Reducing Air Traffic Delays in Los Angeles

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Intro: Los Angeles

- The Los Angeles Area is one of the busiest air traffic regions in the world
  - Population: 18 million (2nd largest in US)
- Commercial air service from 5 airports: LAX, SNA, LGB, ONT, BUR
  - Of these, LAX by far serves the most destinations and has the greatest frequency of commercial flights
  - The 4 other airports almost exclusively serve domestic destinations
- LAX is often preferred due to high frequency of flights and more non-stop destinations
- However, LAX has many problems including delays and efficiency

Intro: LAX

- From 2010 to 2016, LAX ranked as #1 for the longest delay in **taxi-in time**
  - Closely spaced terminals allow only one aircraft on the apron taxiway at a time
  - Closely spaced taxiways can restrict ground aircraft movement
  - Taxiway weight restrictions result in longer taxi times
  - Almost constant construction results in runway and taxiway closures
- Horseshoe terminal layout makes inter-terminal transitions difficult
- Los Angeles road traffic makes LAX difficult to get to
- LAX is bounded in all 4 directions and almost impossible to expand

Intro: LA Area Airports

- The 4 other LA Area airports are far away from operating near capacity
- Airline service already exists at these airports:
  - SNA serves over 20 destinations through 7 carriers
  - LGB serves about 15 destinations through 4 carriers
  - ONT serves about 15 destinations through 7 carriers
  - BUR serves about 13 destinations through 6 carriers
- These airports are located around the Los Angeles Area

Intro: LA Area Airports

- However, these airports carry curfews and restrictions
- SNA has night curfews with operations prohibited between 11PM and 7AM
  - Especially noisy aircraft are also prohibited from flying to the airport
- LGB has noise and flight restrictions, but no curfew
- BUR has noise restrictions and curfew on especially noisy aircraft
- ONT has no explicit noise restrictions or curfew in place
- These airports' runways may not accommodate very large aircraft

Motivation

- Aircraft delays are costly, inefficient, and unpleasant
  - Airlines must pay more for crew time, fuel, and other resources
  - Additional airline costs if delay causes missed connections
  - Interferes with airport departure slots and can cause ripple effect
  - Generates unnecessary noise and fuel pollution
  - Creates stress for travelers

- Air traffic delays affect everybody, especially at a scale such as LAX
  - Travelers
  - Ground Transportation
  - Pilots, Flight Attendants, Airline and Airport Ground Service Agents
  - Air Traffic Controllers

Research Question

- How can these delays be reduced?

- **Proposed Solution**: Redistribute air traffic among LA Area airports
  - Forced market - flights no longer offered based on demand
  - Scheduled flights are assigned based on how congested LAX is at a particular time of day
  - Sole criteria for redistribution: reducing the ground delay at LAX

- **Additional Considerations**
  - Reduced delay will reduce environmental, operational costs
  - Travelers must receive incentives for loss of convenience

Broad Theory

- LAX is not always congested to extreme degrees
    - Most notable delays in later morning and later afternoon rushes

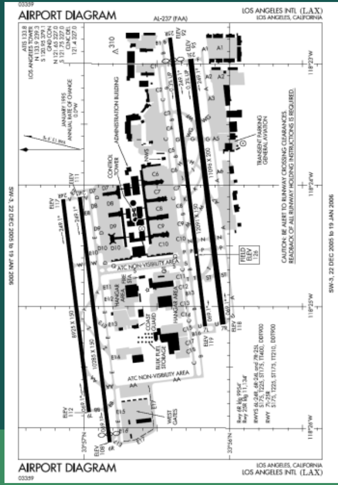
- Travelers are generally flexible
    - Passengers are already willing to pay more for airfare from other airports because of better travel experience
    - Relatively few travelers live exclusively close to a certain airport

- Demand is steady and increasing to other airports

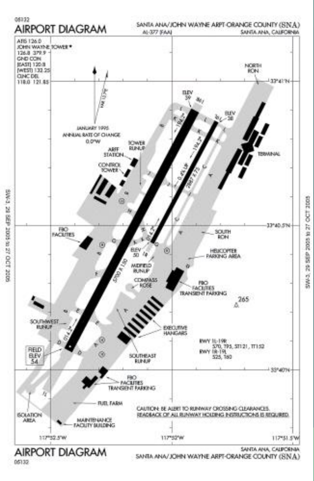
- Costs of loss of free market do not outweigh benefits of better efficiency

Background: Five Major Airports

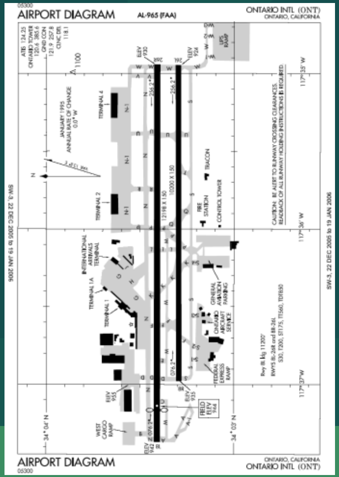
LAX



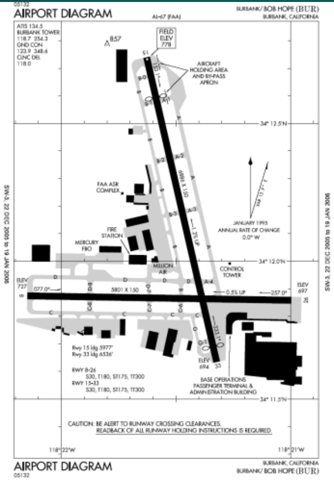
John Wayne



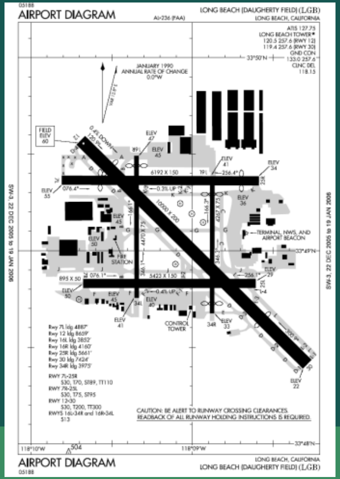
Ontario



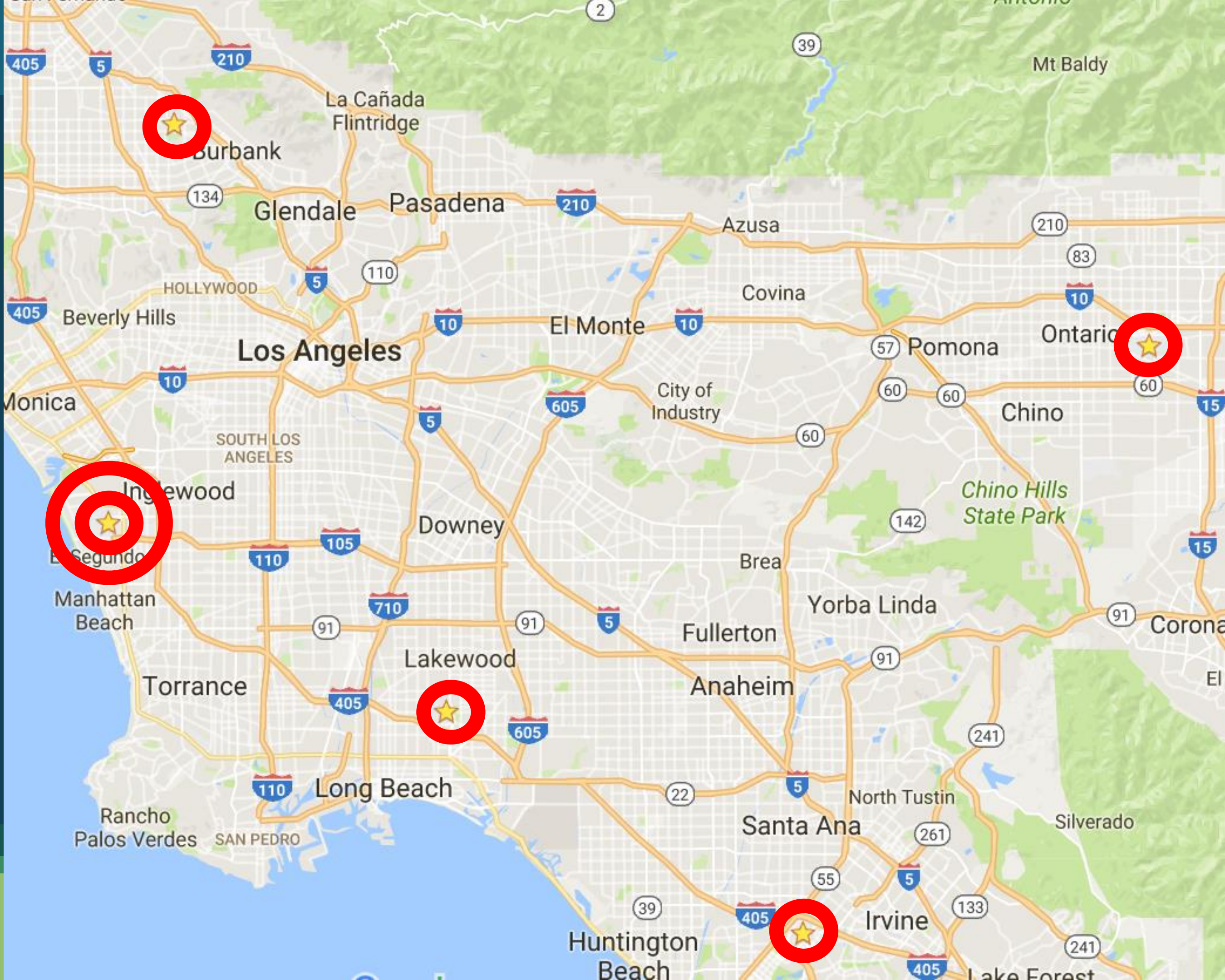
Bob Hope



Long Beach



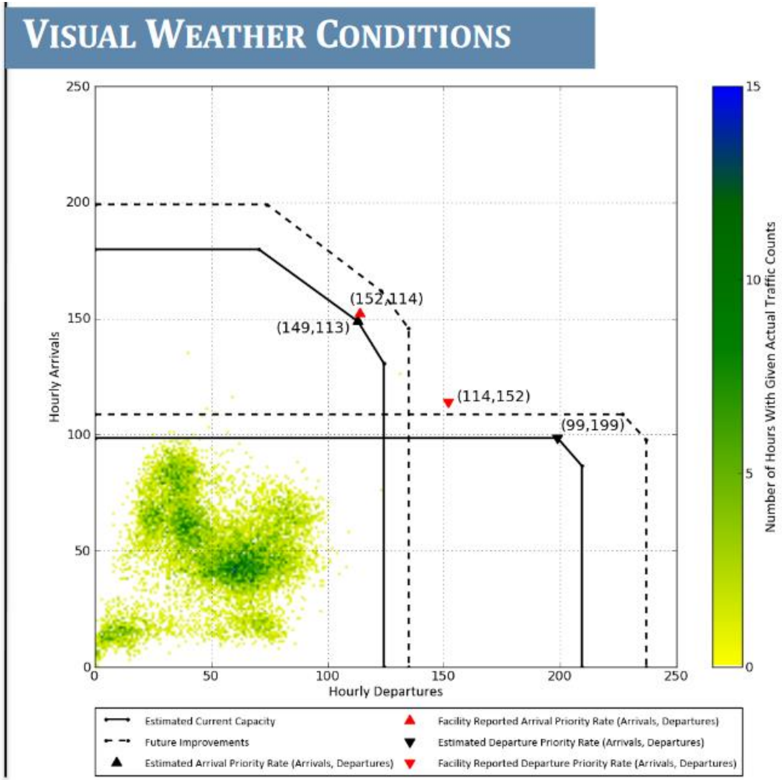
Location: Five Major Airports



Opportunity to Improve

	Total Operations	Yearly Passengers	Runway lengths
BUR	130,000	4,000,000	**15/33:** 6886 **8/26:** 5801
LAX	655,000	75,000,000	**24R/6L:** 8925 **24L/6R:** 10285 **25R/7L:** 12091 **25L/7R:** 11096
LGB	300,000	2,500,000	**25L/7R:** 5423 **25R/7L:** 6192 **12/30:** 10000
ONT	150,000	4,200,000	**26R/8L:** 12198 **26L/8R:** 10200
SNA	260,000	10,000,000	**20R/2L:** 5700

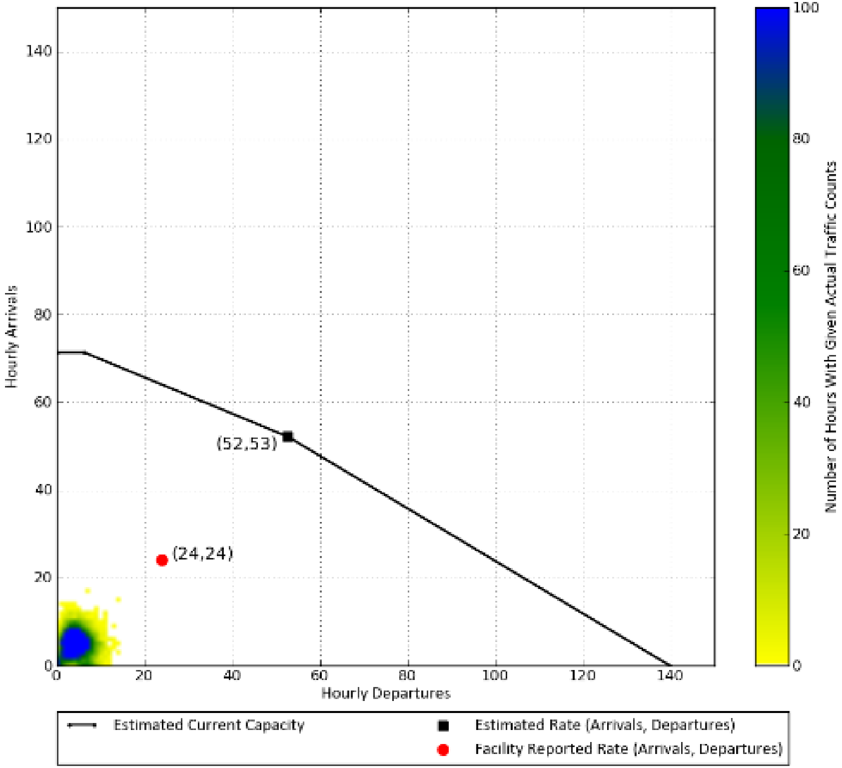
DEN



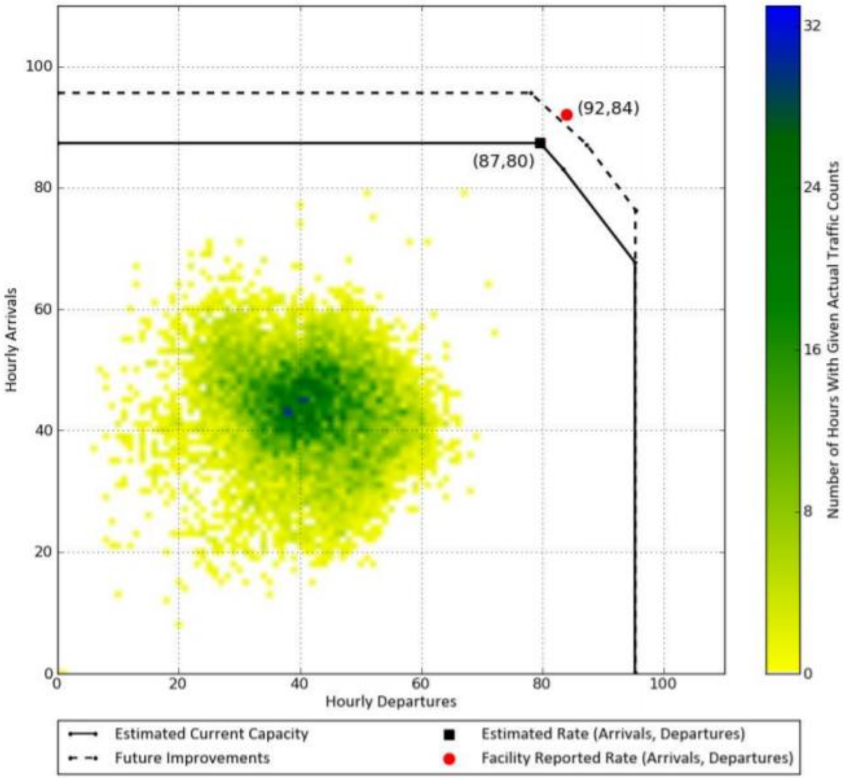
LGB

LAX

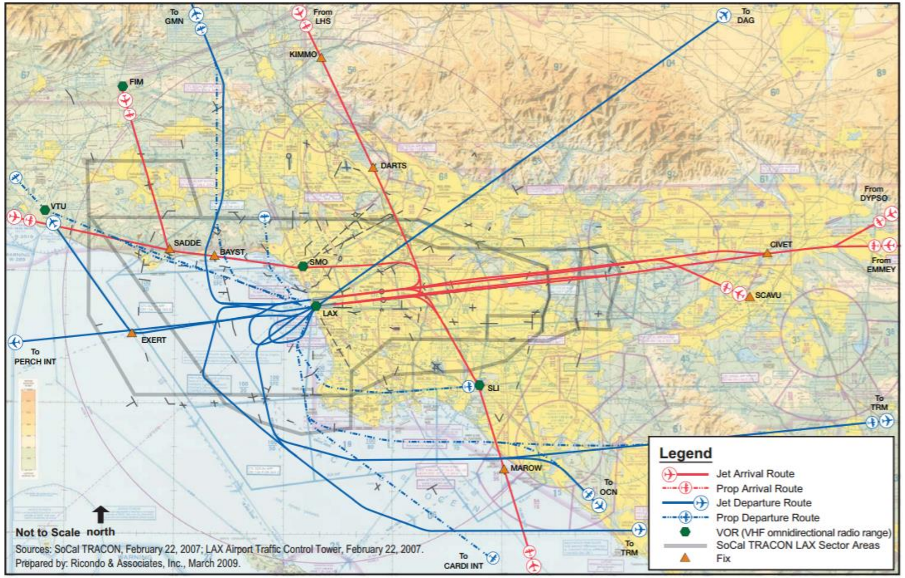
VISUAL WEATHER CONDITIONS



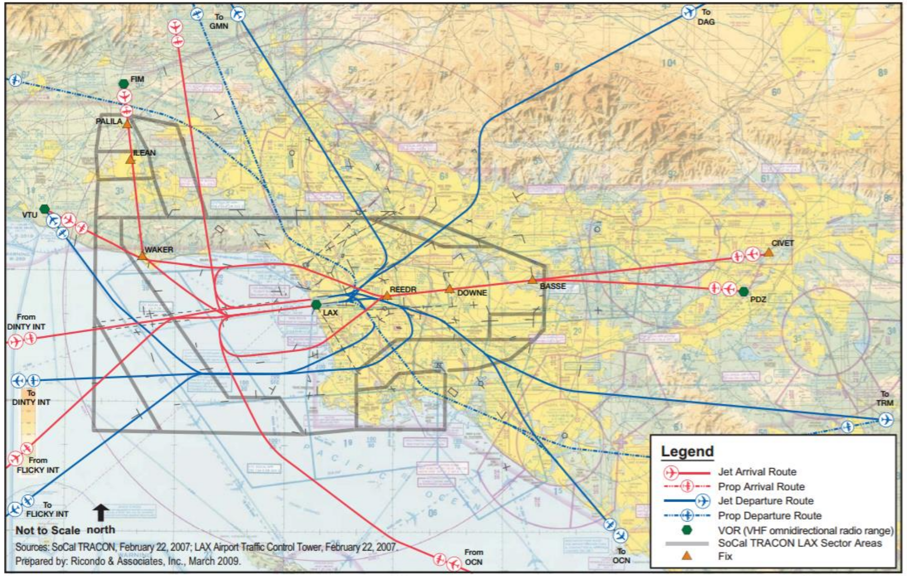
VISUAL WEATHER CONDITIONS



LAX Approach and departure paths



LAX Specific Plan Amendment Study Report	Generalized West Flow Airspace Routes	Figure 5



LAX Specific Plan Amendment Study Report	Generalized East Flow Airspace Routes	Figure 6

John Wayne / Long Beach Trip


GOLDEN BEARS

Southwest

COUNTY OF ORANGE CALIFORNIA
Welcome to ORANGE COUNTY
COURTESY PHONE
949-252-5279
INFORMATION/PAGING/OPERATOR — 0
EMERGENCY/SECURITY — 2-5000

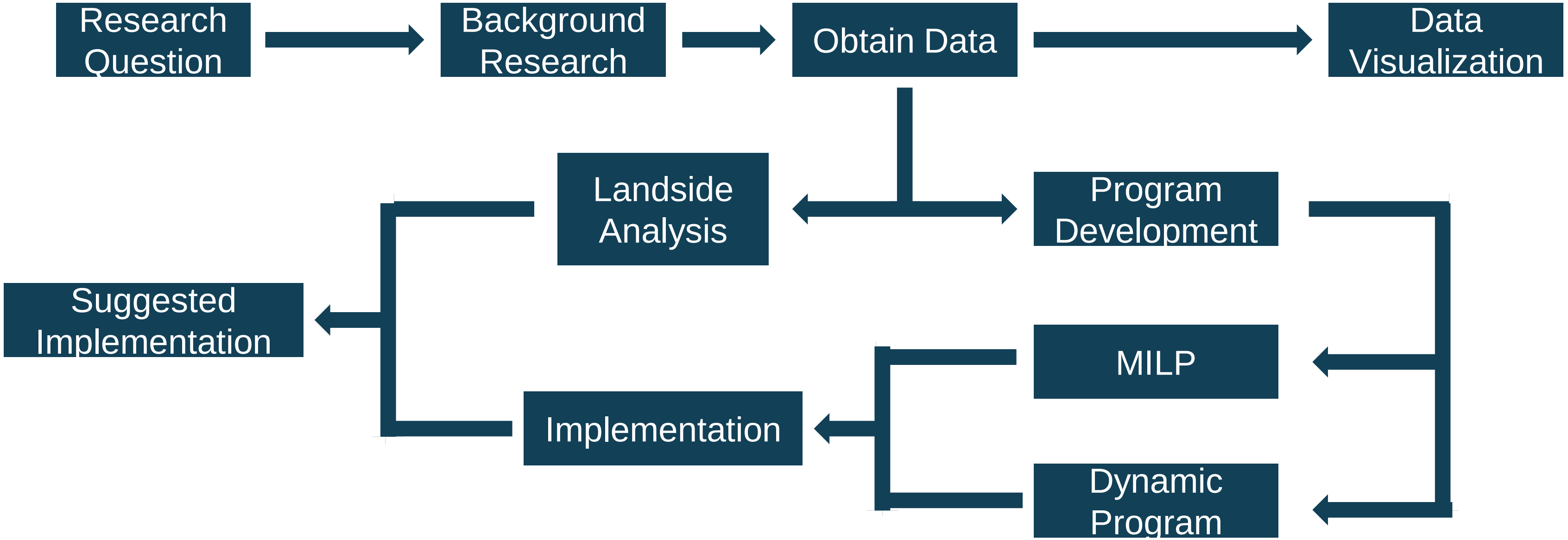


SOUTHWEST

Southwest

Forced market: Can we make this more optimal?

Methodology



Existing Air Service System

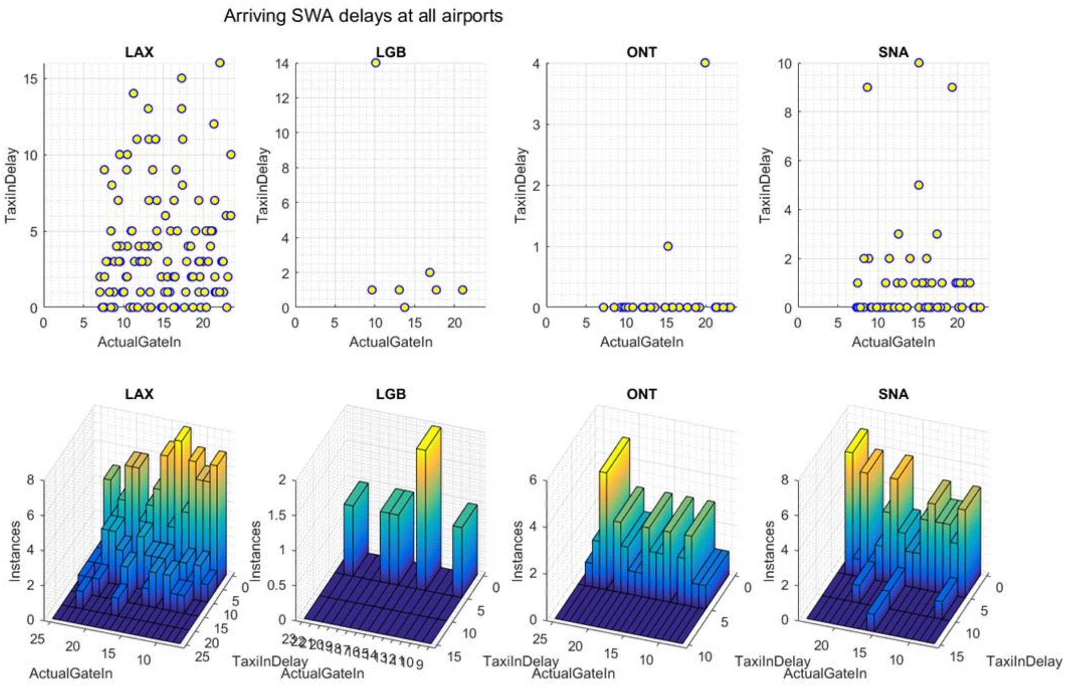
- Airports offer slots to airlines, which set a maximum on airline service
  - May be bounded by number of flights, or number of passengers
  - Are distributed to airlines according to legal procedures
  - Slots can be as restrictive as they need to be
- Airlines schedule flights in accordance with their slot allocations
  - Generally, slots dictate how many gates are available
  - Airlines try to schedule flights to meet service demand

- Airports are competitors, and generally operate independent of another
  - Exceptions for when departure paths cross, or other factors

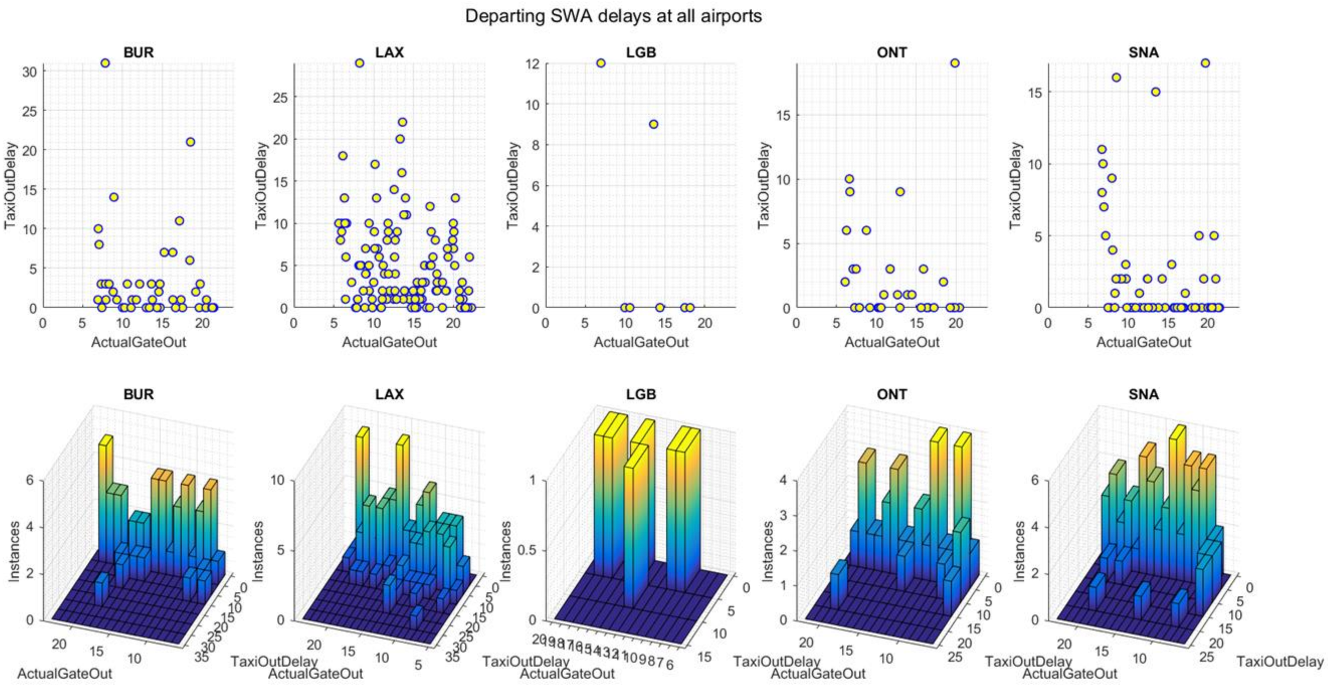
Data Categories

- Carrier
- Airport
- Flight Plan Gate Out
- Actual Gate Out
- Flight Plan Gate In
- Actual Gate In
- Unimpeded Taxi Out Time
- Taxi Out Time
- Taxi Out Time Difference
- Taxi Out Delay
- Estimated Time Enroute
- Tail Number
- ACID
- Actual Airborne Time
- Airborne Time Difference
- Airborne Delay
- Unimpeded Taxi In Time
- Taxi In Time
- Taxi In Time Difference
- Taxi In Delay
- Scheduled Block Time
- Actual Block Time
- Block Time Difference
- Block Delay
- Departure
- Arrival

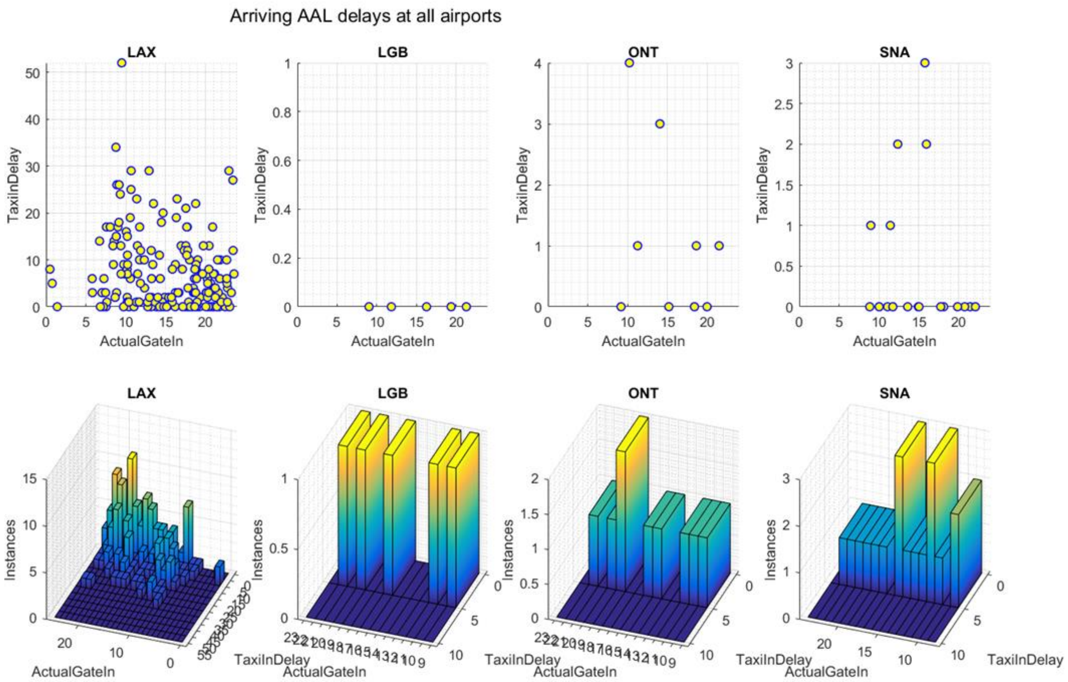
Initial Data Interpretation
Southwest Airlines



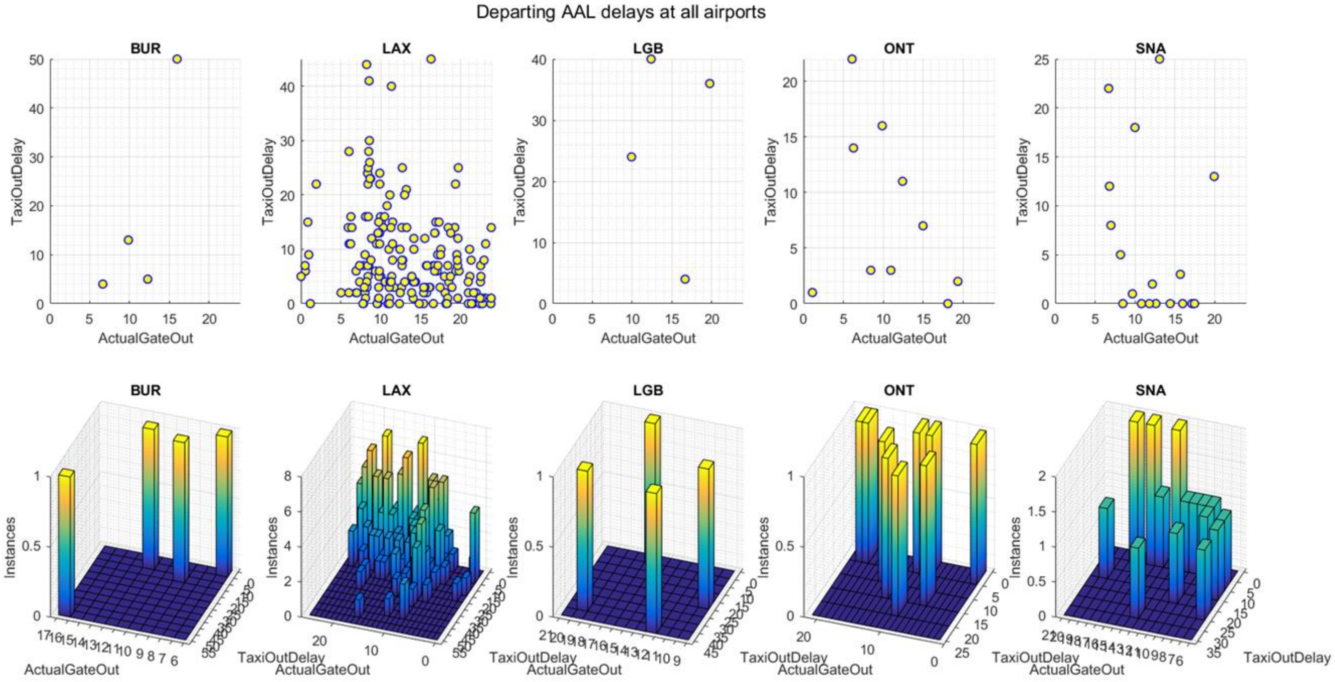
Initial Data Interpretation
Southwest Airlines



Initial Data Interpretation
American Airlines



Initial Data Interpretation
American Airlines



Modeling - Two Approaches

Mixed Integer Linear Programming

- Uses linear programming and branch and bound algorithm to optimize
- Easy to implement and change
- Very time inefficient for large numbers of aircraft
- Time complexity unpredictable for difficult scenarios

Dynamic Programming

- Uses recursion to map optimal solutions
- Complicated to implement
- Theoretically less computationally intensive as MILP, with more predictable time complexity
- Difficult to change constraints

Approach 1 - MILP

Minimize air delays relative to estimated arrival.	Min $\Sigma(t_i - t_e)$

S.t.

Purpose	Constraint
Wheels on time equals estimated air time + additional rerouting time + hold delay +approach delay (Aeq)	$t_i = t_e + \Sigma(x_{ir} AirTime_{add}) + 1.5H + D$
Delay limit per A/C	$(t_i - t_e) \leq DelayLimit$
Single destination constraint	$\Sigma_{r=1}^{R}(x_{ir}) = 1$
Minimum headway constraint (inactive for A/C with different destinations)	$t_i - t_j \geq \Delta T_{ij}(x_{ir} + x_{jr} - 1)$ $t_j - t_i \geq \Delta T_{ji}(x_{ir} + x_{jr} - 1)$
Runway capability constraint	$x_{ir} = 0 \ for\ all\ incompatible\ pairings$

- Minimizes the sum of difference between an aircraft’s earliest possible arrival time and new scheduled time
- Imposes limit on delay of any one aircraft
- Imposes FAA separation requirements on aircraft approaching the same runway.

Assumptions

The MILP makes a number of permissible assumptions about aircraft dynamics and regulations to enable faster computation.

- Schedules repeat over the course of days or weeks.
- 7 Runways for arrivals (2 each at LAX and LGB).
- Aircraft arrive from 4 general directions, meaning additional flight time to each airport varies.
- Once at an airport, all aircraft merge into a single approach path

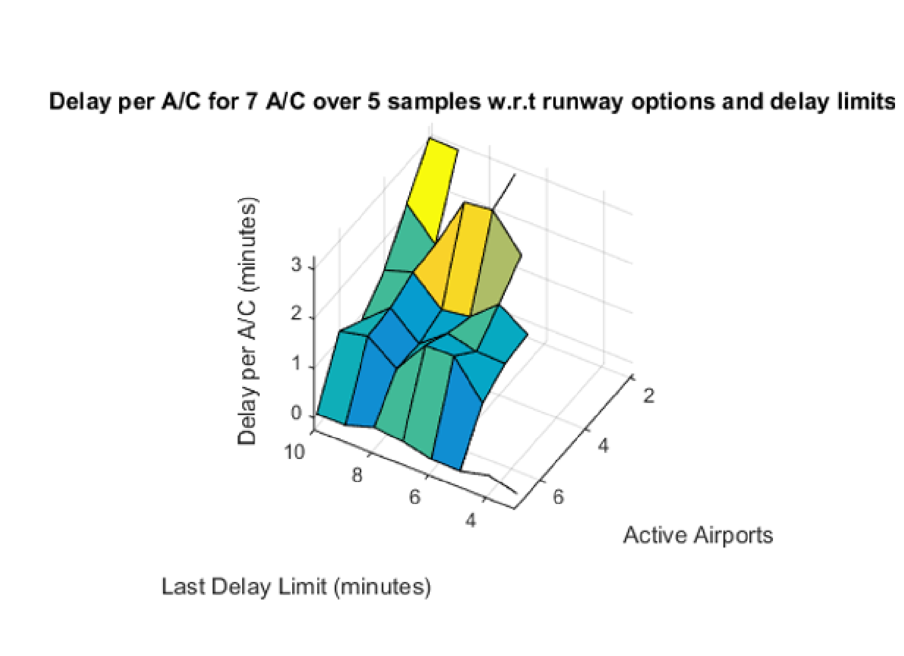
Temporarily Relaxed Details:

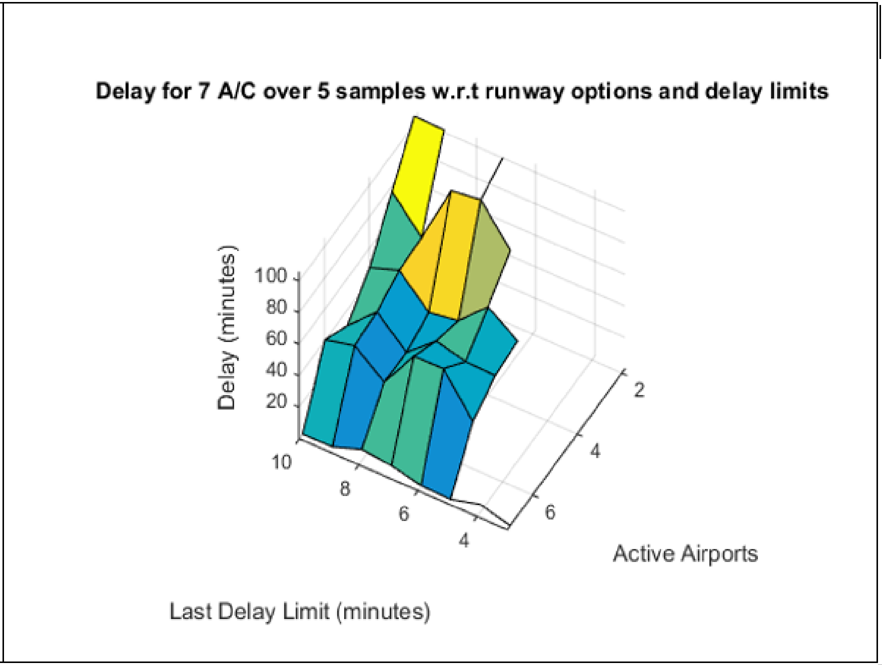
- Runway capabilities (based on weight class)
- Variable headway requirements (an average of 90 seconds used)
- Actual vs random origin direction

Constraint Selection

- Additional function (LongTermPlot.m) developed to explore the effect of constraints on delay
- Looping over different scheduling window limits and available airport constraints, we can determine feasible constraints graphically.
- Generated plots show the delay reduction effect of scheduling over a larger sample of airports.
- LongTermPlot also graphs cumulative rerouting decisions from each sample set

Output of Bivariate Constraint Program - (LongTermPlot.m)



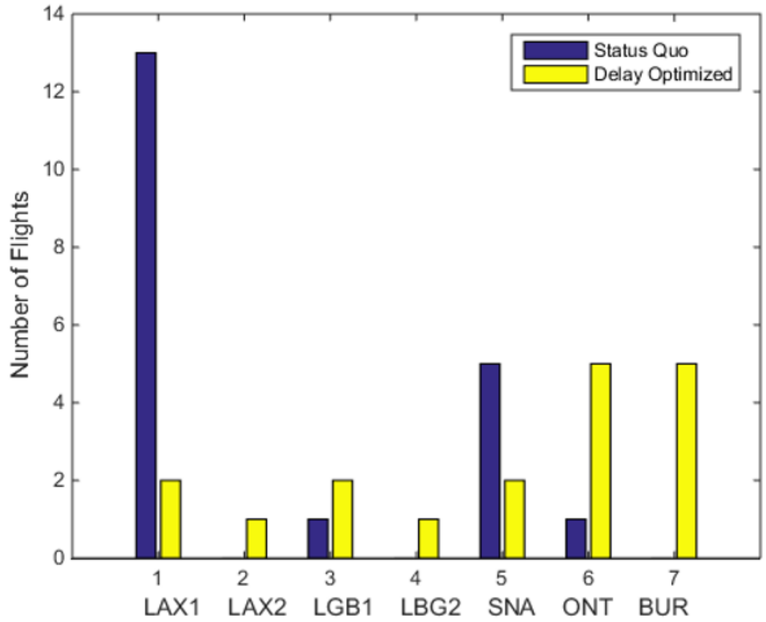


Implementation

1. Individual flight data is extracted from ASPM database
2. Aircraft equipment ID and other databases are used to determine:
   - weight category
   - point of origin
   - separation requirements
   - fuel consumption
   - original destination,
   - time impacts of changing destination
3. For loops assemble the constraint arrays A, B, Aeq, and beq from the data calculated in Step 2
4. Intlinprog function uses the simplex algorithm and branch and bound to explore options and find a delay minimizing schedule

Results

- Every iteration generates a plot of runway decisions and a complete schedule vector.
- Originally sample sizes were too small to produce meaningful results. Most results would be either infeasible or have zero delay
- Proper selection of a scheduling window solves this problem



20 AC

4 second runtime on 8 Mb RAM

```
start=322;
sample=20;
```

Approach 2 - Dynamic

- Dynamic programming takes a desired final state and systematically explores all possible ways of minimizing cost of reaching that state.
- Previous work has been done on using dynamic programming to maximize minimum separation in air traffic (Bayen et al 2004) but minimizing delay takes a new approach.
- This dynamic program seeks to pack “aircraft blocks” or windows of landing time and headway, into as small a timespan as possible.

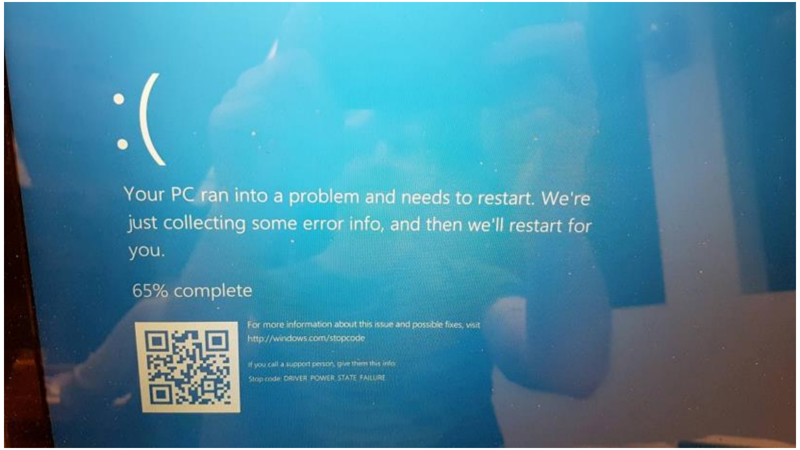
Issues and Improvements

MILP

- Time efficiency has been improved with random points of origin and reducing the aircraft sample size
- Number of variables increases polynomially, unknown O(f(N))
- LongTermPlot.m function has provided optimal constraint combinations to try
- Attempt iteration over entire day with

Dynamic

- Additional debugging required

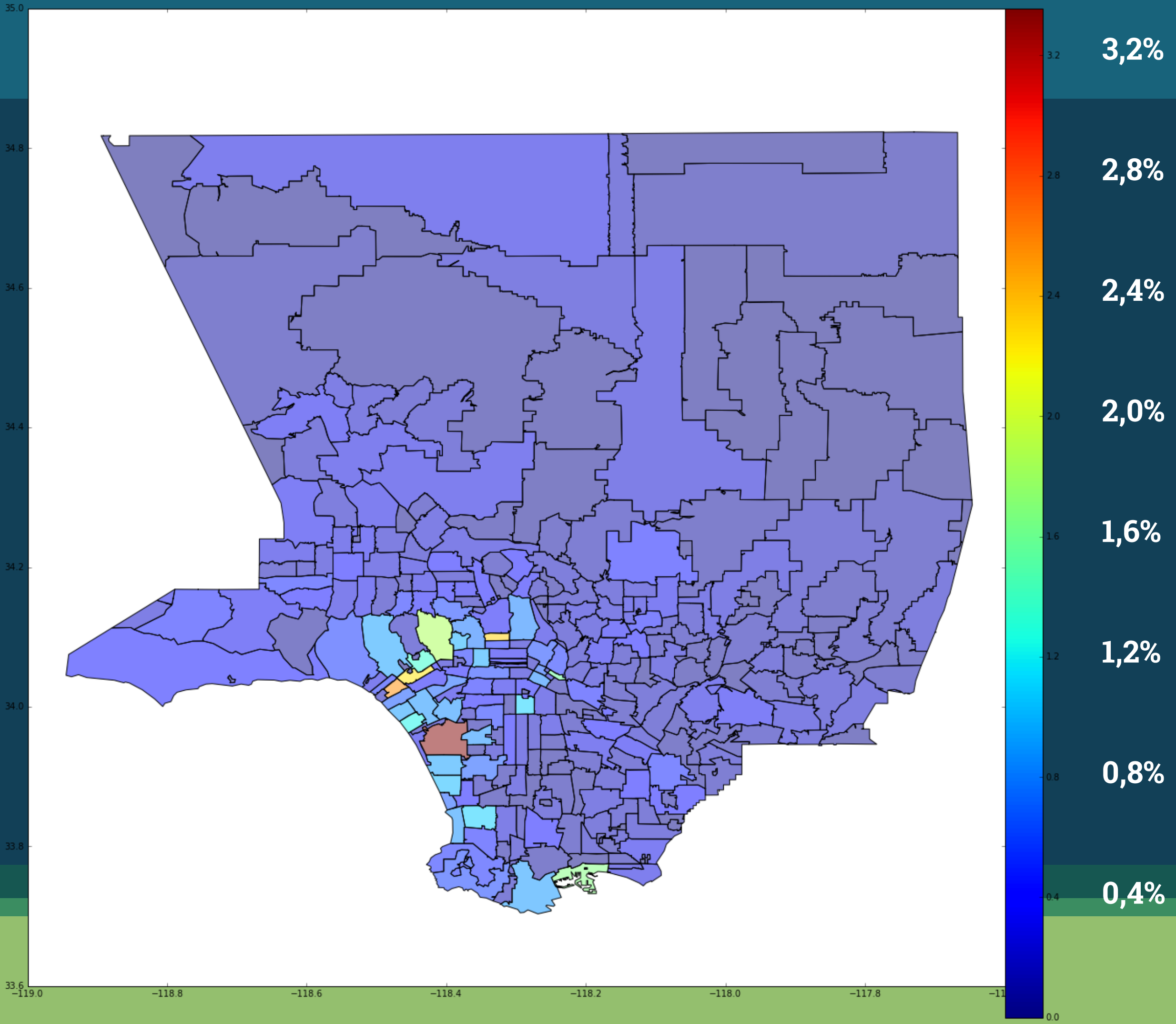


LAND-SIDE

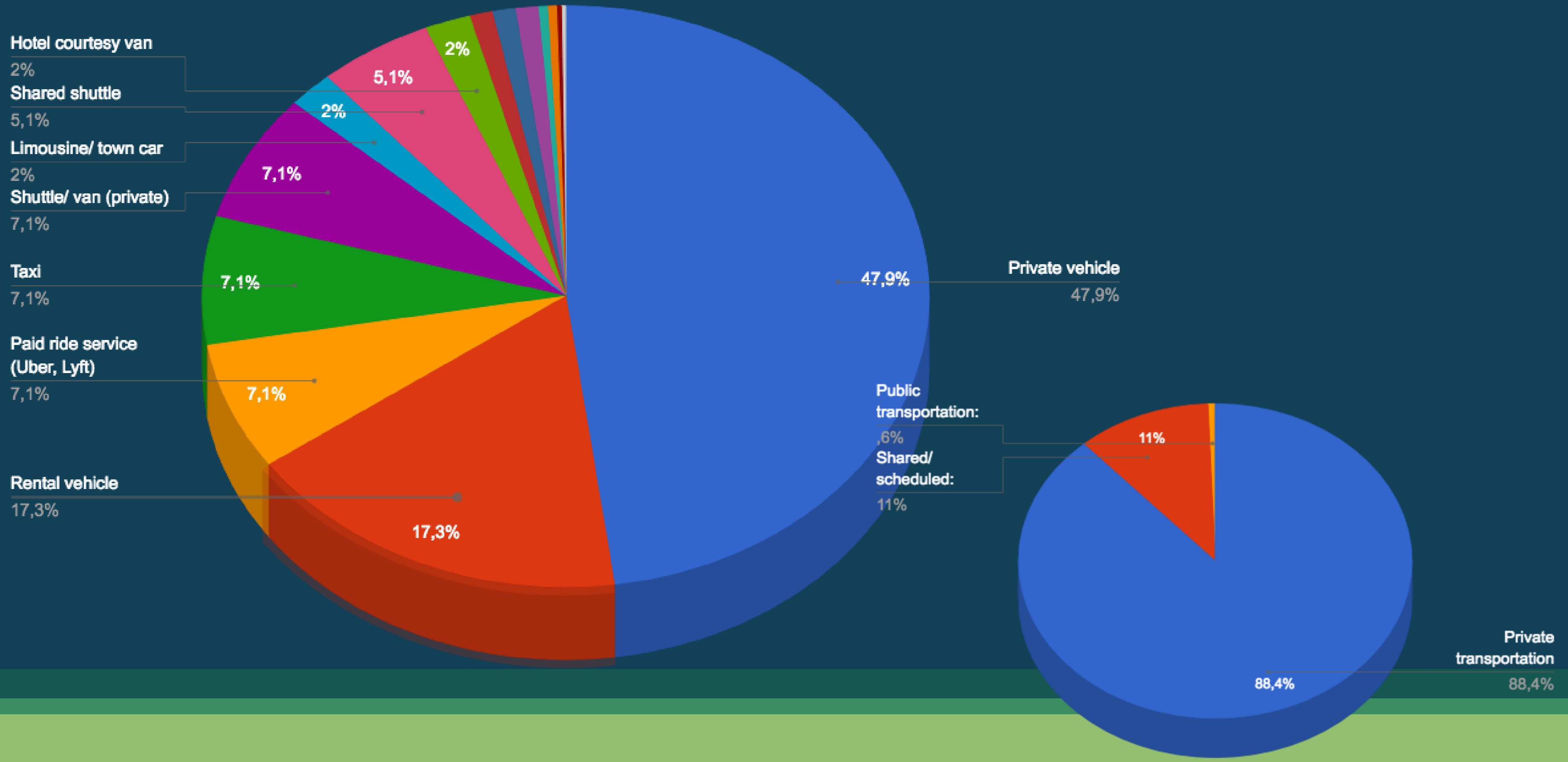
LAX Survey


FINAL REPORT
Los Angeles International Airport
2015 Air Passenger Survey
Results and Findings

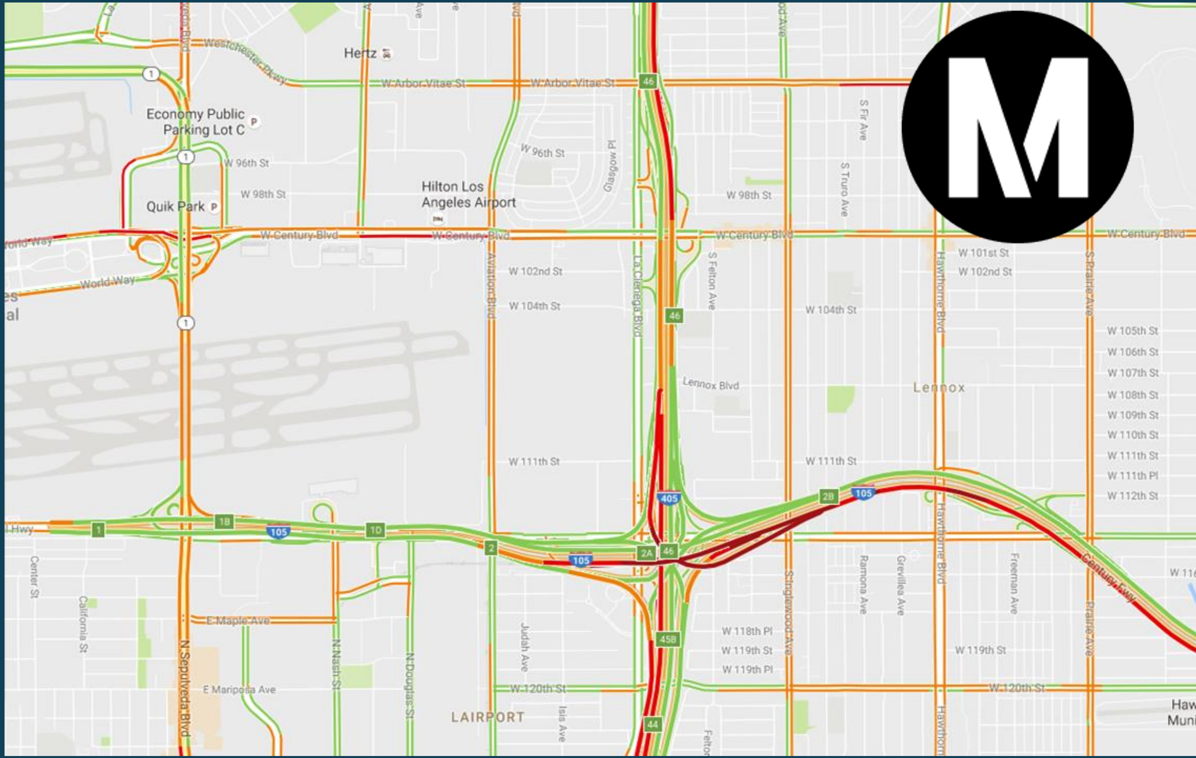
Passenger Origin



Ground Access Mode



LAX


Hertz
W Arbor Vitae St
Economy Public Parking Lot C
W 96th St
W 98th St
Quik Park
Hilton Los Angeles Airport
W Century Blvd
World Way
W 102nd St
W 104th St
Aviation Blvd
La Cienega Blvd
S Felton Ave
Lennox Blvd
Lennox
Hawthorne Blvd
S Prairie Ave
W 101st St
W 105th St
W 106th St
W 107th St
W 108th St
W 109th St
W 110th St
W 111th St
W 111th Pl
W 112th St
W 118th Pl
W 119th St
W 119th Pl
W 120th St
E Maple Ave
E Mariposa Ave
N Sepulveda Blvd
N Nash St
N Douglas St
Judah Ave
Isis Ave
Center St
California St
Singlewood Ave
Ramona Ave
Grevillea Ave
Freeman Ave
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LAIRPORT
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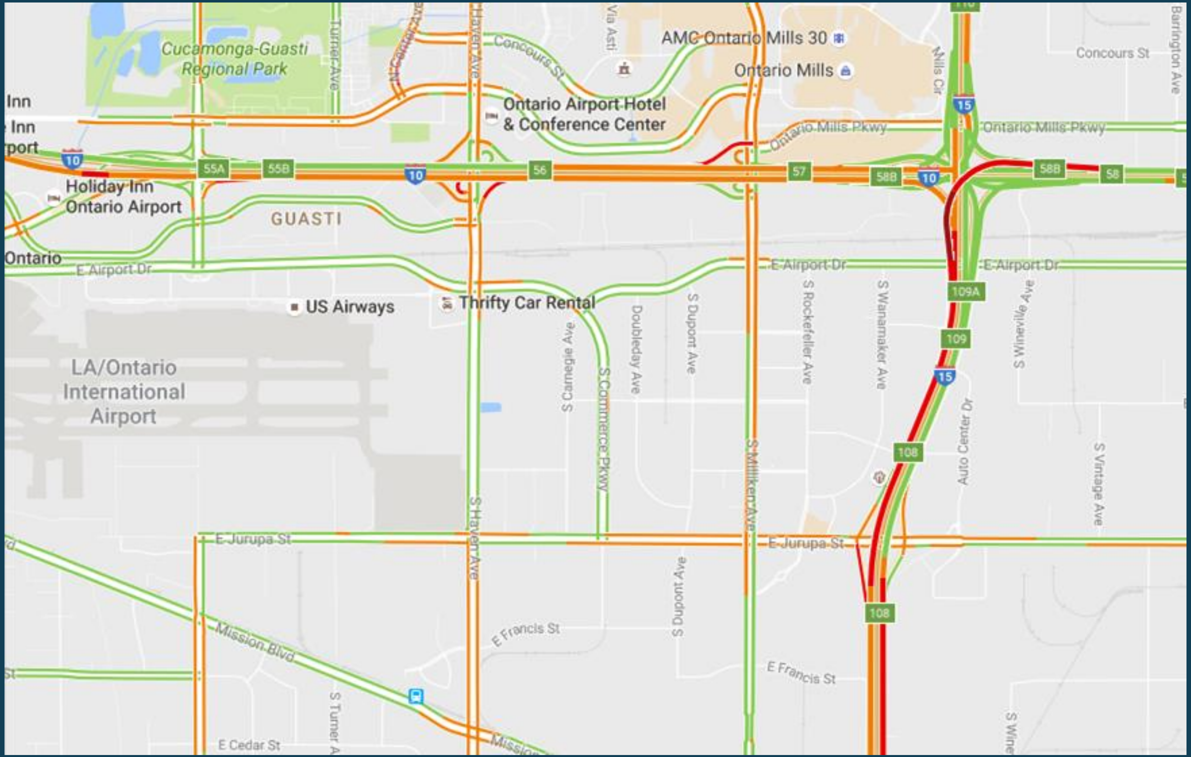
45B
44

ONT


Cucamonga-Guasti Regional Park
AMC Ontario Mills 30
Ontario Mills
Ontario Airport Hotel & Conference Center
Holiday Inn Ontario Airport
GUASTI
US Airways
Thrifty Car Rental
LA/Ontario International Airport
Ontario Mills Pkwy
E Airport Dr
E Jurupa St
Mission Blvd
E Francis St
E Cedar St
Concours St
S Haven Ave
S Milliken Ave
S Commerce Pkwy
Doubleday Ave
S Dupont Ave
S Rockefeller Ave
S Wanamaker Ave
S Carnegie Ave
Auto Center Dr
S Vintage Ave
Turner Ave
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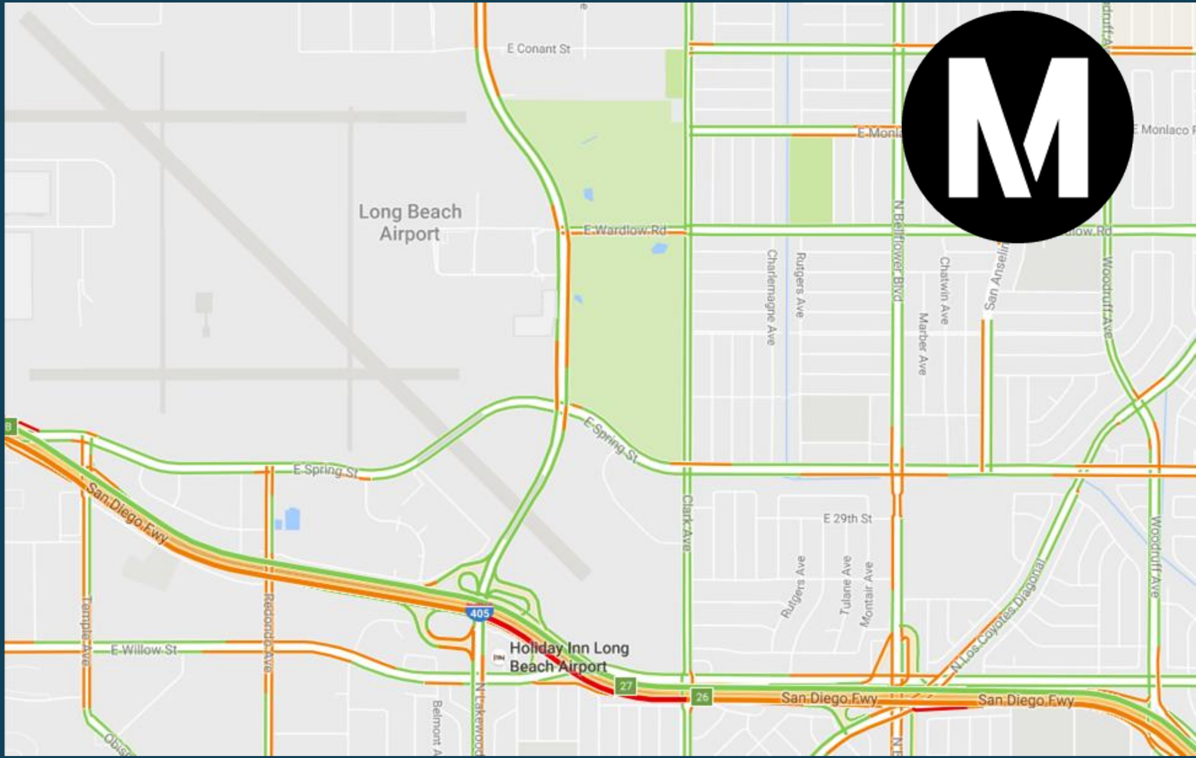
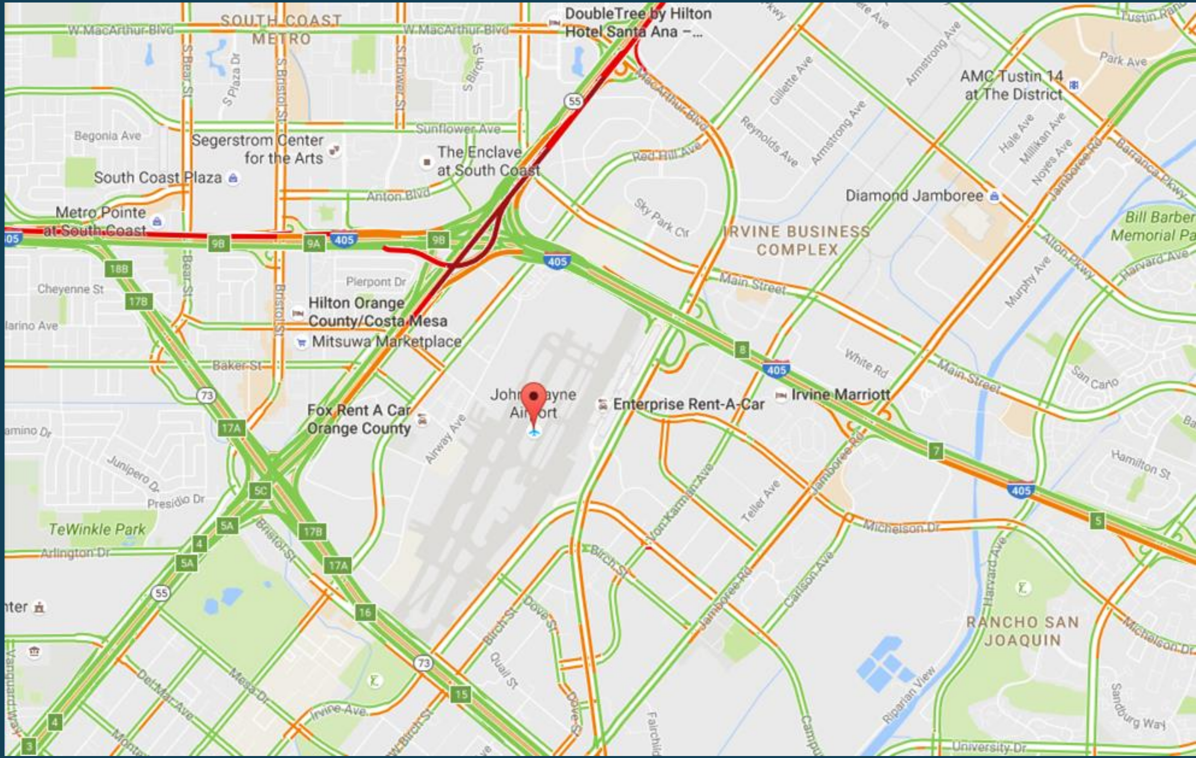
LGB



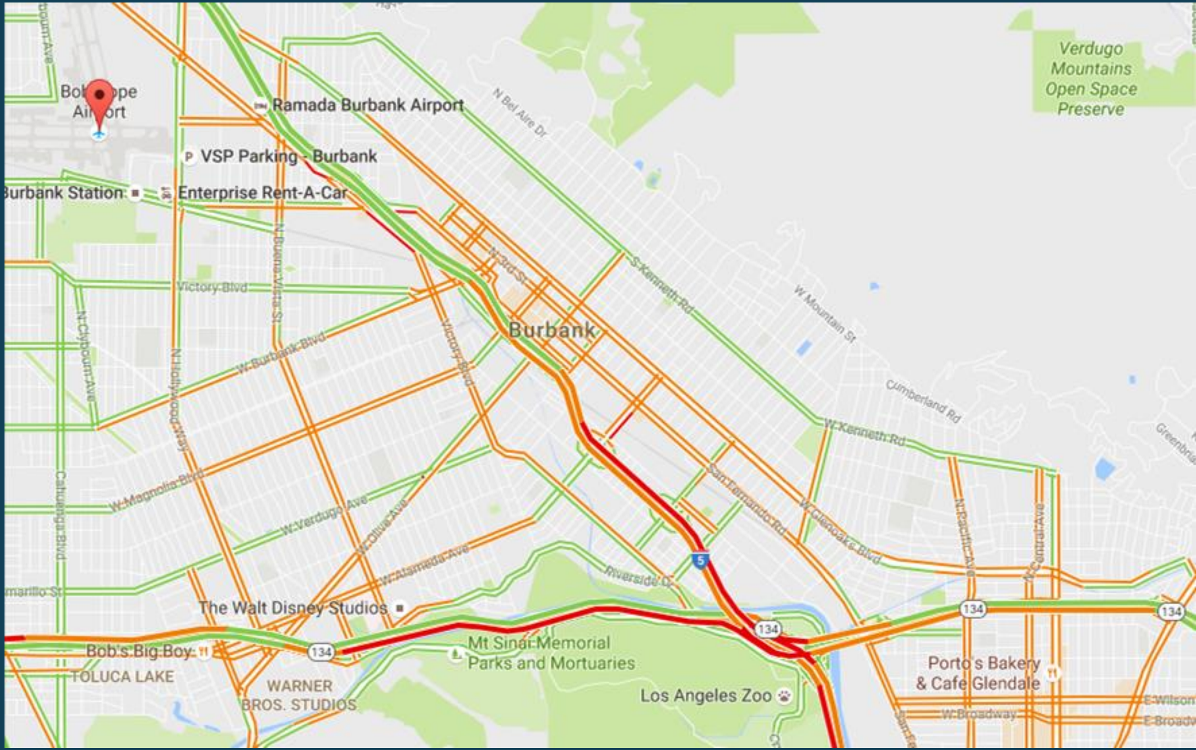
Long Beach Airport
E Conant St
E Wardlow Rd
E Spring St
San Diego Fwy
E Willow St
Holiday Inn Long Beach Airport
405
27
26
Temple Ave
Redondo Ave
Clark Ave
N Bellflower Blvd
Charlemagne Ave
Rutgers Ave
Chatwin Ave
Marber Ave
Woodruff Ave
E 29th St
Tulane Ave
Montair Ave
N Los Coyotes Diagonal

SNA



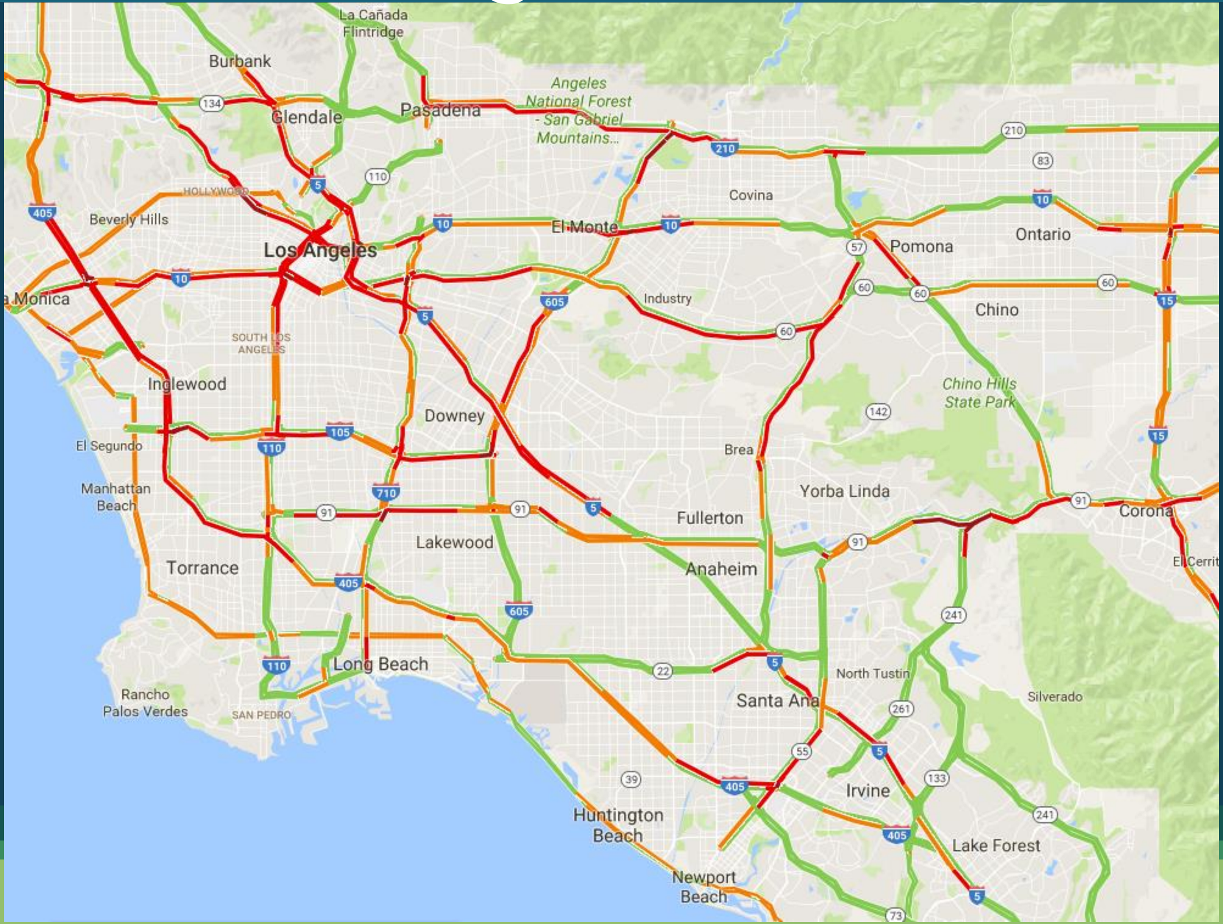
SOUTH COAST METRO
W MacArthur Blvd
DoubleTree by Hilton Hotel Santa Ana –...
AMC Tustin 14 at The District
Segerstrom Center for the Arts
The Enclave at South Coast
South Coast Plaza
Metro Pointe at South Coast
Diamond Jamboree
IRVINE BUSINESS COMPLEX
Bill Barber Memorial Pa
Hilton Orange County/Costa Mesa
Mitsuwa Marketplace
Fox Rent A Car Orange County
John Wayne Airport
Enterprise Rent-A-Car
Irvine Marriott
TeWinkle Park
RANCHO SAN JOAQUIN
Sunflower Ave
Anton Blvd
Red Hill Ave
Main Street
Baker St
Michelson Dr
University Dr
405
55
73

BUR



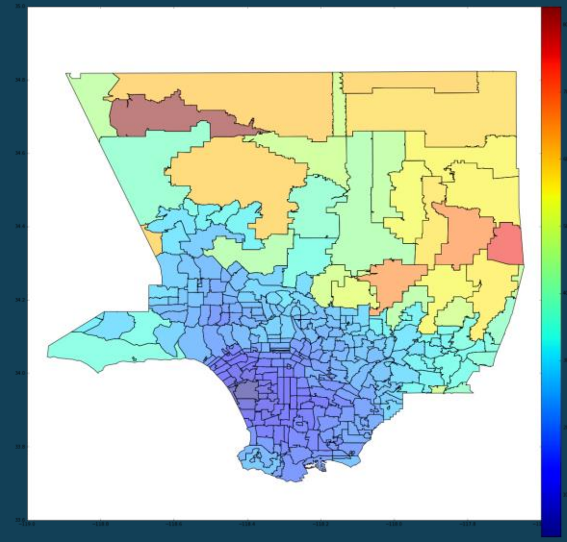
Ramada Burbank Airport
VSP Parking - Burbank
Enterprise Rent-A-Car
Burbank
Verdugo Mountains Open Space Preserve
The Walt Disney Studios
Bob's Big Boy
TOLUCA LAKE
WARNER BROS. STUDIOS
Mt Sinai Memorial Parks and Mortuaries
Los Angeles Zoo
Porto's Bakery & Cafe Glendale

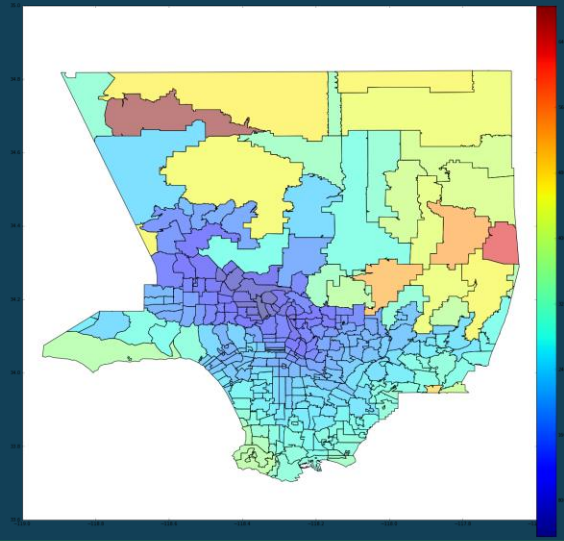
Los Angeles Traffic

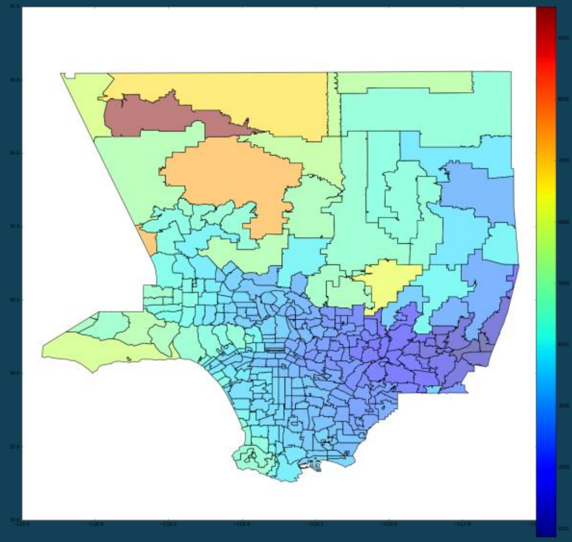


Travel Time

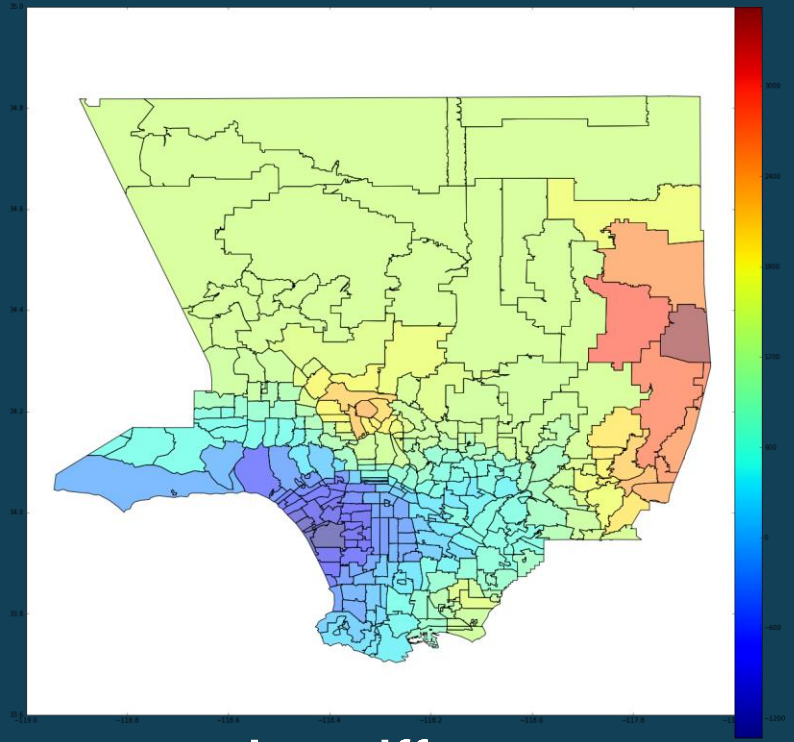
LAX BUR ONT



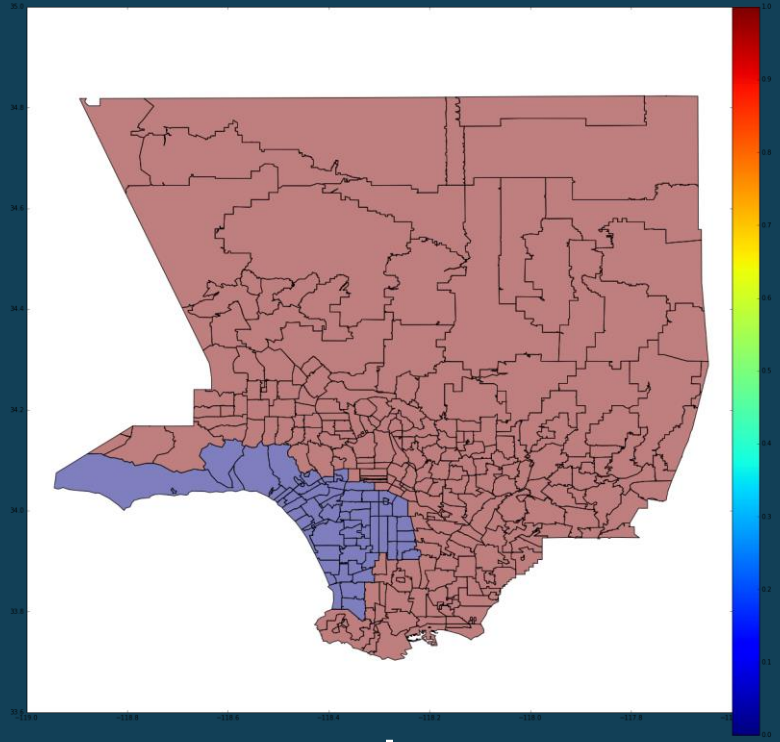




Travel Time

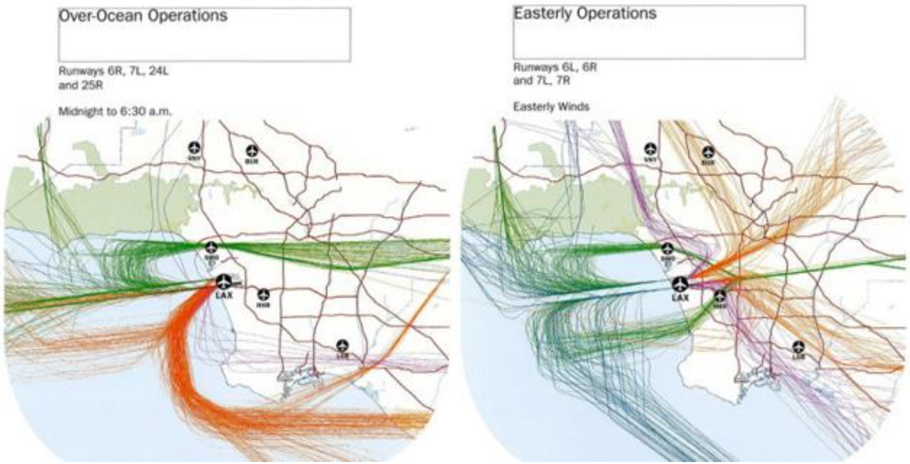


Time Difference



Best option : LAX

Future Analysis



- Particular emphasis will be placed on determining both cost of rescheduling and potential for fuel savings and carbon footprint reduction due to delay reductions.

- We will begin to check the robustness of the scheduler to see if such a method is feasible under conditions of uncertainty.

- Further refinement of the model to reflect real airspace conditions and Improvement of computation time efficiency

Impacts of New Schedule

A theoretical passenger lives somewhere between LAX and BUR, and flies to BUR instead of LAX (assuming Boeing 737-800)

Time

- Like most LA travelers, the passenger travels by car
- Net ground travel time change: +/- 40 minutes
- Reduced air delay: 3.1 min air (5.4 min block)
- Net change for passenger 45.4 minutes less to 36.9 minutes more.

Money

- The airline saves $2.30 on operating cost/passenger on block delay
- The passenger spends +/- $2.94 on fuel
- LAX landing fee and terminal concession revenue goes to BUR

Emissions

- The airline reduces its carbon footprint by 1.65 lbs CO2/passenger
- The passenger's carbon footprint changes by +/- 19.7 lbs CO2
- X passengers end up closer to their destination
- Y passengers end up farther from their destination

The Big Question: How many passengers on that flight will end up closer to vs. farther from their destination?

Implementation

- Air travel to/from LA Area would be similar to pre-deregulation
  - Government or other governing body regulates frequency of flights, departure times, and destination airports

- Many entities involved:
  - Nearly all domestic airlines and some international airlines
  - LA Area airports, and all airports with non-stop service to this region
  - The FAA and Air Traffic Controllers
  - Federal, state and local governments
  - Local communities
  - International communities

Incentives

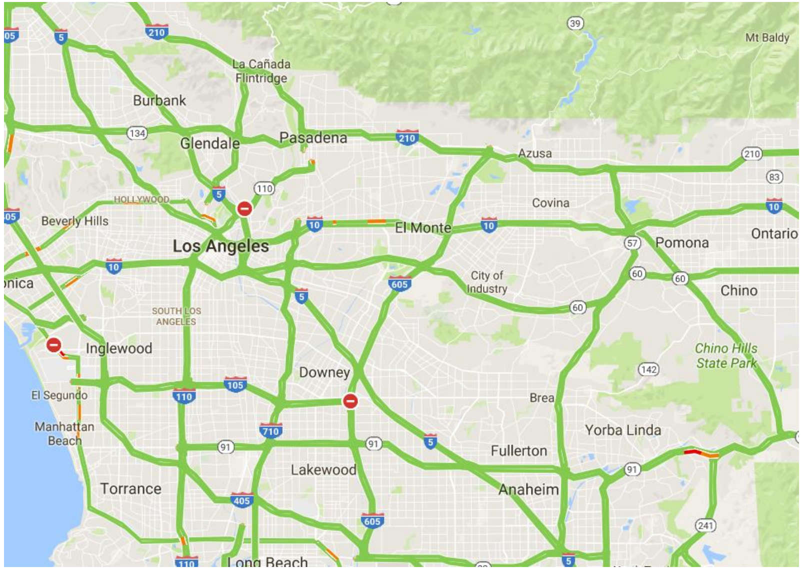
- The current free market minimizes costs to all entities
- Any disruptions will come at costs to at least some users:
  - Costs of increased ground/road travel time and pollution
  - Costs of more complex international connections
  - Costs of reduced airline and airport revenue
  - Psychological costs associated with loss of convenience

- Existing incentives:
  - More efficient airside travel experience
  - Reduced aircraft operating costs and pollution

- Some individuals may not accept any incentives at all

Pros

- Reduced emissions
- Better passenger experience
- Possible cost savings
- A better utilized system
- Reduced ground traffic
- Possible increased profits for airlines
- Time savings!



… but for the air and airport taxiways

Cons

- Changing from the norm
- Rerouting flight paths
- Passengers could be resistant to change
- Increased traffic at 4 airports other than LAX
- Loss of profit for LAX
- Might not be a demand for rerouted flights

Summary

- Background research on the LA airport markets
- Obtained data from ASPM and Google Maps
- Visualized both data sets
- Optimized and analyzed data
- Outline implementation of our proposed solution