INTEGRATED RNAV PROCEDURE DESIGN: CITY-PAIR ANALYSIS

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Abstract

Potential benefits of Area Navigation (RNAV) to operating costs, airspace capacity, and environmental impact are well known. Unfortunately, several real-world RNAV implementations have underperformed benefits expectations. Integrated procedure design seeks to capitalize on the benefits of RNAV and mitigate some of the effects that reduce benefit. This paper focuses on integrating upstream and downstream constraints into procedure design to achieve this goal. It explains a general methodology for combining techniques, such as diverging departures and Q-routes during route development.

The method considers net capacity impact from one or more procedure revisions, using an origin-to-destination view. Some procedure modifications specifically considered include runway efficiency changes, additional egress points, and RNAV-based Q-routes. We present a specific case study with the method and show how it can account for mixed equipage, variable aircraft weight categories, and downstream route merging

Background

Performance-Based Navigation (PBN) in the National Airspace System (NAS) has been evolving for the last six years. PBN initiatives including Area Navigation (RNAV), Required Navigation Performance (RNP), and RNP Authorization Required (RNP AR), play an essential role in the evolution of the NAS to the Next Generation Air Transportation System (NextGen). Of the enabling technologies for NextGen, PBN is the most mature. Many commercial air carriers are currently well-equipped: over 95% of the aircraft of the 10 major airlines are RNAV equipped, 87% of all Part 121 carriers are RNAV equipped, 67% are RNP approach equipped, 40% are RNP AR equipped, while only 12% are RNP AR operationally capable. Moreover, all future commercial air carrier aircraft are being delivered fully equipped for PBN Operations.

The primary uses of PBN in the NAS are: RNAV En Route procedures (Q-Routes), RNAV Standard Instrument Departures (SIDs), RNAV Standard Terminal Arrivals (STARs), and RNP or RNP AR approaches. All PBN procedures provide improved lateral predictability, reduced controller workload, and many provide for access to runways and airports more efficiently than with conventional procedures. These procedures can also provide operational efficiencies resulting in significant monetary savings to the operators. However, the current implementations of the procedures are largely overlays of conventional routes. While overlays are foundational to the propagation of PBN initiatives in the NAS, they produce minimal operational efficiencies or monetary benefits. For continued growth in PBN, the use of these procedures must start to provide tangible benefits to the users of the NAS. Additionally, procedure development must evolve beyond basic overlays to utilize PBN advantages including: RNAV Optimized Profile Descents (OPD), improved airport flow, integrated arrival and departure procedures, increased predictability of operations, direct en route procedures, and more efficient use of airspace. Coordination and integrated development of PBN procedures is key to achieving these advantages.

To fully achieve these benefits, the participation of operators on PBN procedures and the continued development of new, beneficial procedures is required. The Integrated Procedure Design Concept is a means of furthering this development.

This initiative is a framework for integration of PBN features in all phases of flight from departure to approach. Successful implementation of the Integrated Procedure Design Concept includes:

- Utilization of additional Terminal Radar Approach Control (TRACON) ingress/egress points that are not tied to ground based navigational aids (NAVAIDS)
- Integrated Development of PBN SIDs and STARs, including OPDs

- Integrated City-Pair Design
- Decoupling of operations between primary and satellite airports in complex TRACONs

An analysis of the benefit of Integrated City-Pair Design is presented herein.

Overview of Integrated City-Pair Design

In today's NAS, one observes en route congestion between certain city pairs, as evidenced by the frequent need for traffic management initiatives, even in good weather conditions. With the Integrated City-Pair Design approach, RNAV/RNP procedures would be developed in a holistic manner, linking a departure procedure with a Q-route (perhaps via a new TRACON egress point) and then onto an arrival procedure. The navigation precision of RNAV/RNP enables the increased utilization of airspace and enhanced operational efficiency via:

- Decreased route deviation resulting in more closely spaced procedures
- Increased course predictability leading to increased use of diverging departures
- Increased airspace flexibility through utilization of ingress/ egress waypoints that are not tied to ground based NAVAIDS
- Decreased en route flight distance through use of direct Q-routes

The analysis below presents a new analytical capability developed by The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) to analyze the benefits of Integrated City-Pair Design. This capability was developed as part of CAASD's airspace analytical toolbox Integrated Terminal Research, Analysis, and Evaluation Capabilities (ITRAEC). To develop and validate this analytical capability, a case study is presented to:

- Evaluate existing radar track data to yield flow rates and distributions over fixes of interest
- Model a proposed improvement involving: diverging departures, a new TRACON egress point, and, entering en route airspace via a Q-route
- Analyze the operational benefit of the new procedure

In addition, the capability can easily be extended to analyze simulated flight tracks, for "what-if" modeling.

Regarding site selection for the case study, several locations around the NAS were considered for analysis: Atlanta, Denver, Potomac TRACON, and others. While it was easy to find highly trafficked city pairs, the best candidate to test this capability is one with departures concentrated to just a few destinations or directions. This provides a location where the addition of diverging departures and new egress points can be modeled together. After examination of the highest 8 or 10 destinations from various airports, it was decided that Salt Lake City (SLC) and its south departure flow would be a good case for a study. Figure 1 shows flight tracks for a 24-hour period in February 2009 departing SLC in a southerly direction (geographic boundaries outline the states.)

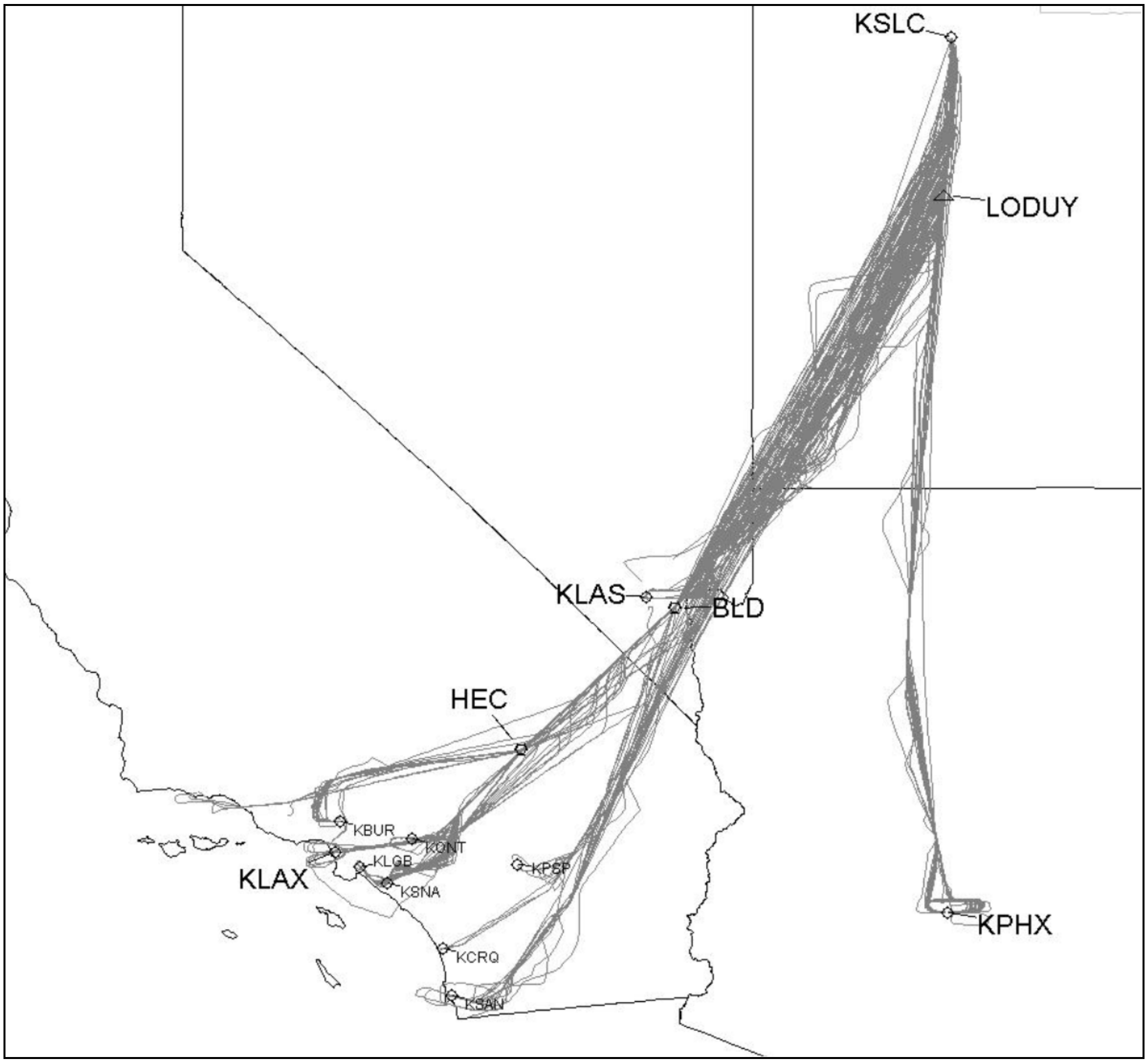

Figure 1. South Departure Flow out of Salt Lake City

Salt Lake City was chosen because it meets several of the selection criterion for a site that would yield benefits from Integrated City-Pair Design. First, it has a distinct flow that is utilized for city-pair routing. The south flow shown in Figure 1 is used by SLC to serve Phoenix Sky Harbor, Las Vegas McCarran, as well as airports in Southern California TRACON (SCT). Additionally, SLC only utilized one egress point for routing these flights. Finally, including the arrivals (in red) and all departures (in blue), Figure 2 shows that there is additional airspace in which the diverging departures can be routed. However, SLC misses one important criterion, namely, significant delay – this indicates that there is often ample capacity. Other, busier sites may exhibit greater benefit with improvements as described here. Despite this fact, SLC is still a good candidate to show the type of improvement one might experience with Integrated City-Pair Design.

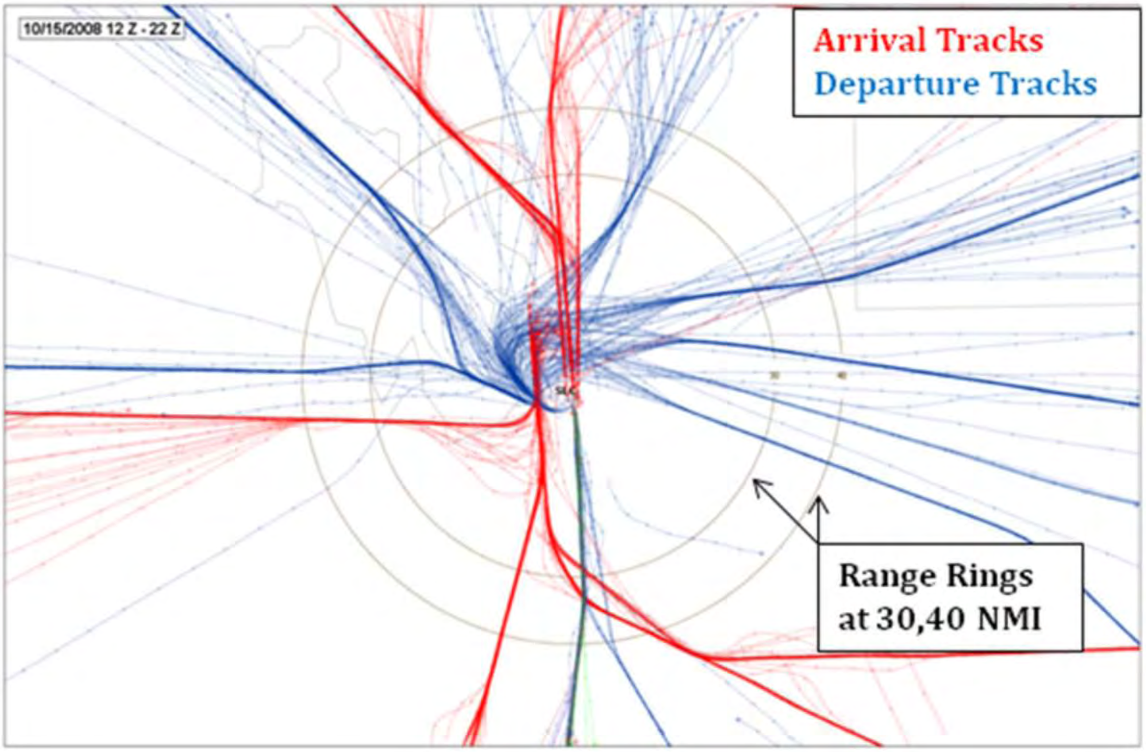

Figure 2. South Flow Departures at SLC with Arrivals

Goals

The goal of the Integrated City-Pair Design feature of the Integrated Procedure Design Concept is to establish more direct routing between city pairs, likely via Q-routes (to take advantage of RNAV/RNP capabilities), resulting in reduced congestion and flight paths with less distance. To connect the Q-route to the airport, the creation of additional TRACON egress/ingress points is considered. This improved integration of TRACON and en route procedures may: reduce delays, increase throughput, enhance predictability, enhance airport flow, and increase utilization of airspace.

Benefit Mechanisms

Integrated City-Pair Design is a technique that mitigates traffic congestion and reduces fuel consumption. By adding dedicated Q-routes between TRACONs that are tied to dedicated ingress/ egress points, traffic can be redirected from congested multi-destination routes and assigned shorter, more direct routes. This methodology differs due to the end-to-end integrated considerations. Rather than the evaluation of a Q-route, a SID, or a STAR, Integrated City-Pair Design identifies the benefit of all phases of flight to provide a complete benefit to the end-user.

For example, on the front end, flights need clearance to use the route. This may require re-routing by Air Traffic Control (ATC), compatible avionics, and/or specialized certification for the cockpit crew. ATC routing may cause some reduction in benefit to a flight in the form of increased flight distance.

On the other end of a Q-route, benefits are vulnerable to erosion at merge points. Traffic from a new Q-route will eventually need to merge with conventional traffic, either at the destination runway or earlier. If this merging necessitates a miles-in-trail restriction, it could erode or negate the benefit of a Q-route that would otherwise allow greater throughput at a lower fuel cost.

Terminal analytical capabilities at CAASD can be used to look at current and expected traffic usage of existing airways that would interact with a proposed new one. This can be as simple as looking at the nearest currently used diverge and merge points, or as detailed as looking at traffic from runway to runway. If the Q-route is constructed to be easy to enter and exit, it will be assigned to more flights and the fuel and capacity benefits will be maximized.

Technical Approach

Section 2 presents a detailed look at the analysis and design changes that will lead to increased capacity and fuel benefit from deployed Q-routes. There are two mechanisms used by Integrated City-Pair Design for Q-route implementation: A direct TRACON-to-TRACON Q-route to increase en route capacity and improve flow at each TRACON, and utilization of proposed airspace and airport design efforts.

Current operations were analyzed to predict the impact of different levels of participation on the new route. Currently observed utilization in the airspace surrounding each fix along each (current or proposed) route is calculated. Proposed increases or decreases in traffic along each route are then added to each fix. The changes can be a combination of overall growth as well as re-routing to use the proposed procedure. Generally this will model an increase on the proposed route and a decrease on the current route while providing an increase in throughput to the system as a whole.

Aircraft can even be segmented by capability if routes vary in equipage requirements. The feasibility of traffic levels at each fix can then be evaluated, and proposed routes can be modified if necessary to better balance expected fix utilization.

A second mechanism is to combine Q-route design with other proposed airspace or airport changes to estimate the impact of a combination of changes to a region. Techniques that can be combined with Q-route design include:

- Predicted fleet avionics upgrades
- A planned new runway
- A planned new operation
- Analysis of forecasted demand

In the following case study, the impact of a diverging departure operation on a new Q-route is considered.

Case Study

To illustrate the use of Integrated City-Pair Design, a study was performed on the impact of a new SID enabling diverging departure operation which links to a new Q-route for traffic from SLC to SCT. Operations traveling from SLC to SCT, currently utilizing the WEVIC One SID will be placed onto a new route that is tied to a direct Q-route. This new route saves 11 nautical miles of flight distance compared to the current route. These two routes can be seen in Figure 3, with the new route consisting of fixes GREEN01 through GREEN09 and ending with a merge over BLD. The proposed new route is plausible, obeying special use airspace restrictions and accounting for current traffic usage, but has not been operationally validated.

This analysis will show the potential usage and impact of the new route on the current operations. This will accurately assess the benefit of this procedure as an opportunity to mitigate overused airspace (previous route). This methodology, while demonstrated on one flow at SLC, is extensible to any location in the NAS.

Figure 3 also shows south departures from SLC during a twenty-four hour period in February 2009. Note that some traffic along WEVIC One diverges east at the WEVIC fix, and more traffic diverges south at the URNUW fix. It will be seen that a Q-route towards SCT can increase capacity along these routes by increasing available capacity for departures towards HOPTO. The full analysis below considers traffic from February 15, 2009 through February 21, 2009.

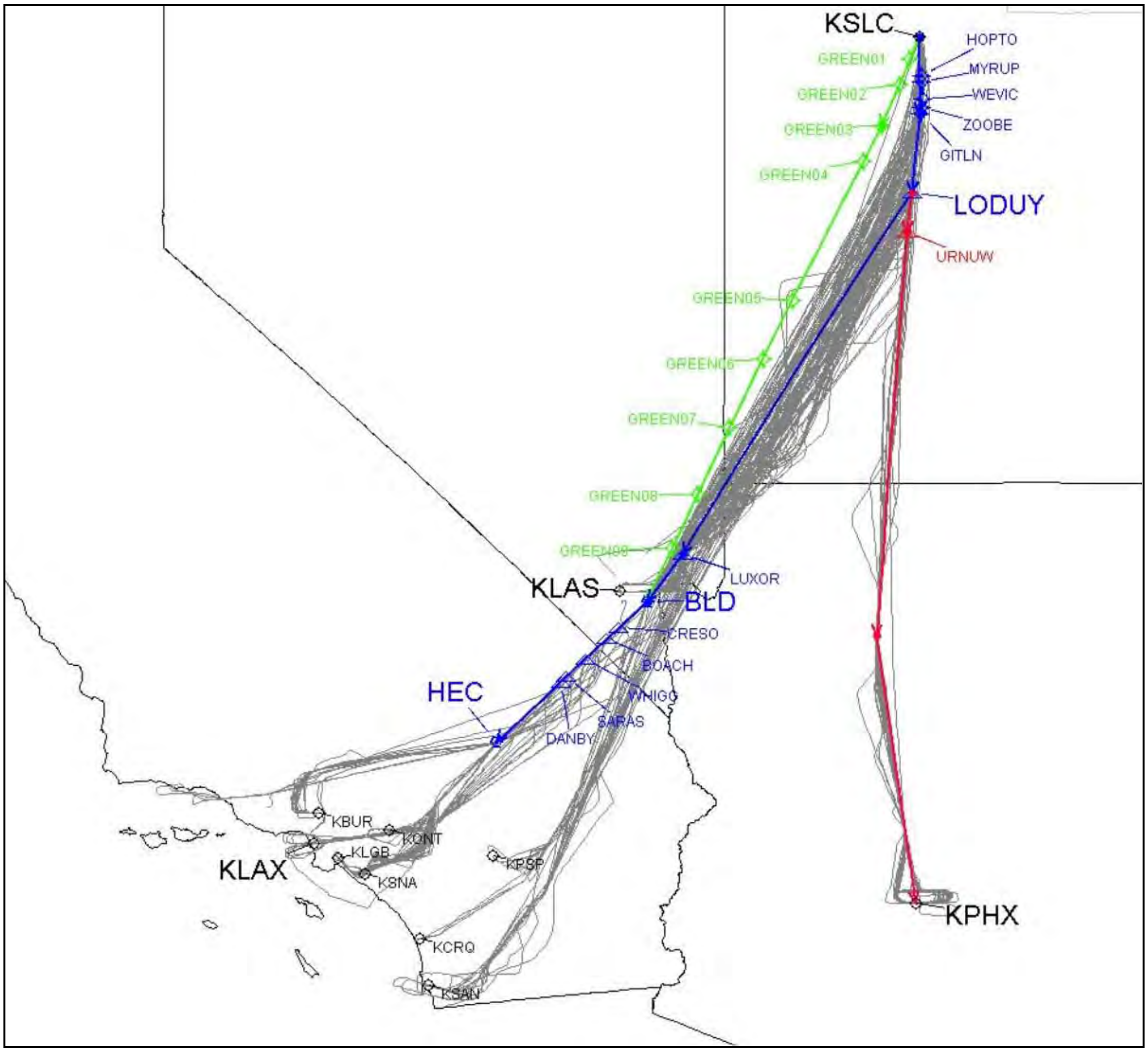

Figure 3. Proposed Q-Route (in green) plus South Flow

Figures 4a and 4b show, respectively, current traffic levels along the current route and the proposed route at each fix. For the purposes of this example, only flights that departed south from SLC were considered, though this methodology can be extended to examine all flights.

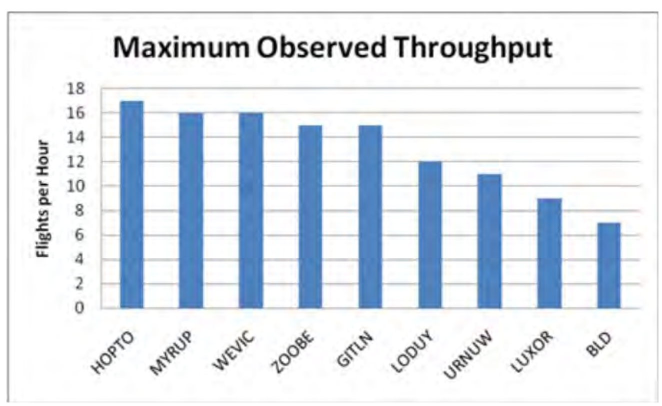

Figure 4a. Current Maximum Hourly Traffic on Current Route

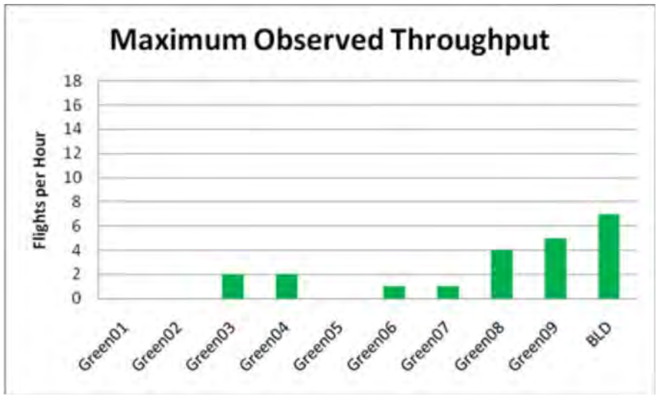

Figure 4b. Current Maximum Traffic in Airspace of New Route

For this analysis, input is required to understand which aircraft would be capable of flying a new Q-route. Since the Q-routes are inherently RNAV, it is important to know that 96 percent of SLC flights are currently equipped capable for RNAV [1]. Additionally, 60 percent of the south bound departures travel towards SCT and may utilize this Q-route. This data, along with the fleet mix at SLC is required to fully understand the benefit of a new Q-route.

Simultaneous route improvements are often preferred since they can make good use of resources and increase the flexibility of benefits. In this scenario, the diverging departure procedure was developed at the same time as the new Q-route. The impact on the current and proposed routes can be seen by predicting the increase in traffic throughput from diverging departures.

Based on extensive studies of diverging departures and the fleet mix at SLC, a prediction is made on how many additional flights per hour can be launched by using diverging departures [2]. By using an egress point to link flights diverging west directly to the new Q-route, capacity gain is maximized while minimizing the air traffic controller work load along the current route. An idealized case with minimal wake separation requirements, full equipage, and serendipitous destination choices is summarized in Figure 5, along with a more realistic case using separation requirements for the actual fleet mix, the current equipage levels, and the current ratios of SCT to non-SCT destinations.

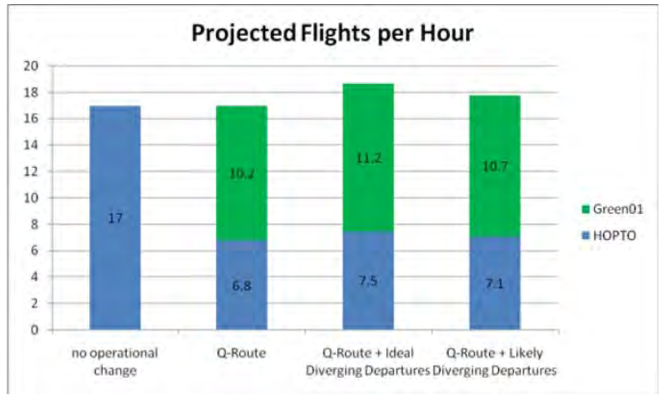

Figure 5. Projected Traffic Levels at Two Fixes

Figure 5 shows a utilization decrease on the old route and a net gain of just under one flight per hour under the likely diverging departures condition. It is also seen that the current airspace which will be used by the proposed route is not uniformly utilized. Using our estimate for the utilization of the route, our designers could confirm that current traffic plus predicted traffic at each of these fixes is still a viable amount. Since the Q-route is not bound to any ground stations, the route can be easily modified by designers to avoid airspace that would become overly congested. While one flight per hour may not seem like a large increase, since SLC is not currently operating at peak demand, these scenarios allow for under utilization of the total capacity. Sites with higher scheduled demand would achieve higher throughput.

Next Steps

The analysis tool has been developed and demonstrated for a single situation. The next step would be to pursue an initial field demonstration. Two approaches for site selection are envisioned. As has been performed for other proposed capabilities, a list of promising candidates could be generated, and then, via modeling, rank-ordered in terms of probable benefit. Another approach would be to look specifically at one or two sites as suggested by the Federal Aviation Administration (FAA) – these sites would be modeled in detail, using several different Integrated Procedure Design Concepts. One or more field site visits would be necessary to understand the local operations and to build consensus toward an initial implementation. This second approach could lead to a more rapid adaptation of the Integrated City-Pair Design concept into the NAS.

References

[1] Devlin, Chris, Scott Williams, 2008, Performance Based Navigation Capability Report 2008, The MITRE Corporation, McLean, VA, Available from: http://mitrecaasd.org/PBNCapabilityReport/.

[2] Shresta, Sanjiv, et al., August 2008, Terminal Separation Analysis: Measurement, Characterization and Capacity Estimation, MTR 080232, The MITRE Corporation, McLean, VA.

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