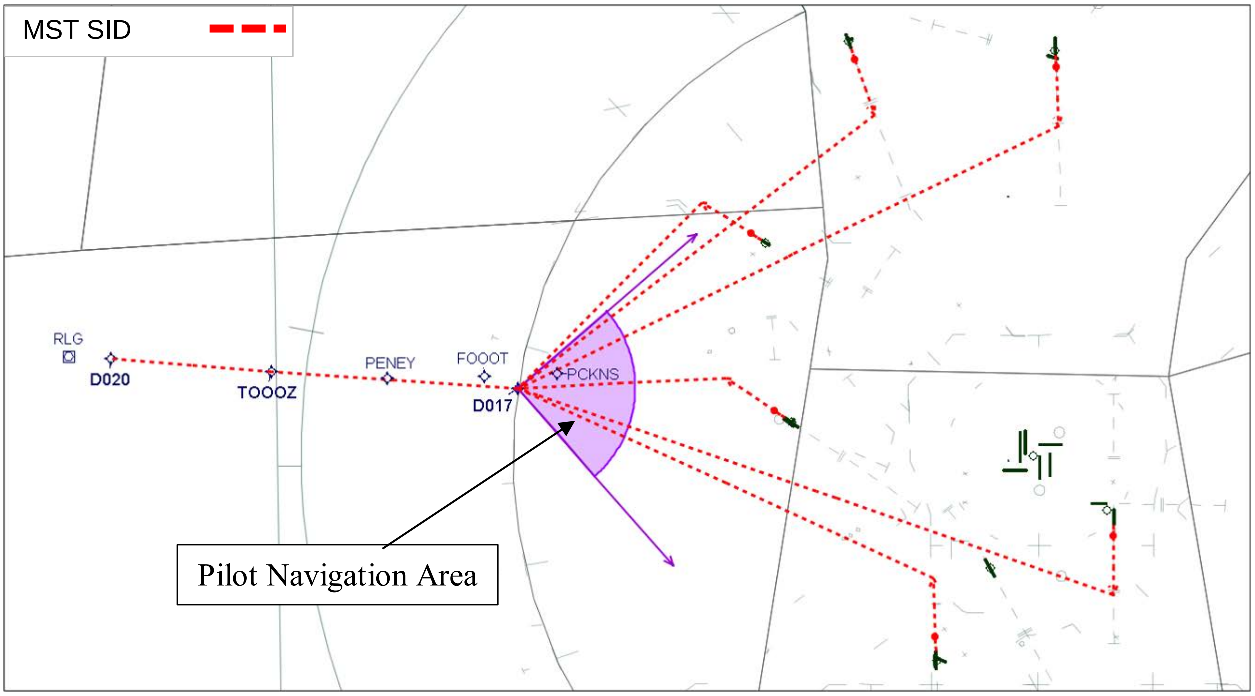

Figure 34. Proposed West PNA Satellite SID

- Benefits
  - Cost benefit analysis was not performed for this procedure.

4.3.5 D01 and ZDV Airspace Change Considerations

The MST proposed designs require considerations for D01 and ZDV to modify airspace in order to encompass the notional designs. Additional airspace considerations will need to be assessed throughout the D&I process as proposed designs are finalized. Figures 35 and 36 depict the sectors at ZDV that the MST identified as needing further airspace analysis.

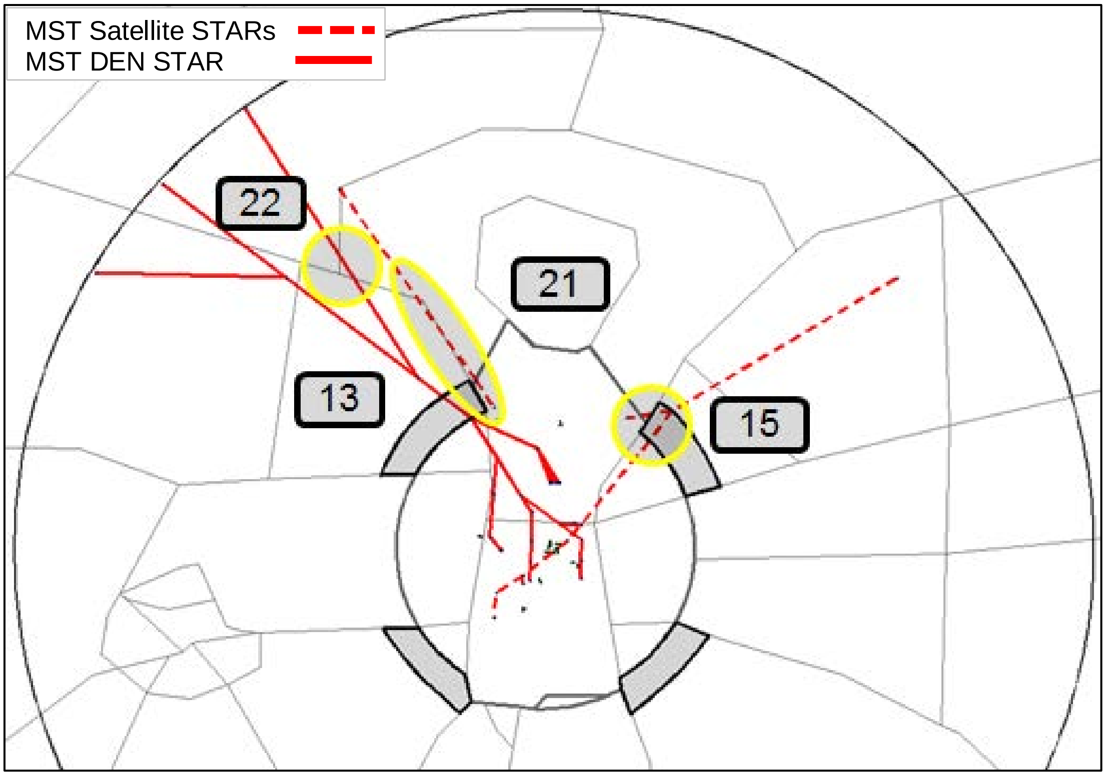

Figure 35. DEN and Satellite STARs Low Airspace Adjustments

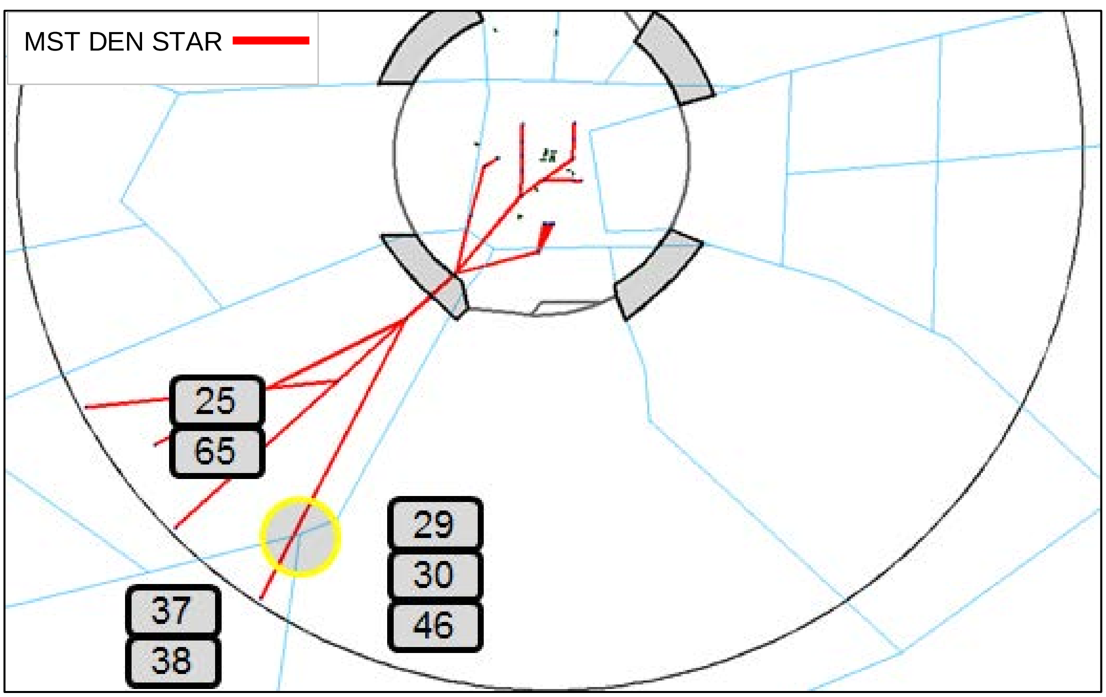

Figure 36. DEN STAR High/Ultra-High Airspace Adjustments

4.4 Industry Concerns

- Issues
  - Multiple clearance changes, vectors off STARs, rejoining STAR inside top of descent.
  - Takeoff clearances from DEN ATCT require use of RNAV off-the-ground phraseology mixed with radar vector assignments.
- Notional Solutions
  - Designed eight STARs with runway transitions.
  - Redesigned DEN SIDs utilizing RNAV off-the-ground procedures.

4.5 Out of Scope Issues

Additional issues were identified that were beyond the scope of the Denver MST and have been recorded for further consideration outside of the Metroplex process. The out of scope issues identified and recorded are summarized below.

- Airspace
  - Class B changes requiring rulemaking do not fit within the Metroplex timeline
- Criteria/National Programs
  - Mountainous terrain designation
  - 7110.65 phraseology changes
  - National Established on RNP (EoR) Program
- Airport infrastructure
  - New DEN runway placement
  - DEN Taxiway redesign
- Issues outside of Metroplex study area
  - GJT procedures

4.6 ASIAS Safety Issues

ASIAS has developed a radar based Traffic Alert and Collision Avoidance System (TCAS) Resolution Advisory (RA) metric which takes NOP radar tracks and passes them through a full TCAS II v7.0 logic engine to simulate TCAS RA events.

- Based on simulated NOP radar tracks, there exists a high rate of TCAS RA events for parallel approaches into DEN Runways 16L/R. The runways are separated by approximately 2,600 feet, but DEN elevation is 5,350 feet MSL and the terrain slopes upward from the north. These factors affect the TCAS sensitivity logic and allow a high rate of nuisance RAs.

- The simulated TCAS RA alerts at APA are mostly triggered close to the runway. General Aviation (GA) aircraft performing touch-and-goes account for a large number of these alerts. These alerts are possibly false positives due to their proximity to the runway.

The Aviation Safety Information Analysis and Sharing (ASIAS) program has a large database of voluntary pilot ASAP reports. Those reports have been aggregated for several safety issues. There are currently nine models applied to the pilot reports. Missed crossing restrictions and altitude deviations have the highest pilot-reported rates as captured by the ASIAS auto-classification model.

- There are several waypoints on DEN STAR procedures (e.g., JAGGR) that have different restrictions depending on the applicable STAR. These procedures contribute to a high missed crossing restriction (MCR) rate.
- There are procedures that have a high number of charted restrictions (e.g., ANCHR). These procedures contribute to a high MCR rate.
- There are procedures that have listed late runway changes as a contributor to MCR (e.g., KOHOE).

DEN has the third highest unstable approach rate below 500 feet in the ASIAS Flight Operational Quality Assurance (FOQA) data when compared to the core 30 airports. The unstable approach rate at DEN is seasonal, but appears to be trending downward over the April 2013–April 2014 timeframe.

The D&I Team will need to consider these identified safety concerns as part of the Metroplex process.

4.7 Q-Routes and T-Routes

To further optimize the Denver Metroplex airspace, it may become necessary during the D&I process to incorporate Q-routes and T-routes into the Metroplex design. These PBN routes may be developed to improve traffic flows into and out of the Denver Metroplex by optimizing the proposed procedures with adjacent facilities. As the FAA transitions to a foundational PBN service environment, the development of necessary Q-routes and T-routes is being coordinated through the FAA's PBN Policy and Support office, AJV-14. Other ongoing Metroplex sites, including Southern California, are already in the process of coordinating the development of their desired PBN routes. The Denver MST recommends that the D&I Team explore opportunities for synchronization with surrounding proposed and/or implemented PBN route structures.

4.8 Additional D&I Considerations

The MST identified and characterized a range of issues and developed a number of notional solutions; however, some require additional coordination and input that could not be addressed within the time constraints of the MST process. The MST recommends that these areas be further explored during the D&I process and are identified below.

- Playbook/swap routes will need to be addressed that incorporate route changes during weather and other events.
- Sectorization/airspace modifications should be assessed and completed.
- Incorporation of holding pattern placements and requirements for proposed procedures in both terminal and en route environments.
- TBFM initiatives will need to be incorporated into the DEN design.
- Review and design an APA "LOOOP" Departure. The initial SID provided to the MST will require more input from both industry and the facilities to continue further design work.
- Synchronization of ILS and RNAV Y approaches will need to be addressed to ensure fixes and altitudes match as necessary during procedure development.
- If necessary, modify DEN RNP procedures to align with proposed/finalized downwinds. Additionally, the Runway 17R RNP may need redesign to address any safety related issues.
- Inter and intra facility issues such as Letters of Agreement/Standard Operating Procedures (LOAs/SOPs) changes in conjunction with Metroplex designs.
- FUSION implementation.
- Ten degree course divergence for departures (ELSO).
- ASIAS safety concerns.

5 Summary of Benefits

5.1 Qualitative Benefits

The qualitative assessments are those benefits and improvements that the MST could not measure, but the implementation of the proposed solutions would provide immeasurable benefits to ATC and industry.

5.1.1 Near-Term Impacts

The benefits of the PBN procedures proposed by the MST include, but are not limited to the following:

- Reduced phraseology, frequency congestion, and pilot workload

  Reduced phraseology due to PBN will reduce the number of transmissions needed to accomplish required restrictions by combining multiple clearances into a single transmission. Prior studies have demonstrated transmission reductions on the order of 18% to 34% with 85% RNAV equipage,[7] and the MST believes it is reasonable to expect a similar level of savings. Reduced transmissions will translate into less frequency congestion which could potentially reduce "hear back/read back" errors. In addition, the consolidation of clearances associated with an RNAV procedure reduces pilot workload, which allows for more "heads-up" time and allows the crew to focus on high-workload situations.

- Repeatable, predictable flight paths and accurate fuel planning

  The predictable flight paths help assure procedurally segregated traffic flows and allow industry to more accurately plan for a consistent flight path. It also allows users to more accurately predict the amount of fuel required for a procedure.

- Enhanced lateral and vertical flight paths

  Optimized climbs and descents and shorter lateral paths reduce the number and length of level-offs and total distance flown, thereby reducing fuel burn and carbon emissions. Altitude windows can vertically separate traffic flows and allow for industry-standard glide paths.

5.1.2 Long-Term Impacts to Industry

Implementation of these proposed procedures will have long-term effects for industry.

- Flight planning

  Metroplex proposed procedures will result in reduced mileage and fuel burn in the long-term, particularly as more metroplexes are optimized. In the near-term, more

[7] Sprong, K., et al., June 2006, "Benefits Estimation of RNAV SIDs and STARs at Atlanta," F083-B06-020, (briefing), The MITRE Corporation, McLean, VA.

direct paths that are not dependent on ground-based navigational aids, plus optimized flight profiles, will lead to reduced fuel burn only within an optimized metroplex. Reduced fuel loading will also allow for a reduction in cost to carry.

- Timetable

  Shortened, more efficient routes will necessitate timetable adjustments, particularly as more metroplexes are optimized. This will potentially benefit crew scheduling, connecting information, time on gates, ramp scheduling, etc.

5.2 Quantitative Benefits

The quantified benefits of The Denver MST recommendations are divided into annual fuel savings in dollars, annual fuel savings in gallons, and annual carbon emissions reductions in metric tons. The primary benefits are improved vertical profiles and reduced miles flown.

Benefits from notional arrival procedures

- RNAV STARs with OPDs.
- More efficient lateral paths created by adjusting terminal entry points and removing doglegs.
- Removal of unused en route transitions and development of runway transitions.

Benefits from notional departure procedures

- A combination of RNAV off-the-ground procedures and radar vector procedures to join RNAV routes.
- Departure procedures designed to facilitate unrestricted climbs by mitigating existing level-offs.
- Procedurally segregate from other SIDs and STARs where practical.

Table 16 depicts the total benefits for Denver. The total potential annual fuel savings is estimated $2.8 million. These numbers were derived by comparing currently flown track miles, published procedure miles, and vertical profiles to proposed PBN procedure track miles and vertical profiles. The benefits analysis assumes aircraft will fly the specific lateral and vertical RNAV procedures. It is fully expected that ATC will continue to offer shorter routings and remove climb restrictions, when feasible, further increasing operator benefits.

Table 16. Denver MST Total Annual Benefits

DEN Notional Benefits		
Estimated Annual Fuel Savings	Fuel Burn (Distance and Profile)	$2.2M
	Cost to Carry	$597K
Total Estimated Annual Fuel Savings (Dollars)		$2.8M
Total Estimated Annual Fuel Savings (Gallons)		718K
Total Estimated Annual Carbon Savings (Metric Tons)		6,900

Appendix A: Acronyms

Acronyms	
ARTCC	Air Route Traffic Control Center
ASAP	Aviation Safety Action Program
ASIAS	Aviation Safety Information Analysis and Sharing
ASPM	Airport Specific Performance Metrics
ATALAB	Air Traffic Airspace Lab
ATC	Air Traffic Control
ATCT	Air Traffic Control Tower
ATSAP	Air Traffic Safety Action Program
BADA	Base of Aircraft Data
CTC	Cost to Carry
D&I	Design and Implementation
EA	Environmental Assessment
EIS	Environmental Impact Statement
ELSO	Equivalent Lateral Spacing Operation
EoR	Established on RNP
ETMS	Enhanced Traffic Management System
EUROCONTROL	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration
FL	Flight Level
FOQA	Flight Operational Quality Assurance
FPDG	Flight Pattern Distribution Generator
GA	General Aviation
IFR	Instrument Flight Rules
ILS	Instrument Landing System
L/R	Left/Right
LOA	Letter of Agreement
MCR	Missed Crossing Restriction

Acronyms	
MIT	Miles-in-Trail
MOA	Military Operations Area
MSL	Mean Sea Level
MST	Metroplex Study Team
NAT	National Analysis Team
NAVAID	Navigational Aid
NEPS	Noise Exposure Performance Standards
NM	Nautical Mile(s)
NOP	National Offload Program
NOTAM	Notice to Airmen
NTML	National Traffic Management Log
OPD	Optimized Profile Descent
PBN	Performance Based Navigation
PDARS	Performance Data Analysis and Reporting System
PNA	Pilot Navigation Area
RA	Resolution Advisory
RITA	Research and Innovative Technology Administration
RNAV	Area Navigation
RNP	Required Navigation Performance
ROM	Rough Order of Magnitude
RTCA	Radio Technical Commission for Aeronautics
SID	Standard Instrument Departure
SOP	Standard Operating Procedure
SRM	Safety Risk Management
STAR	Standard Terminal Arrival Route
SUA	Special Use Airspace
TARGETS	Terminal Area Route Generation Evaluation and Traffic Simulation
TBFM	Time-Based Flow Management
TCAS	Traffic Collision and Avoidance System

Acronyms	
TCP	Transfer of Control Point
TEM	Total Energy Model
TFMS	Traffic Flow Management System
TMI	Traffic Management Initiatives
VMC	Visual Meteorological Conditions

Appendix B: Examples of Integrated Airspace and PBN Toolbox

Sample Integrated Airspace and PBN Toolbox Options
Adding an arrival route
Adding a departure route
Extend departure routes
Build in procedural separation between routes
Reduce route conflicts between airports
Changing airspace to accommodate a new runway
Adding a parallel arrival route (to a new runway)
Splitting a departure fix that serves more than one jet airway
Increased use of 3 NM separation
Increased use of terminal separation rules
Static realignment or reassignment of airspace
Adaptive realignment or reassignment of airspace
Improving sector boundaries (sector split, boundary move, new area of specialization)
Shifting aircraft routing (Avoiding re-routes, shorter routes)
Eliminating altitude restrictions
More efficient holding (design, usage and management)
Adding surveillance coverage
Adding en route access points or other waypoint changes (NRS)
Adding en route routes
Reduce restrictions due to Special Use Airspace
TBFM initiatives