RUNWAY INCURSION STUDIES IN NASA'S FUTURE FLIGHT CENTRAL

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Abstract

In recent years the Federal Aviation Administration (FAA) has made reduction of runway incursions a priority for surface operations throughout the national airspace system. In a series of experiments conducted in April 2001, NASA studied alternatives designed to improve the efficient movement of surface traffic and reduce runway incursions at Los Angeles International Airport (LAX). The experiments were conducted in NASA Ames Research Center's FutureFlight Central (FFC), a full virtual reality air traffic control tower cab simulator. This paper details the lifecycle of the safety studies from design to execution, describes the alternatives that were proposed for runway incursion reduction, and offers a brief summary of the experiment results.

Nomenclature

AAR	Airport Arrival Rate
ASDE-X	Airport Surface Detection Equipment Next Generation Version X
ATC	Air Traffic Control
ATIS	Automated Terminal Information System
ATSP	Air Traffic Service Provider
D-BRITE	Digital Bright Radar Indicator Tower Equipment
FFC	FutureFlight Central
LAWA	Los Angeles World Airports
NAS	National Airspace System
NATCA	National Air Traffic Controllers Association
STA	Scheduled Time of Arrival
TRACON	Terminal Radar Approach Control
TMC	Traffic Management Coordinator

Introduction

In 2001 the FAA Office of Runway Safety released a report summarizing the number and severity of runway incursion events at towered airports in the United States between 1997 and 2000. According to the report, the national airspace system managed approximately 266 million flights over that period, 1,369 of which resulted in a runway incursion, approximately five incursions for every 1 million operations. The number of incursions increased by 110 events the following year.[1]

The FAA and the Los Angeles World Airports (LAWA), operator of LAX, commissioned a series of studies in NASA's FutureFlight Central tower cab simulator in 2001 to explore alternatives designed to reduce runway incursions at LAX, which is the nation's fourth busiest airport. While air traffic demand for LAX has increased over the past ten years, there has been no corresponding increase in airfield capacity. Numerous changes to airborne and on-ground operating procedures, runway and taxiway markings, and airport lighting have been implemented to better manage traffic flow. Despite these efforts LAX reported 19 runway incursions in 2000, with "deviations from FAA clearances" - the second most frequently violated regulation (c.f. FAR 91.123(a) - recognized as a major contributing factor.[1]

The goal of the two-phase FFC study was to elicit feedback from LAX controllers on six proposed runway incursion reduction alternatives. Working closely with LAWA personnel, LAX controllers, and representatives from United Airlines, FFC engineers recreated LAX for the experiments, not only the out-the-window view of the airfield from the tower, but also traffic flow scenarios that mimic the airport's day-to-day operations, both on the surface and in the terminal area.

This paper follows the development lifecycle and execution of the two LAX experiments. The authors will provide an abbreviated summary of experiment results; a comprehensive summary may be found under separate documentation.[2] A brief introduction to the FutureFlight Central facility is provided for clarity.

Overview of FutureFlight Central

Located at the NASA Ames Research Center, Moffett Field, California, FutureFlight Central uses twelve rear-projection screens and computer generated imagery to create a 360-degree “out-the-window” representation of an airfield and its environs as seen from the tower cab. FFC’s image generator is an SGI, Incorporated Onyx 2 Reality Monster computer configured with six graphics engines and 16 processors that provide a nominal 30Hz update rate.

FFC’s lower floor Operations Center is comprised of three main areas: the Pseudo-pilot Room, Test Engineer Room, and the Operations/Ramp Control Room.

The Pseudo-Pilot Room hosts thirteen pilot stations, each with a 2-D map display of the airport surface on a 21-inch, color high-resolution monitor. This display is the pilot’s interface to the aircraft in his or her area of responsibility; from here, the pilot controls aircraft speed, heading, taxi routing, gate operation (push-back, taxi-in), runway operation, departure profile, and arrival routing, among other parameters. A flight may be moved to any position on the airport surface that has been defined for the operation, and fine adjustments to the aircraft position are possible. A pilot is able, for example, to comply with a controller’s direction to exit the runway at a given high-speed taxiway, taxi forward for maximum spacing, and hold short of the active parallel.

The pilot communicates with tower and/or ramp controllers via voice communications system (VCS) located at the station. The VCS emulates standard radio communication; each pseudo-pilot has the ability to transmit and receive on appropriate frequencies (ramp, ground, local, departure) as the flight progresses through the area of positive control. Frequency values match those of the airport that is currently being simulated.

The Test Engineer's Room is the control center for all of the facility’s audio/visual and simulation systems, and the facility’s data collection and reduction equipment is located here as well. The Test Engineer is connected via VCS to all other participants in the simulation, and is responsible for starting and stopping the simulation software. Next to the Test Engineer’s Room is the Operations/Ramp Control Room, which can be configured to simulate an airline ramp control operations center.

The upper floor of the FFC facility accommodates the projection display system and the air traffic control tower cab. The tower cab is modular and can be configured to match the layout of the airport tower being simulated. Recessed into the perimeter console are 16-inch, flat panel touch screens on which radar equipment, wind indicators, clocks, and altimeters are simulated. Flight progress strips and container banks are provided, along with Digital Bright Radar Indicator Tower

Equipment (D-BRITE) monitors, and multiple VCS plug panels at each station. Figure 1 is a view of the inside of the FFC tower cab.

Figure 1: The FFC Tower Cab

Recreating LAX in the FFC Tower

As mentioned above, the FFC tower cab provides a 360-degree representation of an airfield as seen from any eye-point; for the purposes of the LAX experiments, the eye-point was located at the center of the air traffic control tower cab. The 3D model of the out-the-window view was based on computer aided design (CAD) drawings provided by the LAX airport engineering department, and overlaid with high-resolution aerial photographs to provide a high-fidelity representation of the airfield as viewed from the tower. Figure 2, below, is a comparison of actual and simulated views from the LAX tower.

Horizon features (buildings, freeways, etc.) were modeled for realism and visual orientation. Although air traffic associated with the Los Angeles basin’s other airports is often visible from the LAX tower, no overflights were simulated. Ground vehicle traffic movement was not simulated, with the exception of aircraft tugs for pushback operations. Refer to Figure 3 for an LAX airport diagram, including typical arrival/departure traffic flow markers.

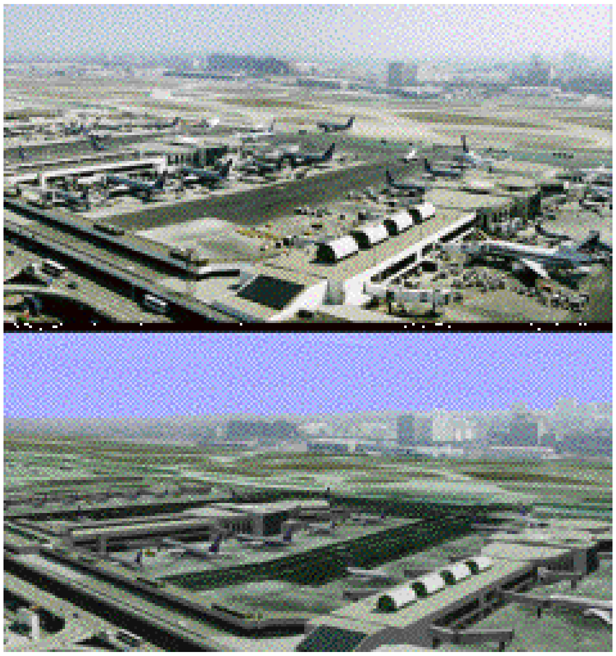


Figure 2: Comparison of Actual and Simulated Views from the LAX Tower

Controller Staffing and Responsibilities in the FFC Tower

In preparation for the LAX experiments, FFC engineers visited the airport to study the layout of LAX's control tower and record information about controller staffing, the type and positions of various tower tools, and the physical placement of controller positions relative to the out-the-window view of the airfield. Observations about airport demand, traffic flow and surface congestion points were used to determine pseudo-pilot staffing requirements and responsibilities for the tests.

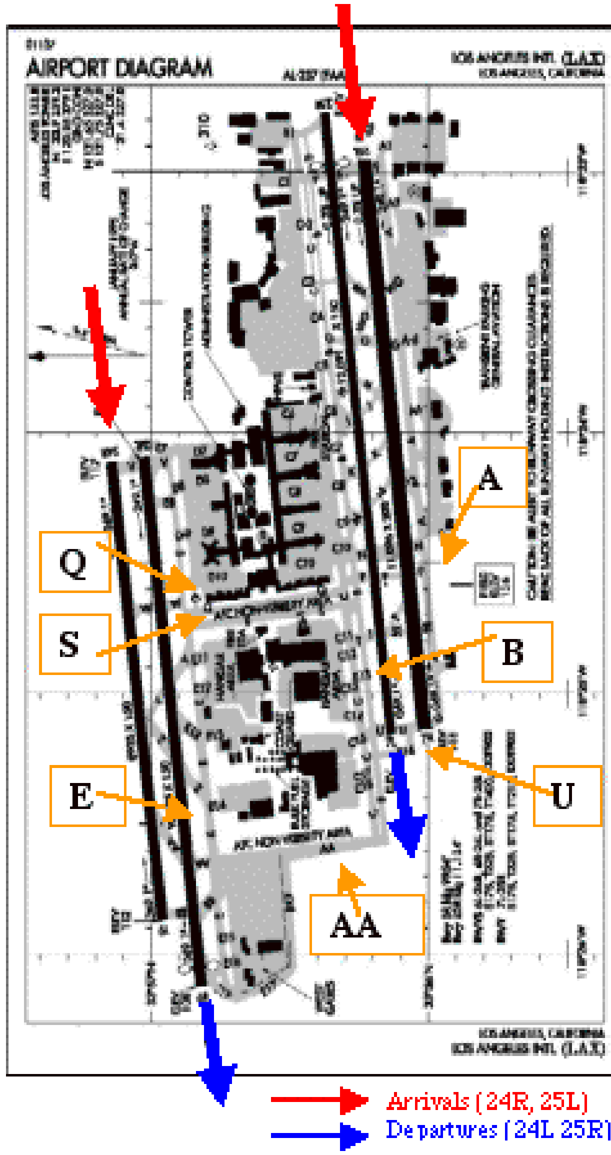
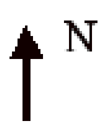


Figure 3: LAX Airport Diagram

Normal staffing for the LAX tower includes three local controllers (Local One, Two, and Three), three ground controllers (Ground One, Two, and Three), a clearance delivery specialist, and a Traffic Management Coordinator (TMC). Only the Local and Ground positions were staffed for the LAX experiments. Five full performance level controllers currently on staff at LAX attended the experiments to rotate through the tower positions for the tests.

Refer to Figure 4 for a diagram of controller positions in the virtual tower.



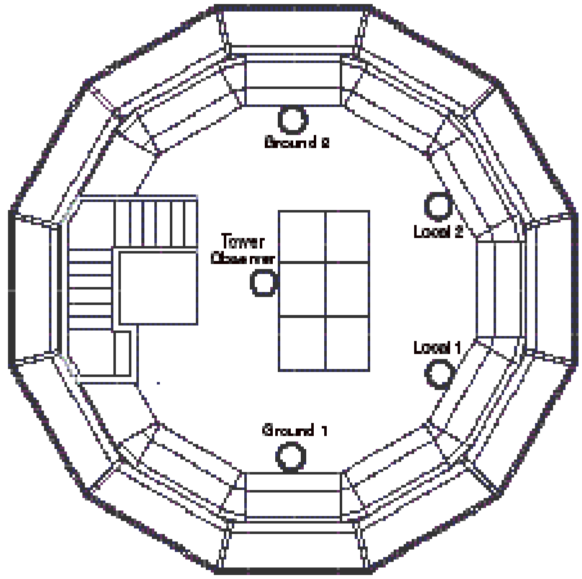


Figure 4: Controller Positions in the Virtual Tower

FFC Personnel Training and Staffing

In addition to the five LAX controllers, 20 people were needed to staff each experiment run, including 17 pseudo-pilots, one test engineer, and two pseudo-pilot coordinators. Of particular importance to the successful execution of the experiment scenarios was training the pseudo-pilots to become comfortable with the controllers' rapid speech delivery and shorthand clearances. Having LAX controllers attend dry run sessions before the actual experiment dates was helpful in this regard.

Pseudo-pilots communicated with controllers on LAX frequencies using standard ATC phraseology. In addition to this standard phraseology, controllers were able to issue the "shorthand" taxi clearances which they have developed with the airlines at LAX. The pseudo-pilots had been trained, for example, to recognize clearances involving the "Bridge Route," or the "North Route," thus eliminating the need for lengthy taxi instructions and alleviating frequency congestion.

Pseudo-pilots were also instructed to advise possession of current ATIS information on initial contact with controllers.

Scenario Design

Key to the success of the experiments was the design of realistic and challenging traffic scenarios which presented controllers with problems identical to those they solve on a daily basis at LAX: runway crossing restrictions, wake turbulence delays, heavy taxi-in/taxi-out delays, long departure queues, and the like. With these considerations in mind the FFC engineers designed two 45-minute traffic scenarios:

- Peak Arrivals: 92 arrivals/78 departures originating either in the departure queue, airline gate, alleyway, or in flight
- Peak Departures: 62 arrivals/107 departures originating either in the departure queue, airline gate, alleyway, or in flight

Each of the alternatives was tested under both conditions. The mix of traffic included flights from American, Southwest, United, Delta, Qantas, Hawaiian and SkyWest air carriers; a total of 22 airlines was represented. FFC visual database engineers provided liveries and aircraft type models appropriate to each airline's fleet.

Gate assignments were determined with the help of airline consultants and through observations made by FFC engineers during site visits to LAX. The intent of these observations was to identify allowable gate assignments based on airline and aircraft type information and to provide a comprehensive, realistic gate assignment rationale for the airport.

All parties agreed not to simulate ramp control, ground vehicle traffic, and maintenance tows for the experiments. Although this decision reduced the complexity of the airport simulation, the parties agreed to narrow the experiment focus to safety and operations in the airport movement areas only.

Experiment Phase 1 Purpose and Key Findings

The purpose of the Phase 1 experiments was to validate the LAX recreation and to elicit controller feedback as to the efficacy of the Peak Arrival and Peak Departure traffic scenarios. The results of the Phase 1 evaluations were to have a direct bearing on preparations for the Phase 2 tests.

Results of the Phase 1 tests revealed that the LAX controllers found the FFC simulation to be an accurate recreation of their airport environment, taking into consideration the simulation constraints and modifications agreed upon by the participants.

Specific feedback included the following:

- Controllers rated their workload as "about the same" as LAX
- Controllers rated the realism of the simulation as "about the same" as LAX
- The simulation successfully tasked controllers with the highest sustained traffic arrival and departure rates experienced at LAX
- Controllers requested that additional flights be included at the start of each scenario for increased workload and realism
- Outbound taxi times were accurate within 1-2 minutes of LAX times for aircraft originating in the north and south complex gates (approximately 82% of the total flights in the simulation)
- Runway occupancy times were within three seconds of corresponding LAX times for the

inboard runways (24L, 25R), although the FFC occupancy times were longer than LAX times
- Duration of voice transmissions was on average 5-8% longer at FFC
- An average of 10-15% fewer voice transmissions per hour was accomplished at FFC as opposed to LAX [2]

Feedback from the controllers proved that FFC engineers had been successful in recreating realistic traffic scenarios for the simulations. Controllers reported becoming involved in the problem at hand, working traffic and making sequencing decisions as if the aircraft out the window were real. With the Phase 1 results in mind, FFC engineers completed modifications to the experiment scenarios and proceeded with preparations for the Phase 2 tests.

Phase 2 Experiment Objective and Subjective Measures

Three types of test data were collected during each Phase 2 experiment run: controller subjective measures, airport operations statistical data, and controller voice communication data.

FFC test engineers collected subjective measures in an eight-question survey completed by participants after each experiment run. For each question, FFC data reduction engineers calculated the mean rating and standard deviation by controller position. For questions one through seven, controllers were asked to evaluate the proposed alternative in terms of the following parameters:

- Overall efficiency
- Potential for runway incursion
- Traffic complexity
- Manageability of traffic flow
- Communication
- Coordination

A 1-5 scale was used for the survey, where a value of 3 indicated that the alternative resulted in an operational complexity “about the same” as current LAX operations, and a value of 1 corresponded to a “worse than LAX today” rating.

For question eight, controllers were presented with six operational criteria and asked to select up to three to indicate the most challenging aspects of each alternative. The total number of occurrences for each criterion was divided by the total number of forms filled out for any particular alternative. The resulting value indicated how frequently this criterion was marked as critical across all positions.

Airport operations data was collected in order to compare the baseline LAX operation with the alternative scenarios. FFC engineers compared average arrival rates, average departure rates, average inbound taxi times by route, and average outbound taxi times by route against baseline

LAX values.

Finally, controller voice communication data was recorded for post-simulation analysis of controller-pilot time-on-frequency, and the type and duration of controller-to-controller communication for the separate alternatives.

Phase 2 Experiment Proposed Alternatives

The primary objective of the Phase 2 experiments was to evaluate "... air traffic control techniques, pilot procedures, airfield pavement geometry, and traffic management solutions to help eliminate runway incursions at LAX."[3] As in the Phase 1 experiments, controllers were to provide subjective feedback about each of the alternatives, and FFC engineers were to collect objective measures such as total taxi time, time on frequency, throughput, and aggregate delay. A comprehensive summary of results from the Phase 2 experiments may be found under separate documentation; see reference [2].

Six alternatives were tested during Phase 2:

- Alternative 1: Swapping Inboard and Outboard Runway Operations
- Alternative 2: Adding a Second Local Controller to the South Side Operations Position
- Alternative 3: Using the Proposed B-16 Extension with AA Taxiway (One-way)
- Alternative 3a: Using the B-16 Extension with the Bridge Route Open
- Alternative 4: Using the B-16 Extension, Controller Discretion
- Alternative 5: Using the B-16 Extension with Two Local Controllers on South Side Operation

The proposed B-16 taxiway extension is diagrammed in the figures below. Currently under consideration by airport planners, this extension will allow controllers to route south side arrivals to the north and south gate complexes without staging flights on the high speed taxiways between runways 25L and 25R.

The following sections will detail each of the alternatives and provide a brief summary of experiment results for each.

Alternative 1: Swapping Inboard and Outboard Operations

Alternative 1 explored the ramifications of swapping arrival/departure runways at the airfield. LAX typically handles arrivals on the outboard runways (25L, 24R) and departures on the inboards (25R, 24L). In Alternative 1 these operations were reversed, although controllers had the option of reverting to the standard LAX operation on a per-flight basis, depending on traffic demand.

Data collected from Alternative 1 objective and subjective measures indicated that, in comparison with baseline LAX operations, swapping the inboard and outboard runways resulted in a reduction of overall taxi times and increased the airport departure rate by about nine percent. Participants felt that Alternative 1 raised the overall complexity of the airport operation for local controllers and in general lowered the complexity level for ground controllers. The mean ratings for communication criteria and controller subjective comments indicate that Alternative 1 increased the amount of inter-controller and pilot-controller communications.

Finally, controller subjective data indicated that the potential for runway incursions under this alternative remained “about the same” on the south side of the airport, and decreased slightly on the north side.

<u>Alternative 2: Adding a Second Local Controller to the South Side Operations Position</u>

Under Alternative 2, control of runways 25R and 25L was split between two local controllers, LC-1 and LC-3 respectively. The LC-3 controller coordinated crossing of the inboard runway with LC-1 internally and communicated these clearances to pilots.

After the first week of the Phase 2 testing, participants from FAA, LAWA, and United Airlines requested that NASA discontinue consideration of Alternative 2 as a viable option since controllers and observers both agreed that this option significantly increased coordination between tower positions without reducing the possibility of runway incursion.

<u>Alternative 3: Using the Proposed B-16 Extension with AA Taxiway (One-way)</u>

Alternative 3 was the first to make use of the proposed extension to taxiway Bravo, “B-16”. Under this alternative, all aircraft arriving runway 25L were to turn left onto taxiway Alpha and proceed to the B-16 extension, thus eliminating the need to stage flights between the parallel runways for crossing to the north and south complexes. Pilots were instructed to remain with local control until reaching taxiway Uniform, at which time they were to contact ground control.

Flights bound for the north complex from the south runways were to taxi via AA and contact north ground control at checkpoint 3 (see Figure 5); south complex arrivals were to taxi via B and monitor south ground for instructions.

The Bridge Route (i.e., AA southbound) was closed to aircraft arriving runways 24L and 24R bound for the south complex. These flights were instead directed along the South Route (taxiway Sierra).

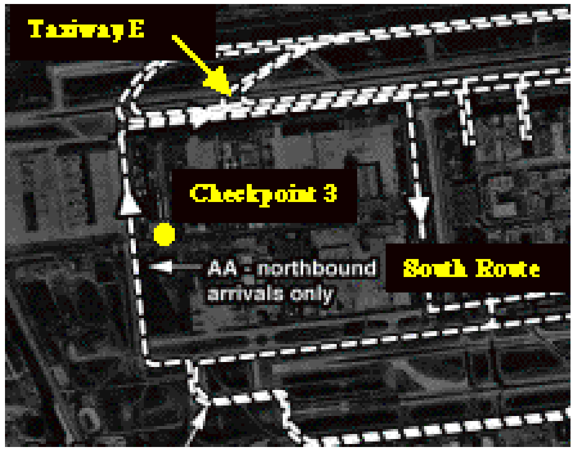


Figure 5: Alternate 3 Operations

After the first week of the Phase 2 testing, participants from FAA, LAWA, and United Airlines requested that NASA discontinue consideration of Alternative 3 since controllers and observers both agreed that this option increased congestion on taxiway Echo to the point of gridlock, due to the flow restrictions imposed on the AA taxiway.

Alternative 3a: Using the Proposed B-16 Extension with the Bridge Route Open

Alternative 3a was a requested modification to Alternative 3, in an attempt to improve traffic flow and workload distribution between north and south arrival ground controllers. Aircraft arriving runway 25L were to turn left onto taxiway Alpha and proceed to the B-16 extension, and contact ground control upon reaching taxiway Uniform. At the ground controller's discretion, flights bound for the north complex were routed along either AA or Quebec taxiways; aircraft parking at the south complex were routed to taxiway Bravo (see Figure 6 and Figure 3). The Bridge Route was open.

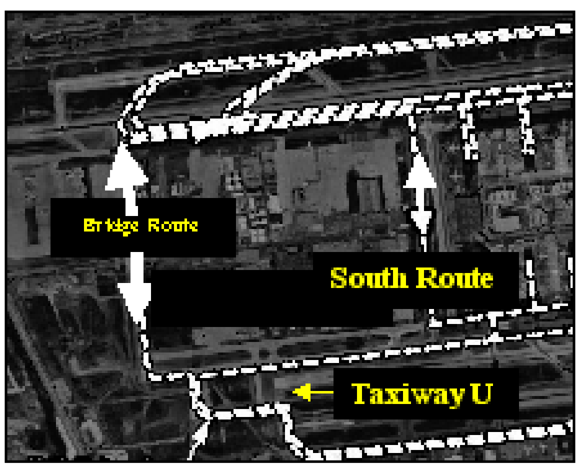


Figure 6: Alternate 3a Operations

Subjectively, controllers rated Alternative 3a better, or slightly higher than current LAX operations. Controllers considered traffic flow “easier to manage” overall, with the exception of the south local one controller position, which was rated “more difficult” to manage under Alternative 3a operations.

Alternative 3a taxi times on arrivals from the south runways to the south complex were 85% higher than the baseline taxi times, and 8% higher from the south runways to the north complex. Arrival taxi times from the north runways to both north and south complexes were 15% lower than baseline values.

Voice data analysis revealed that the amount of controller-pilot communication at the south local control position was “about the same” as for the baseline, while the corresponding ground control position required less communication.

Controller subjective data indicated that the potential for runway incursions under this alternative was significantly reduced when compared to the baseline LAX operation.

<u>Alternative 4: Using the B-16 Extension, Controller Discretion</u>

Under Alternative 4 controllers were given discretion over the use of the B-16 extension. For 25L arrivals, if the controller felt that a flight could cross 25R without holding short for other traffic, the Juliet and Kilo high-speed taxiways were used. If the controller anticipated having to issue a hold short instruction, the Alpha taxiway and B-16 extension were used.

South arrivals bound for the north complex were routed either via AA or taxiway Quebec at the south ground controller's discretion. Traffic bound for AA was directed to hold short of AA and contact north arrival ground before proceeding. South arrivals to the south complex were routed along taxiway Bravo. Refer to Figure 7 for a diagram of Alternative 4 traffic flow.

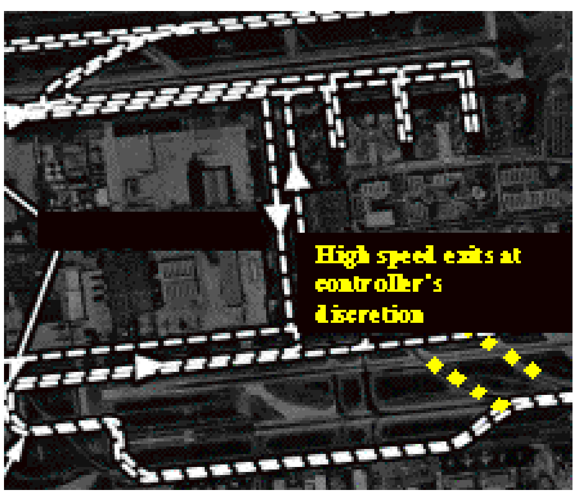


Figure 7: Alternate 4 Operations

Controllers rated Alternative 4 traffic flow generally “about the same” as LAX baseline operations. The LC-1 position was rated “slightly easier to manage” than baseline operations and the GC-3 workload increased slightly. According to controllers, this increase can be attributed to the need for additional coordination with local control as flights transition from the south side of the airport to the north complex. Taking flights along the Bravo taxiway via the B-16 extension resulted in generally longer taxi times, which increased controller workload.

Routing arrivals along the B-16 extension instead of staging them on the Juliet and Kilo high-speed exits resulted in a 57% increase in taxi times for south arrivals to the south complex. Taxi times for south arrivals to the north gates were 16% higher relative to the baseline. North arrivals to the south complex recorded a 27% decrease in taxi times, and north arrivals to the north complex recorded a 22% decrease compared to the baseline.

Departure taxi times for the south runways for flights originating in the south complex were reduced by 15% as compared to baseline values. Departures originating in the south complex bound for the north runways recorded a 20% reduction in average taxi time, while north runway departures originating in the north complex recorded no significant change in taxi time.

In general, the amount of controller-pilot communication for Alternative 4 was judged to be "about the same" as that required during baseline operations.

Alternative 5: Using the B-16 Extension with Two Local Controllers on the South Side Operation

In Alternative 5 control of the south runway complex was split between two local positions, LC-1 and LC-3. LC-1 controlled 25R and LC-3 controlled 25L. The traffic flow rationale from Alternative 3a (B-16 extension in use, Bridge Route open) was used for Alternative 5 as well.

Subjectively, all controllers except the south ground control GC-1 position rated Alternative 5 "a better operational environment" than LAX baseline operations. GC-1 controllers indicated that aircraft were on taxiways for longer periods of time and therefore required more coordination. One GC-1 controller remarked that Alternative 5 operations resulted in fewer runway crossings, but "too much [traffic] to look at" on the west end of the field. All controllers agreed that the critical problem with Alternative 5 was the requirement for increased pilot-controller and inter-controller communication.

Controllers rated Alternative 5 traffic flow "easier to manage" than LAX baseline operations. South arrivals to the south complex experienced a 57% increase in taxi times; south arrivals to the north complex experienced a 25% increase in taxi times. North arrivals to the south gates experienced a 25% decrease in taxi times, while north arrivals to the north gates experienced a 22% taxi time decrease.

Taxi times for departures on the south runways were reduced by 20-30% compared to the baseline. Departures originating in the south complex bound for the north runways experienced a 16% reduction in taxi times, while departures originating in the north complex bound for the north runways experienced no significant change in taxi times.

The presence of an additional local controller in the tower increased the number of pilot-controller transmissions per hour. The sum of LC-1 and LC-3 transmissions was slightly greater for both pilots and controllers than that of the baseline condition for the LC-1 position alone.

Summary of Results

Subjective data collected from controller surveys indicated a preference for alternatives involving the B-16 extension over those that did not include modifications to the airport pavement geometry. Specifically, Alternatives 3a, 5, and 4 were ranked most desirable, while Alternatives 1, 2, and 3 were judged least likely to result in a change in the number of runway incursions at LAX. The B-16 alternatives were regarded as resulting in operations "more easily managed" than those currently in use at LAX.

Of the preferred alternatives, Alternative 3a (Using the B-16 Extension with the Bridge Route Open) was selected as having the most potential to reduce the conditions under which human errors could be made that might result in runway incursions. Alternative 3a also afforded the largest increase in operational efficiency (reduced taxi times, a more easily-managed operation, less coordination between controllers) while at the same time increasing the safety of airport operations in general.

Of the alternatives that did not involve modifications to the taxiway geometry, Alternative 1 (Swapping Inboard and Outboard Runway Operations) was ranked lowest in terms of safety of operations, and was regarded as having about the same potential for runway incursions as the LAX baseline operation. Alternative 2 (Adding a Second Local Controller to the South Side Operations Position) resulted in a lower airport departure rate and was judged by controllers as having a higher potential for runway incursions than current operations. Controllers indicated that the need for additional coordination between local controllers was the primary cause of the increased potential for operational errors.

Figure 8 represents controller subjective ratings of the proposed alternatives against LAX baseline operations. Note the preference for Alternative 3a as discussed above.

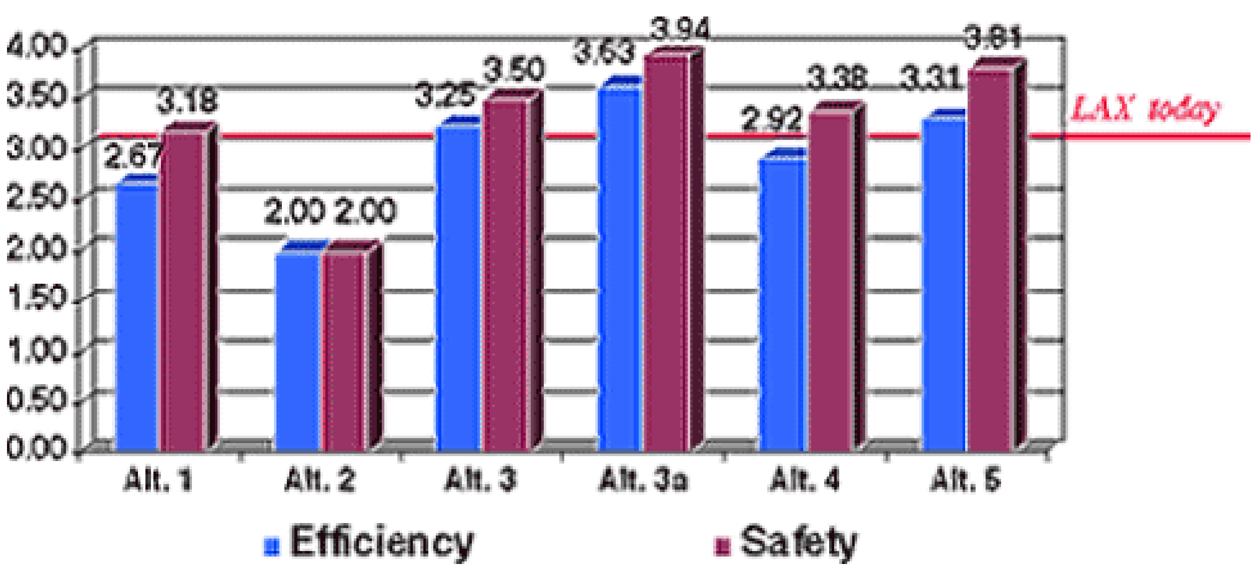


Figure 8: Controller Subjective Ratings of Proposed Alternatives

Figure 9 is a diagram of controller subjective ratings vs. airport departure rate, an important indicator of the efficiency of the proposed alternatives.

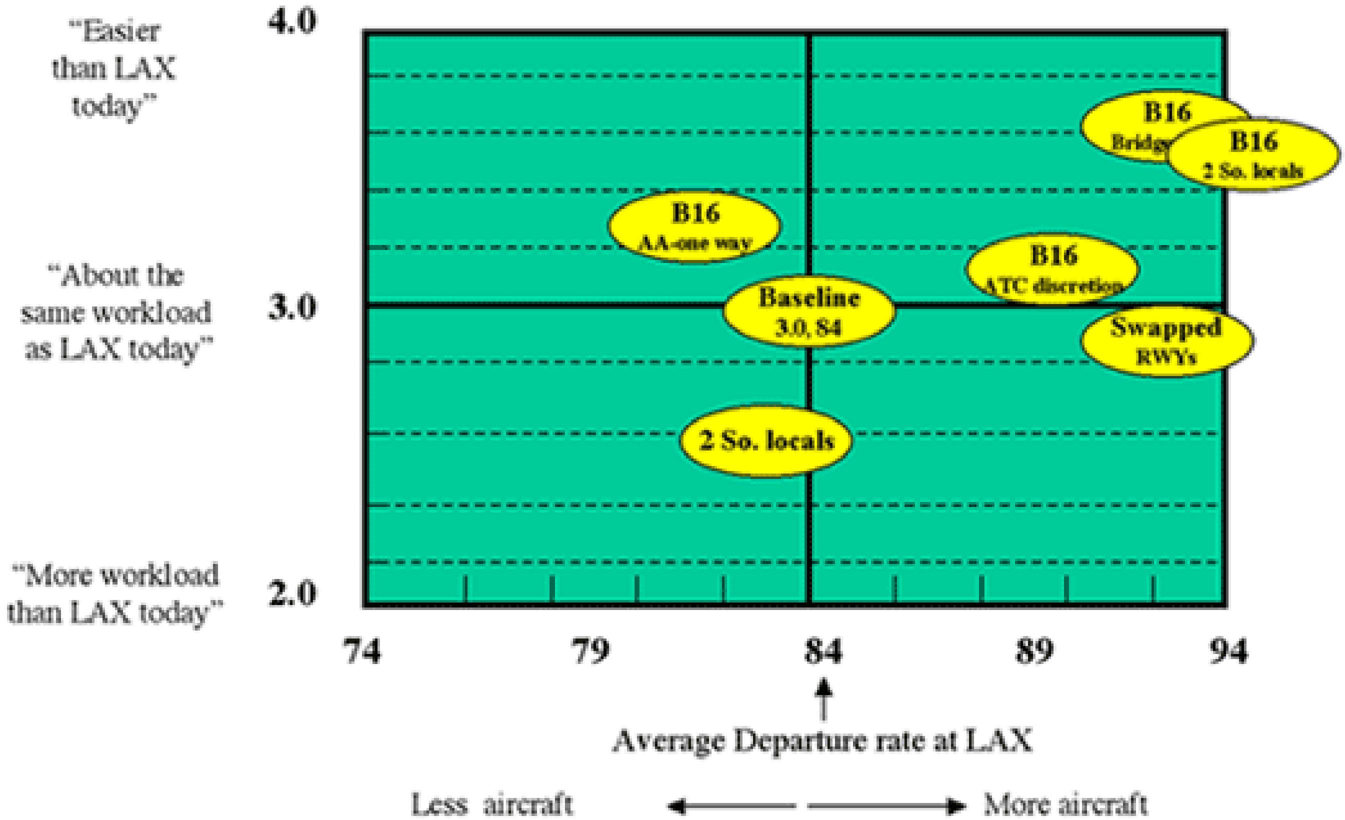


Figure 9: Controller Subjective Ratings vs. Airport Departure Rate

Conclusion

The FAA has made reduction of runway incursions a priority for airports throughout the national airspace system. A two-phase experiment conducted in NASA's FutureFlight Central facility explored six alternatives designed to reduce the number of runway incursions at Los Angeles International Airport, and to increase the overall efficiency and safety of the airport operation. Three of the alternatives proposed a modification to the airport's Bravo taxiway (the "B-16 extension") which would allow controllers to route south arrivals to the north and south gate complexes without crossing an inboard parallel runway. Three of the alternatives did not propose changes to the airfield pavement geometry, but rather to the LAX baseline operation itself; these alternatives were judged less desirable in terms of safety, efficiency, and potential to decrease the number of runway incursions than the alternatives involving the B-16 extension. Based on evaluation of controller subjective measures, airport operation statistical data, and controller voice communication data, Alternative 3a (Using the B-16 Extension with the Bridge Route Open) was selected as having the greatest potential to reduce the number of runway incursions at LAX while at the same time increasing the safety and efficiency of airport operations.

References

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3. [3] N. Dorighi, B. Rabin, "NASA Uses Virtual Reality to Target Runway Incursions at LAX," 2002 Federal Aviation Administration Technology Transfer Conference, Atlantic City, New Jersey, May, 2002.

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