Airport and Aviation Demand

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Presentation

- Aviation demand (historical perspective)
- Forecast methods
- Constrained demand
- Examples
- Conclusions

Introduction

- Demand forecast is part art and part science
- Demand forecasts have substantial amount of uncertainty
- Most airport and aviation forecasts are off by 25% in 5 years (deNeufville and Maldonado)
- Demand should be estimated for multiple airport development scenarios
- Estimate demand uncertainty and include alternatives that will minimize the investment risk for the airport authority

Why so Much Demand Uncertainty?

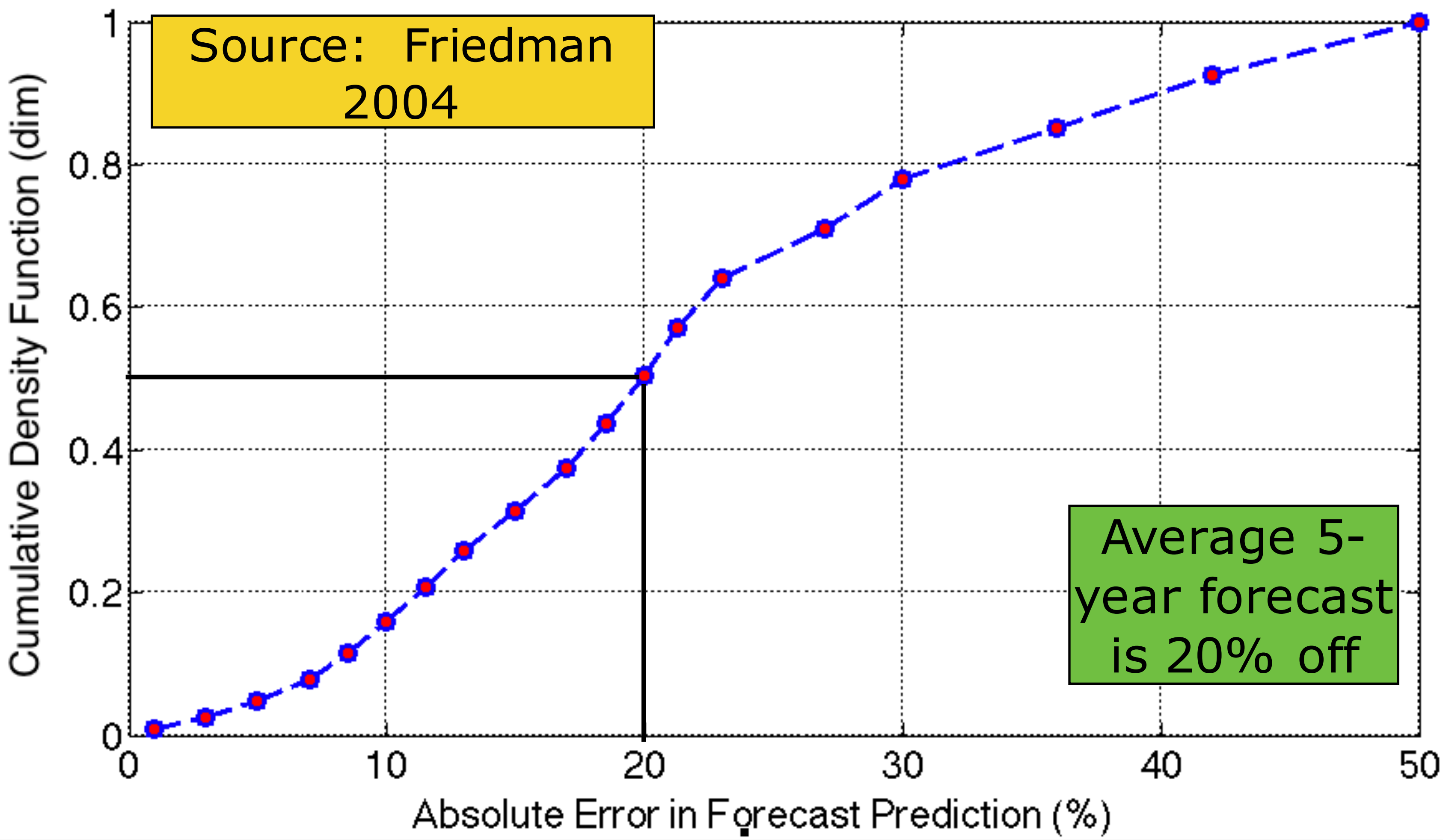
- Many exogeneous factors
- Deregulation, low cost carriers
- Terrorism
- Uncertainty in the economy of the country or regions of the World
- Environmental impacts and constraints
- Multi-airport competition
- Political factors
- Demographic changes and land use

Impact of Demand Uncertainty

- We need to develop multiple scenarios in how the airport will develop
- Plan the development of the airport so that demand changes can be accomodated with minimum risk
- Decision analysis is a tool used to examine multiple demand forecast solution

Goodness of Airport Aviation Forecasts

- Percent Absolute Error of FAA Terminal Area Forecast (Five year forecast)



CEE 4674 – Airport Planning and Design (copyright A. Trani)

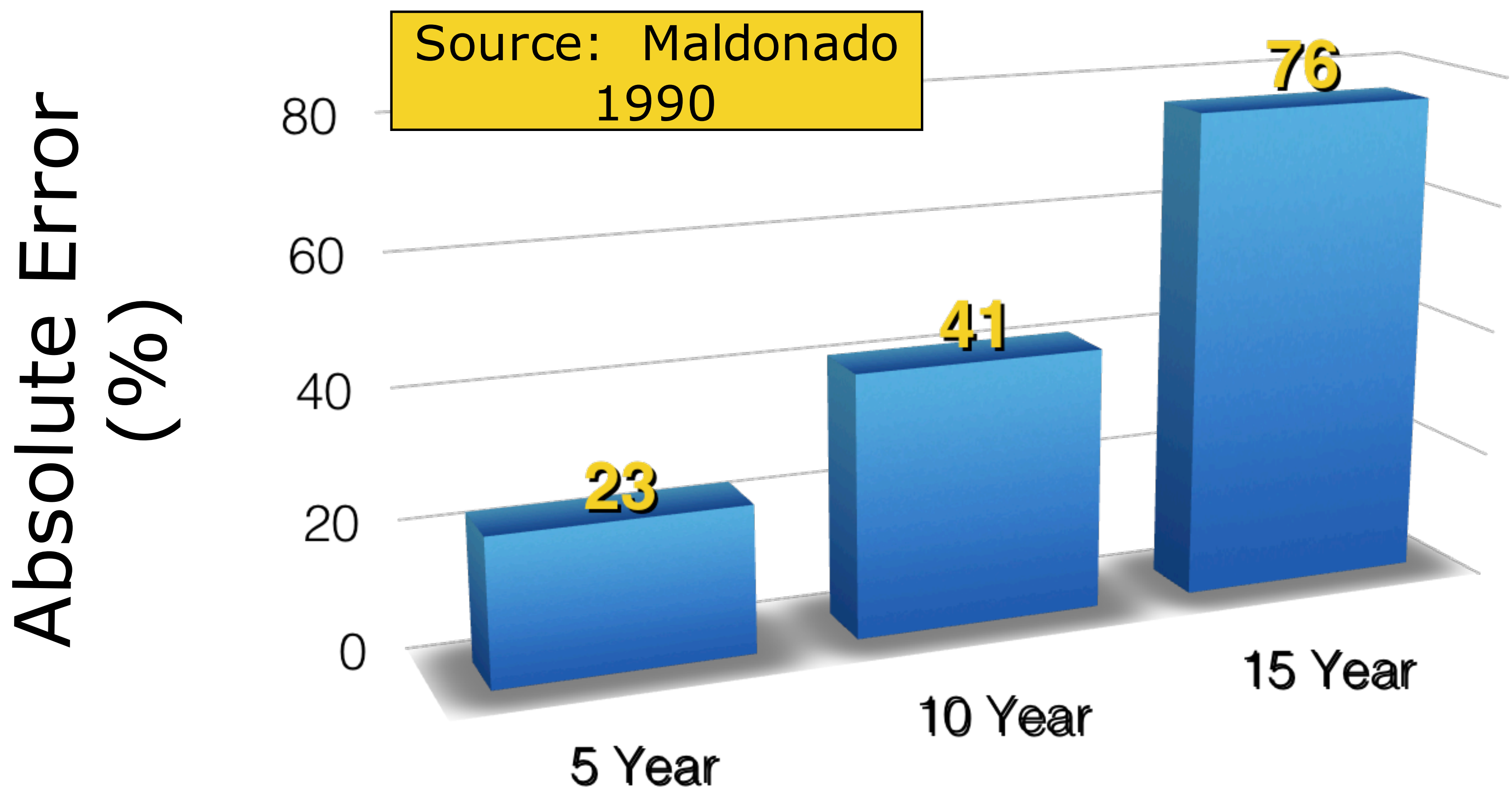
Uncertainty in Aviation Forecasts Applies to Many Markets

- Average difference between a 5-year forecasts and actual international passenger demand was 22%
- Average difference between a 10-year forecasts and actual international passenger demand was 40% (Nishimura, 1999)

Source:of map
http://www.yadyad.com

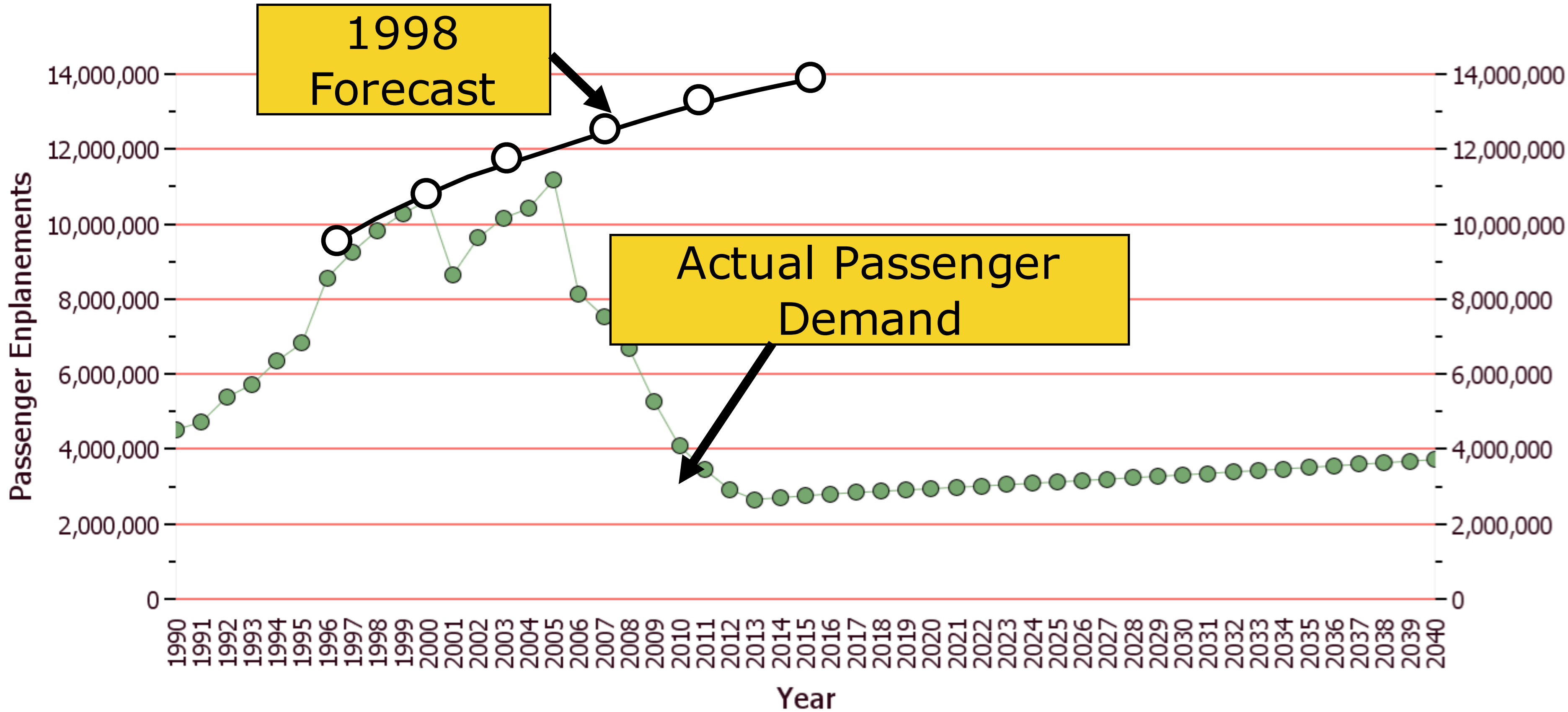
United States Airport Master Plan Forecasting Experience

- Longer term forecasts have higher inaccuracies than short-term forecasts



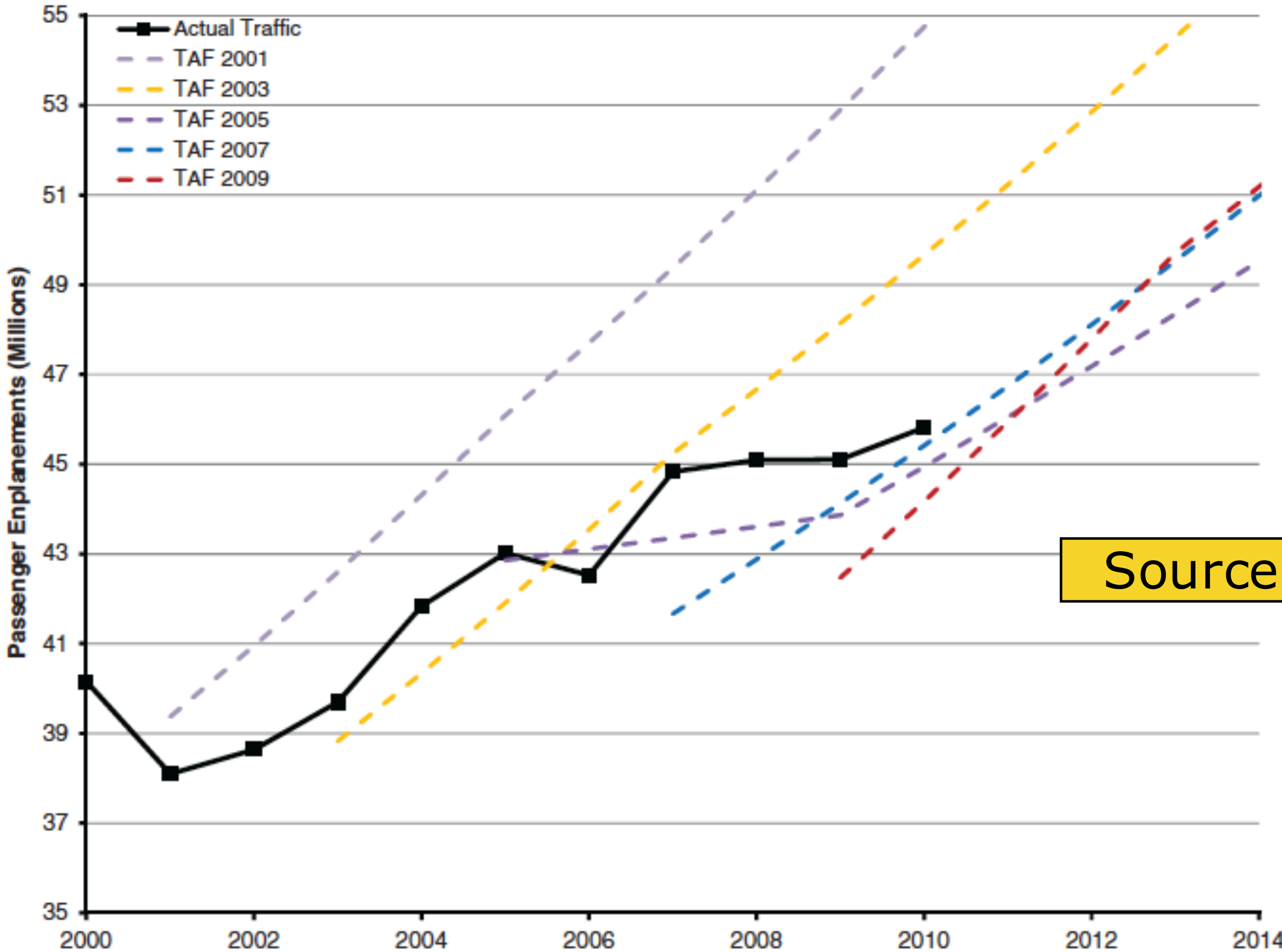
Example Volatility in Airport Demand (Cincinnati International Airport - CVG)

- Cincinnati was a hub for Delta Airlines
- Delta moved its hub operations from CVG in 2005



Source: FAA Terminal Area Forecast 2013

Example: Passenger Enplanement Forecasts for Atlanta International Airport

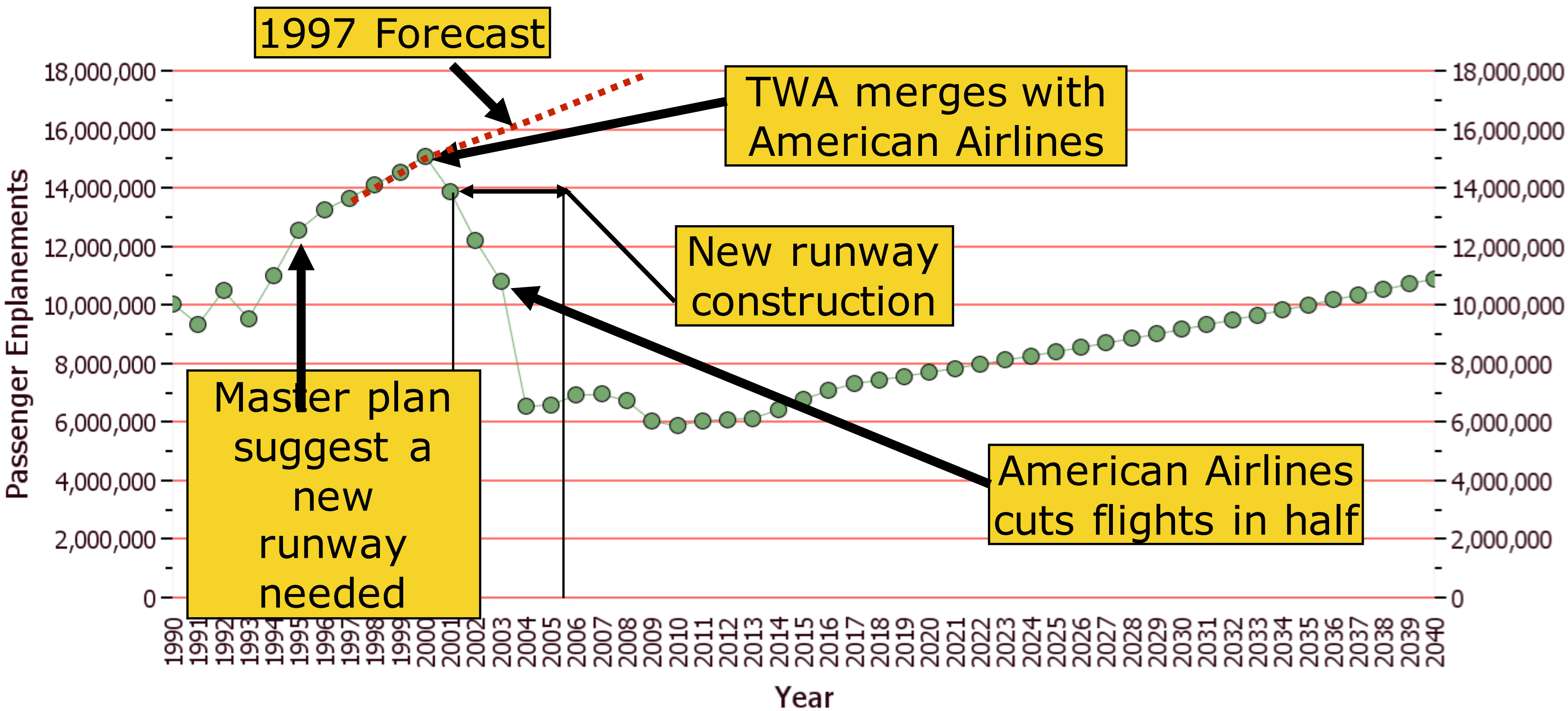


Source: Hartsfield-Jackson Atlanta International Airport operational statistics and FAA TAFs.

Source: ACRP 76

Example Volatility in Airport Demand (Saint Louis International Airport)

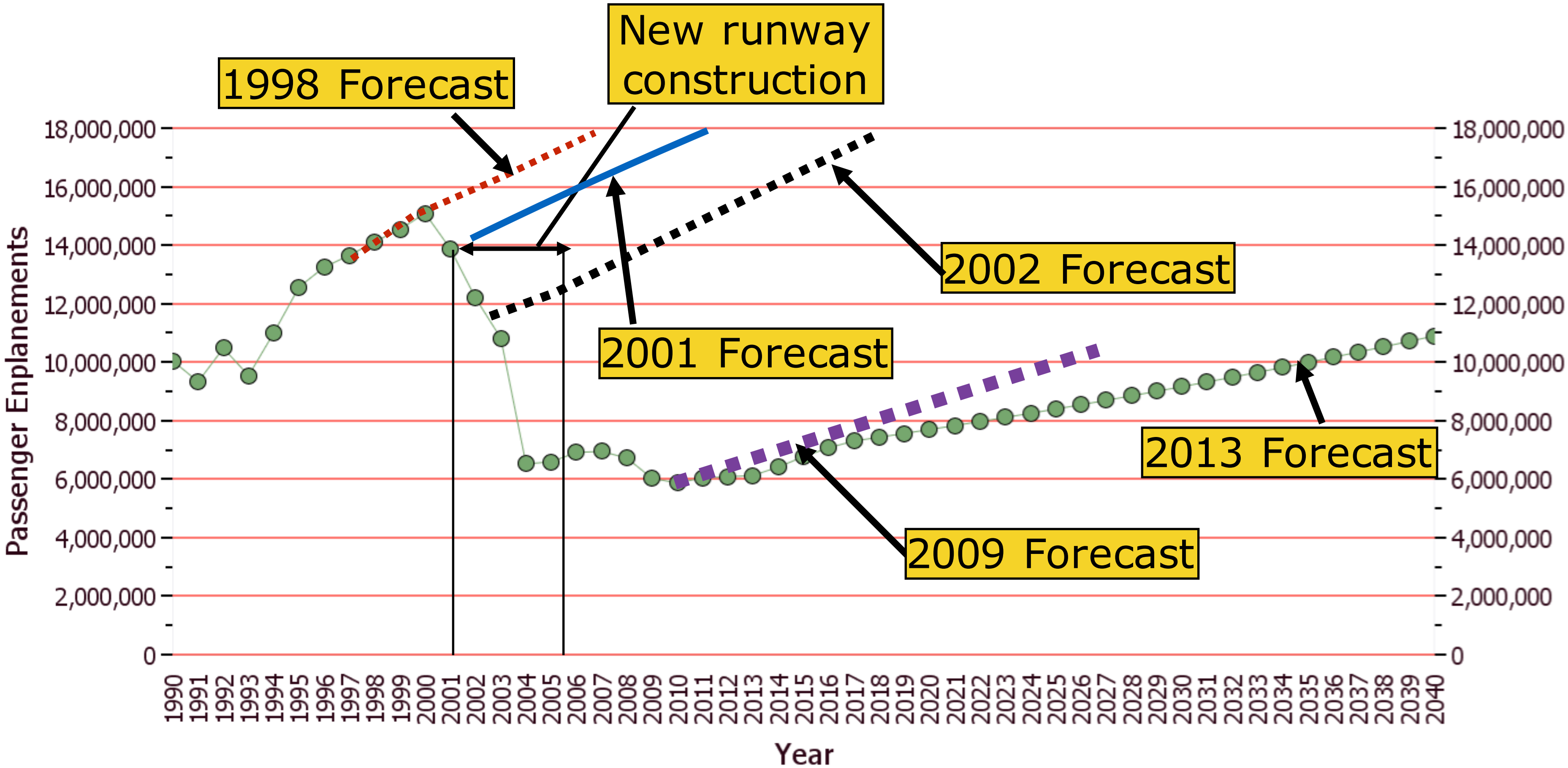
- St. Louis was a hub for Trans World Airlines (TWA)
- TWA merged with American Airlines in 2001



Source: FAA Terminal Area Forecast 2013

Example Volatility in Airport Demand (Saint Louis International Airport)

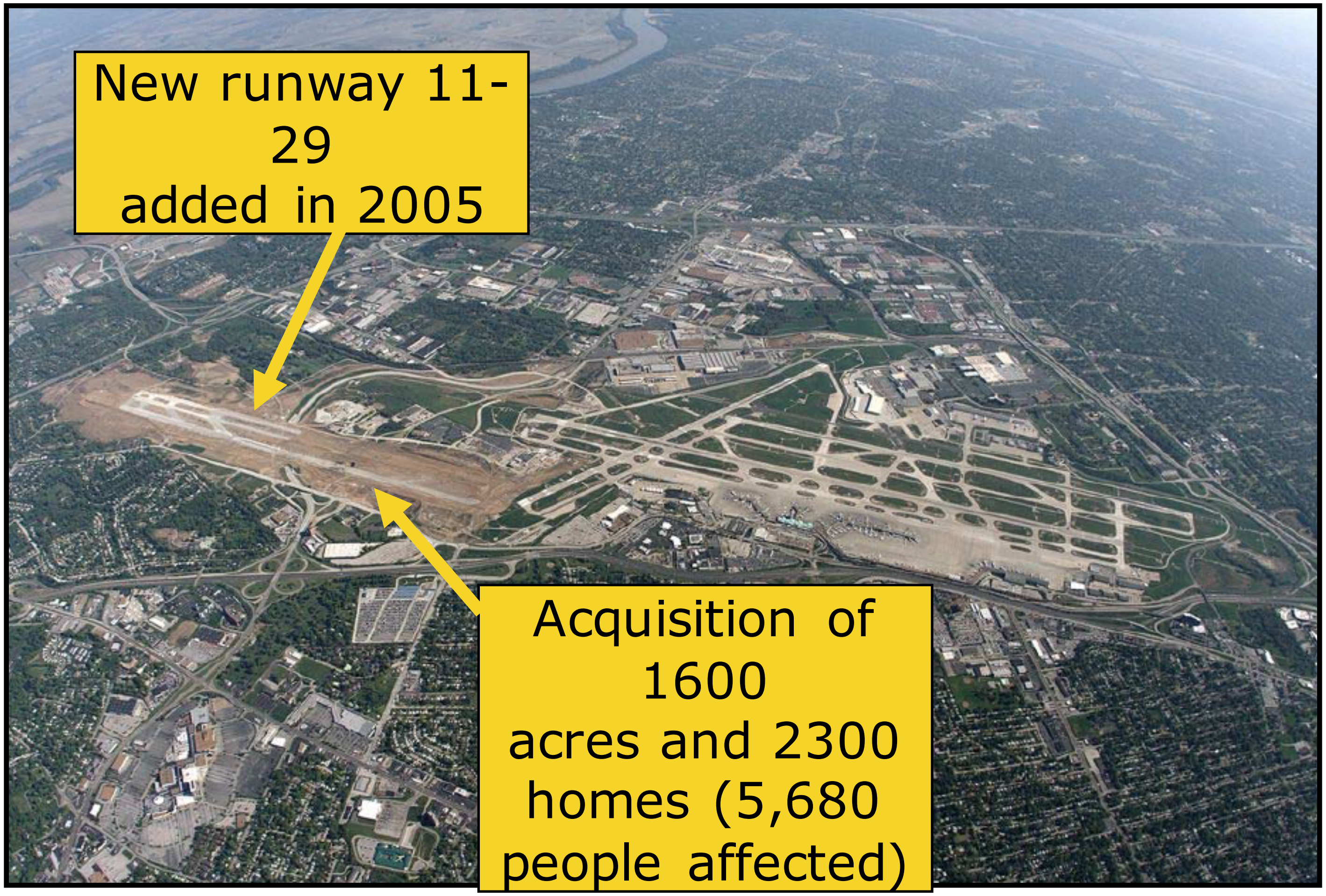
- St. Louis passenger demand forecasts over time



Source: FAA Terminal Area Forecasts

Saint Louis International Airport

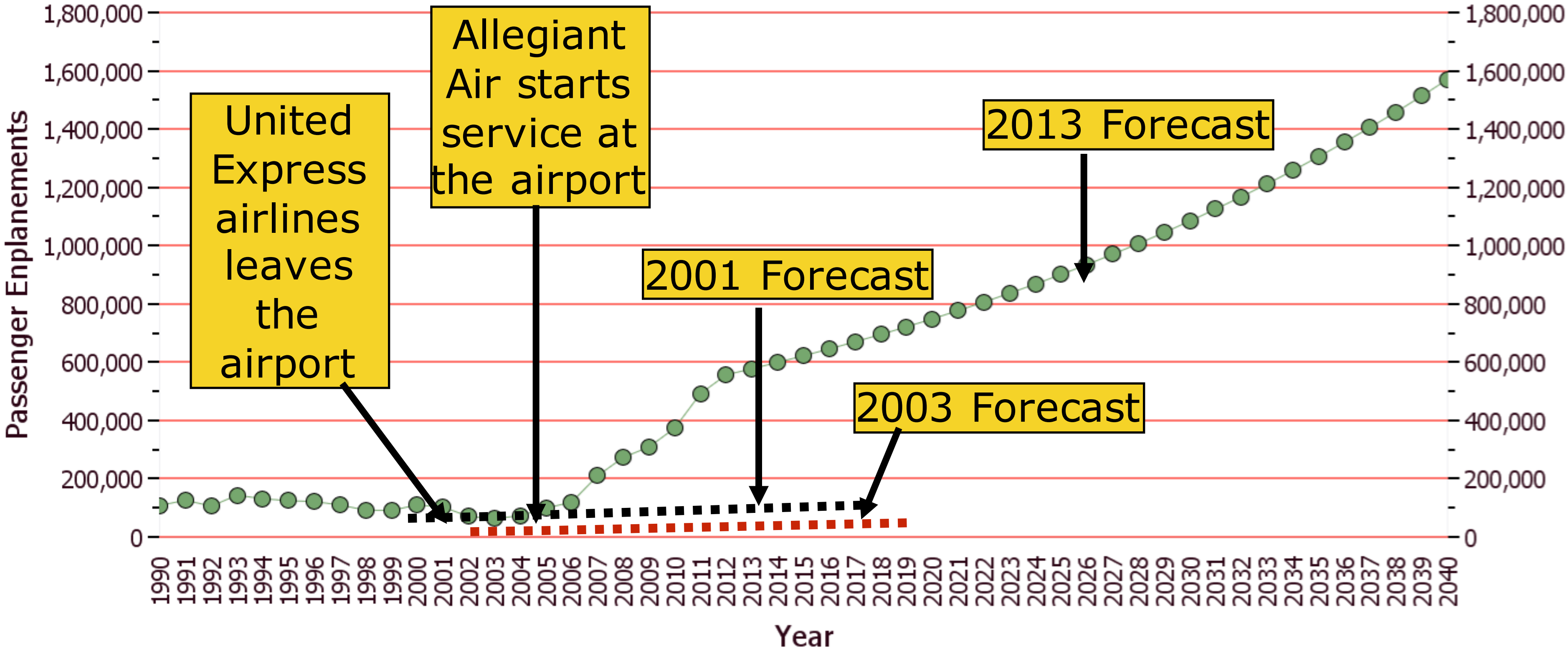
- Saint Louis International added a new runway (at the cost of 1.02 billion dollars in 2005)



Source: http://www.thebhc.org/publications/BEHonline/2011/rust.pdf

Example Volatility in Airport Demand (Bellingham International Airport - US)

- Demand at Bellingham has developed more rapidly than anticipated due to flight by a Low Cost Airline (Allegiant Air)



Source: FAA Terminal Area Forecasts and BLI Data

Summary of Airport Forecast Accuracy

- Previous studies suggest airport forecasts are off by an average 20-23% in five years
- Longer-term forecasts (15 years) can be off by an average absolute error of 76%
- For this reason, airport planning should rely on careful examination of various alternatives
- Short-term forecasts can favor mathematical models
- Long-term forecasts require both modeling and also common sense (i.e., expert opinion)

Dealing with Airport Forecast Uncertainty

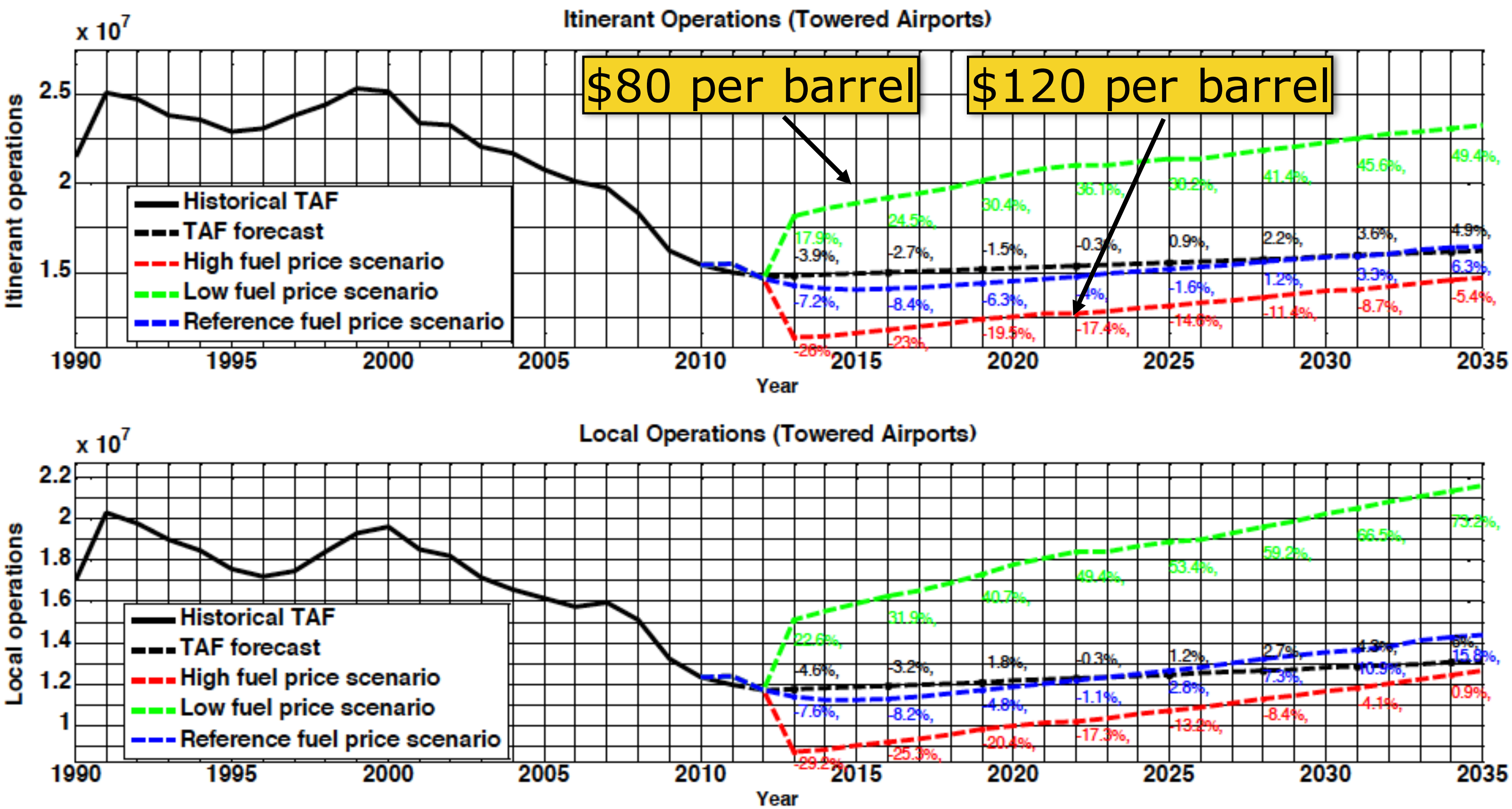
- Airport master planning is not a linear process: Risk assessment is key in today's airport planning environment
- Strategic thinking requires a solid understanding of the airport/airline industry in the context of the airport development
- Airport are connected systems and thus affected by other airports in a national and international environment
- National government directed plans are rare in today's competitive airport environment
- Flexible or dynamic strategic airport planning requires an assessment of risk and financial planning simultaneously

Techniques to Deal with Airport Demand Uncertainty

- Data-driven approaches
  - Low-High forecast
  - What-if analysis
  - Sensitivity analysis
  - Prediction intervals in Time-Series methods
  - Extrapolation of empirically observed errors
  - Distribution fitting and Monte Carlo simulation
- Judgement procedures
  - Delphi techniques

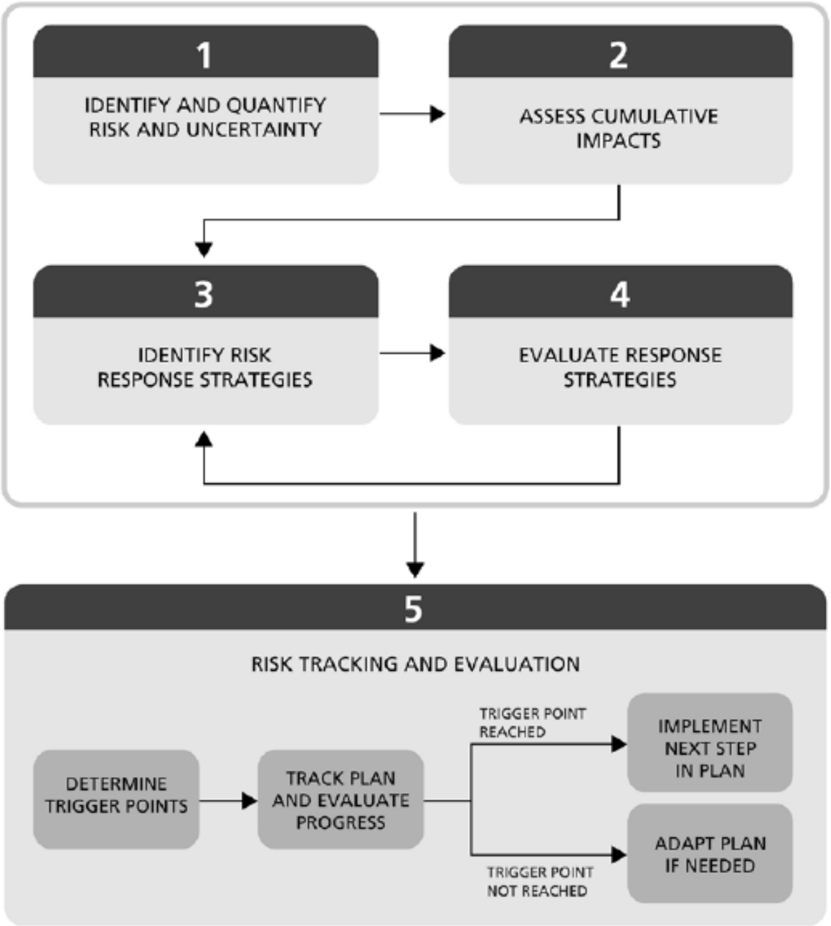
Example of Sensitivity Analysis Applied to a Forecast of General Aviation Demand in the US

Li and Trani, 2013



Airport Cooperative Research Program Method to Address Airport Demand Uncertainty

- Multi-step process to deal with airport demand uncertainty
  - Step # 1 - Identify risk and uncertainty
  - Step # 2 - Quantify cumulative impacts
  - Step # 3 - Identify risk response strategies
  - Step # 4 - Evaluate response strategies
  - Step # 5 - Risk tracking and evaluation



Source: Airport Cooperative Research Program Report 76

Methodology and Its Variations to Deal with Airport Demand Uncertainty

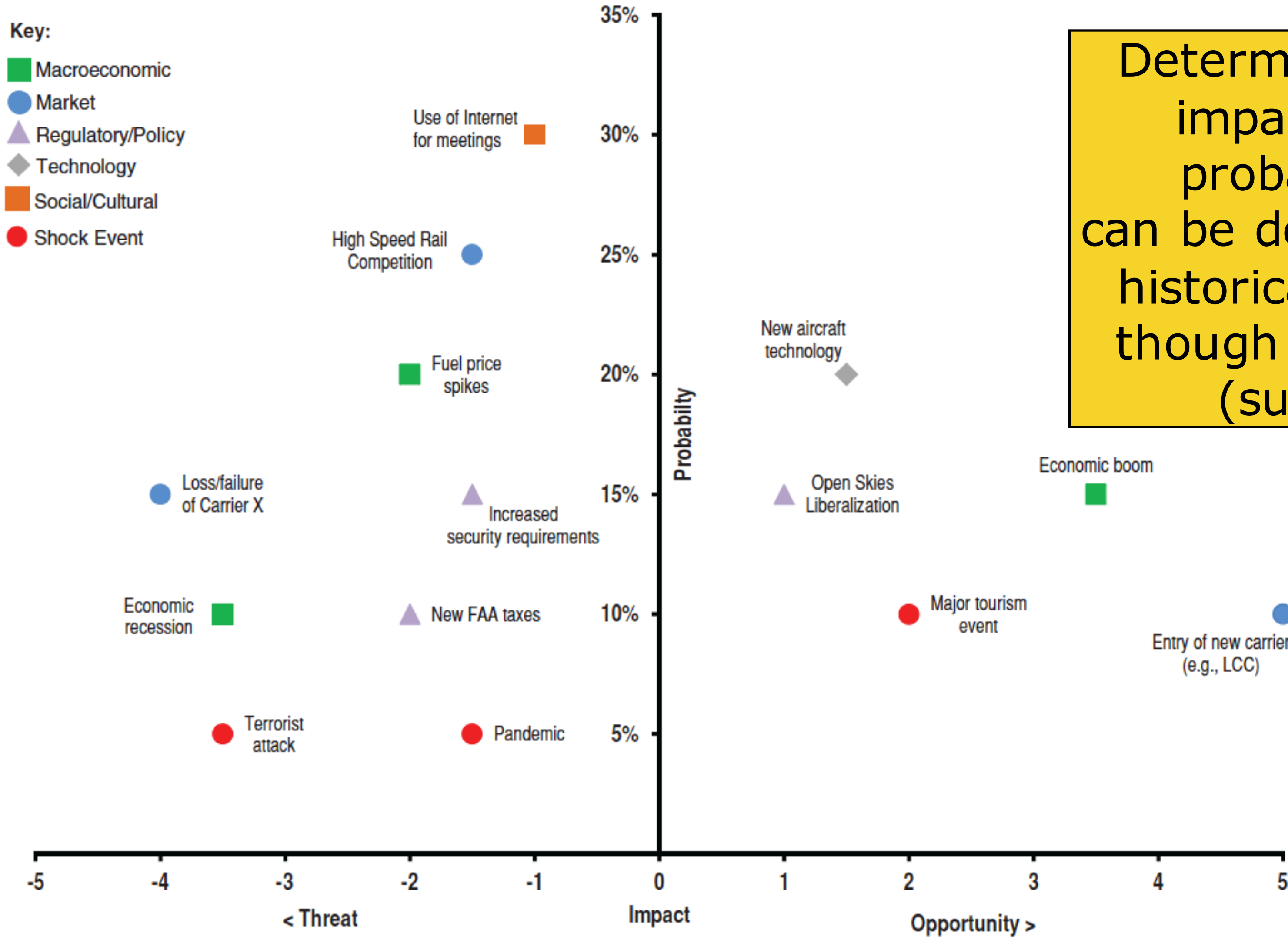
Step	Track A Mostly Qualitative	Track B Some Quantification	Track C Quantitative, with Limited Stakeholder Involvement	Track D Quantitative, with Peer Review and Structured Elicitation
1. Identify and quantify risk and uncertainty	Development of the risk register based largely on the guidebook combined with qualitative analysis, visual aids, and informa elicitation within the airport.	Development of the risk register based largely on the guidebook combined with qualitative analysis, visual aids, and formal elicitation (e.g., Delphi) within the airport.	Development of the risk register based on quantitative analysis, where possible, combined with formal elicitation (e.g., Delphi) within the airport and with key stakeholders.	Development of the risk register based on quantitative analysis, where possible, combined with formal elicitation (e.g., Delphi and structured workshops) with airport management/planners, subject matter experts, and a wide range of stakeholder groups.
2. Assess cumulative impacts	Based on basic scenario analysis and qualitative approaches.	Based on basic scenario analysis and other simple modeling approaches.	Use of more advanced modeling procedures such as Monte Carlo simulation.	Use of more advanced modeling procedures such as structure and logic diagrams and Monte Carlo simulation.
3. Identify risk response strategies	Based largely on the information provided in the guidebook with informal elicitation within the airport.	Based on the guidebook and research on examples and best practice at other airports with informal elicitation within the airport.	Based on research of examples and best practice at other airports and informal elicitation within the airport and with key stakeholders.	Based on research of examples and best practice at other airports and formal elicitation within the airport and with stakeholders.
4. Evaluate risk response strategies	Largely qualitative and basic quantitative assessment.	Largely qualitative and basic quantitative assessment.	Quantitative analysis such as expected net present value.	Quantitative analysis such as expected net present value.
5. Risk tracking and evaluation	Tracking of traffic against forecasts and trigger points and annual review of risk register.	Tracking of traffic against forecasts and trigger points and annual review of risk register.	The risk register is updated continuously (possibly using a database system) whenever new pieces of information come in. Full periodic reviews of the risk register.	Major risks may be assigned to specific airport staff (risk managers) for tracking and updates. The risk register is updated continuously (possibly using a database system) whenever new pieces of information come in. Full periodic reviews of the risk register.

Source: Airport Cooperative Research Program Report 76

Step # 1: Sources of Airport Forecast Uncertainty

- Global, regional or local economic conditions
- Airline strategy changes
- Low cost carrier market share growth
- Multi-airport systems competition
- Technology changes
- Social and cultural factors
- Exogenous shock events
- Regulatory and government policies
- Statistical model errors

Step # 1: Summary Plot of Risks and Uncertainties

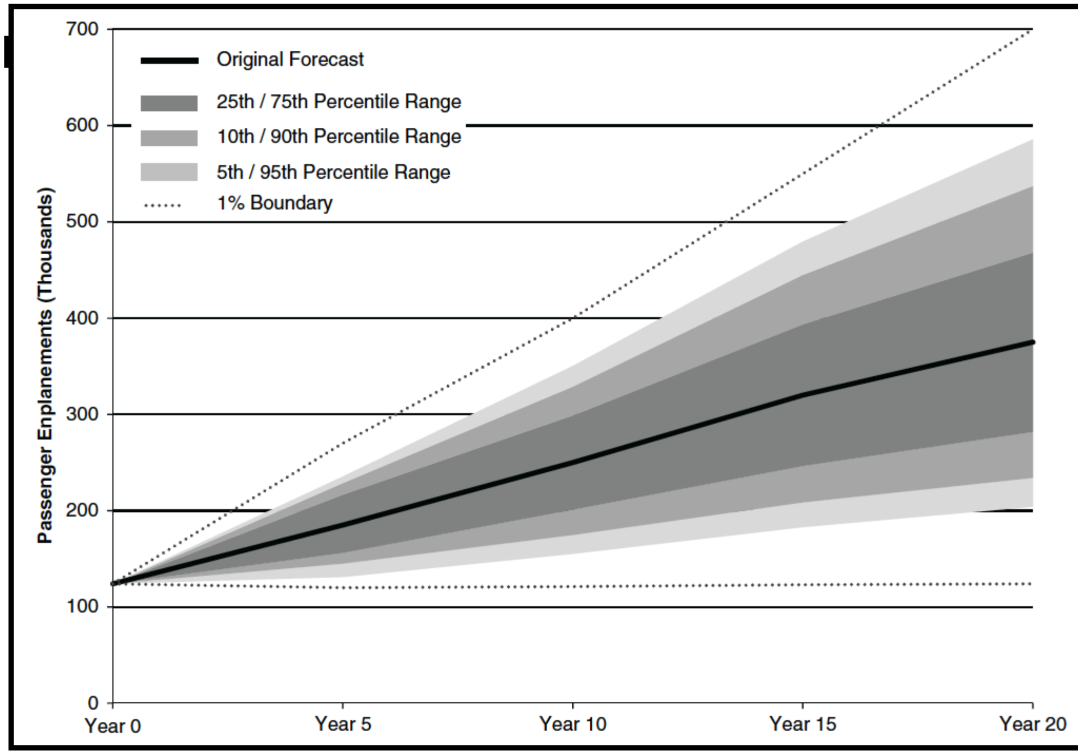


Determination of impacts and probabilities can be derived from historical data or though elicitation (survey)

Source: Airport Cooperative Research Program Report 76

Step # 2: Assess Cumulative Impacts

- This steps *"integrates the risks identified in Step 1 into a structural model of uncertainty"* (ACRP 76)
- Structured, logic or causal diagrams can be used to explain the causality between model variables
- Quantifying the cumulative impacts requires:
  - Monte Carlo simulation
  - Scenario analysis



Source: Airport Cooperative Research Program Report 76

Step # 3: Risk Response Strategies

- This steps identifies *"risk and uncertainties facing the airport as threats and opportunities."*
- Quantifying threats and opportunities requires:
  - Anecdotal evidence
  - Judgement

Field Name	Example of Content
Risk ID	M1
Status	Active, Dormant, Retired
Risk Type	Market
Date Identified	01-01-2011
Risk Name	Loss of major carrier
Description	Carrier X removes the majority of its operations from the airport either through financial failure or change in strategy.
...	...
Risk response strategies	Linked to the following files: RR1; RR8

Field Name	Example of Content
Risk Response ID	RR1
Risk Strategy	Air service development
Description	Air service development program to attract additional carrier to the airport
Current Status	Targeting airlines Y and Z
...	...

This step establishes trigger points

Source: Airport Cooperative Research Program Report 76

Step # 4: Evaluate Risk Response Strategies

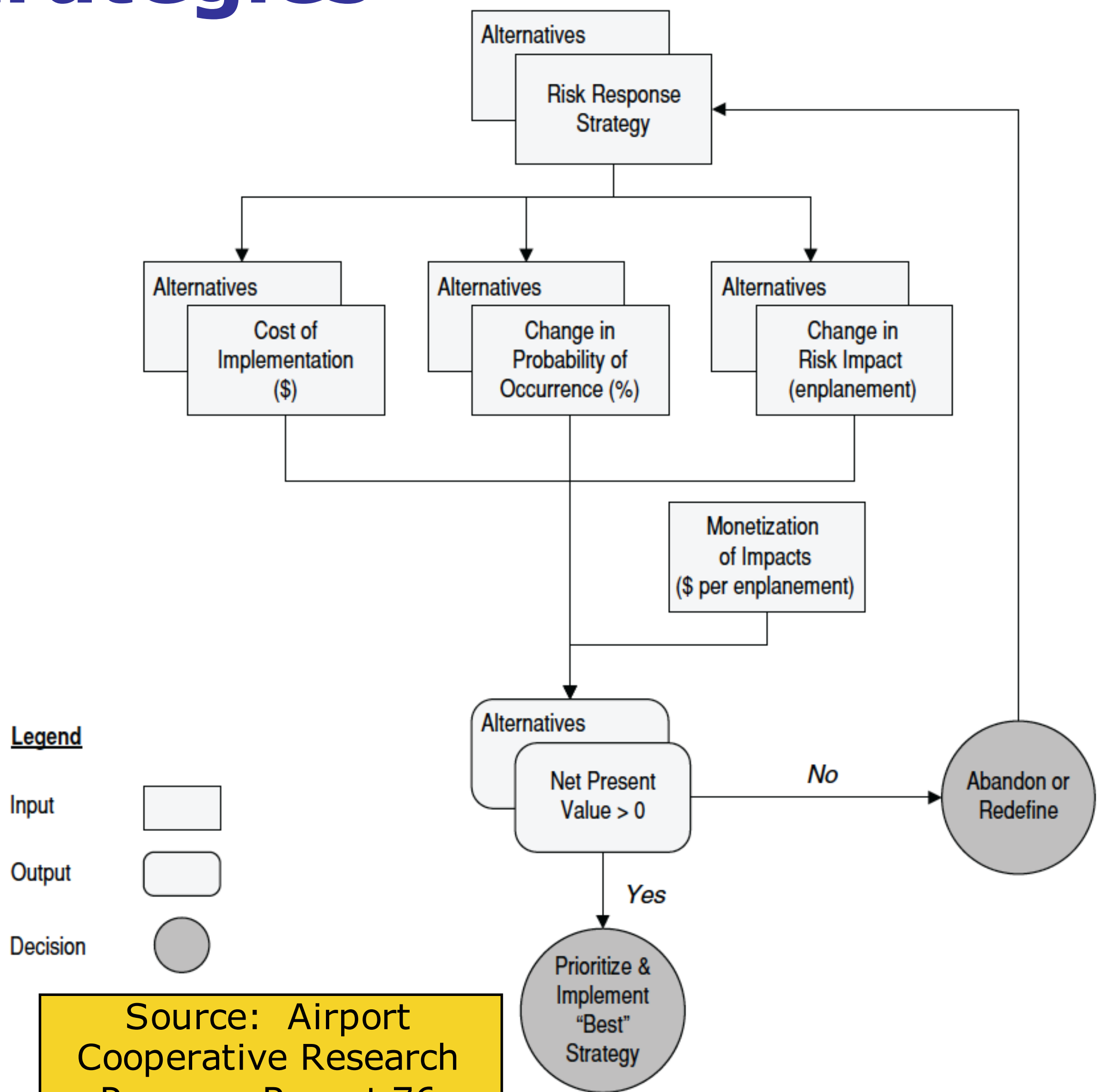
- This steps quantifies "*threats and opportunities facing the airport.*" *(ACRP 76)*
- *Specific goals are:*
  - *Identify the highest value risk response strategy*
  - *Demonstrate robustness over a wide range of outcomes*
  - *Determine value for money*
- Quantifying threats and opportunities requires:
  - Anecdotal evidence
  - Judgement

Source: Airport Cooperative Research Program Report 76

Step # 4: Evaluate Risk Response Strategies

Approaches to evaluate risk response strategies:

- Judgement
- Monte Carlo simulation
- Decision tree analysis
- Economic techniques (NPV, CBA, etc.)



Source: Airport Cooperative Research Program Report 76

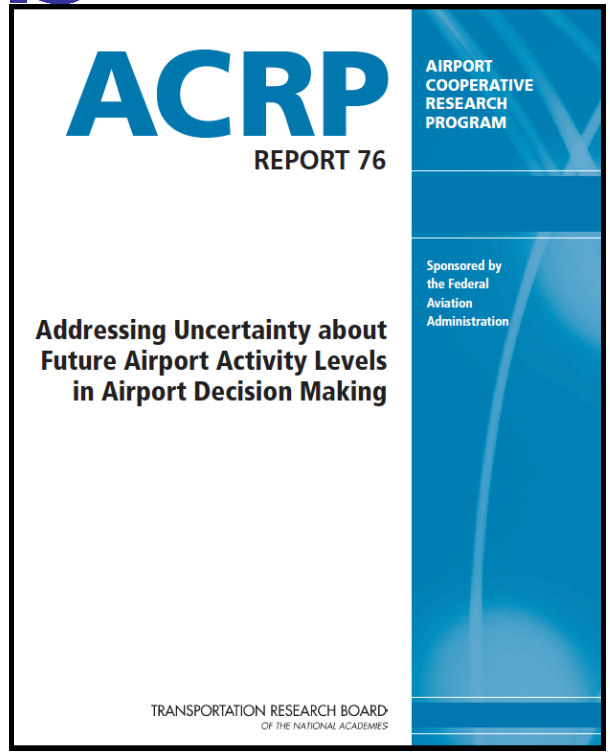
Step # 5: Risk Tracking

- This steps *"is an ongoing process of review, revision, and engagement." (ACRP 76)*
- *Specific goals are:*
  - *Continually assess the risk environment facing the airport*
  - *Identify new or changing risks, and*
  - *Take action where necessary*
- Actions
  - Periodic updates
  - Airport benchmarking

Source: Airport Cooperative Research Program Report 76

Reference Materials

- ACRP Report 76 Addressing Uncertainty about Future Airport Activity Levels in Airport Decision Making
- Deneufville R. and Odoni A., Airport Systems: Planning Design and Management, McGraw Hill, 2013
- Maldonado, J., Strategic Planning: An Approach to Improving Airport Planning under Uncertainty", MS Thesis, MIT (1990)
- Flyvbjerga, B, M. K. Skamris Holma and S. L. Buhla, Inaccuracy in Traffic Forecasts, Transport Reviews: A Transnational Transdisciplinary Journal, Volume 26, 2006.



Reference Materials

- Federal Aviation Administration (FAA), Terminal Area Forecast (TAF), https://aspm.faa.gov/main/taf.asp
- Li, T, and Trani, A.A., General Aviation Demand Estimation Model, ICNS Conference, Washington, DC 2013.
- Nishimura, T. Dynamic Strategic Planning for Transportation Infrastructure Investment, MIT M.S. Thesis,, 1999
- Freidman, J., Terminal Area Forecast Accuracy Assessment Results, MITRE CAASD, unpublished report, 2004.

The Basic Idea Behind Demand Forecast

- Demand can be expressed as the number of passengers that travel or the number of flights in a given unit of time
  - Demand is sensitive to airline fares and level of service attributes
  - The number of operations depends on how operators shoose to the serve the existing demand (supply side) which leads to canges in operator price, schedules, amenities, etc.
- Reasons for travel
  - Business
  - Pleasure (vacation)
- A passenger reacts differently if he/she pays for the trips than if someone else pays

Observations

- Air transportation demand is related to the socio-economic characteristics of the region in question
- Demand for air transportation services is greater in more developed regions of the world
- The noted dependencies between the demand for air transportation services and the socio-economic characteristics of the region are used in the air transportation planning process
- This process entails the planning of airports, needed transportation facilities, route networks, and planning the network of airways

Measures of Demand, Supply and Efficiency

Demand

- Revenue Passenger Enplanements (RPE) = The total number of passengers boarding an aircraft
- Revenue Passenger Miles (RPM) = revenue passenger enplanements multiplied by the distance flown by the passenger

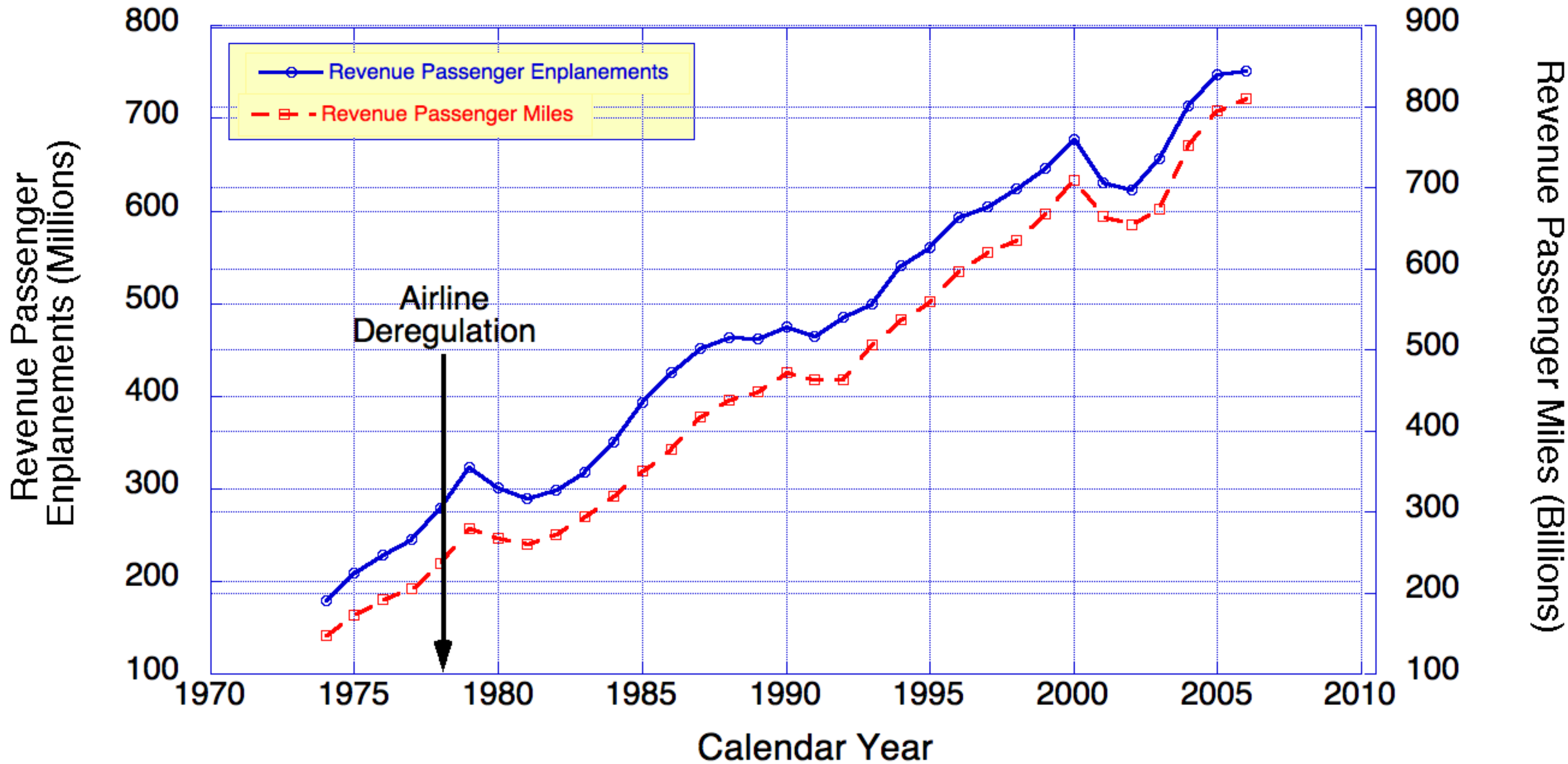
Capacity

- Flights Departures (FD) offered = number of departures (flights)
- Available Seat Miles (ASM) = number of seats offered by airlines multiplied by the miles flown by each flight

Productivity

- Load factor = ratio of RPM and ASM

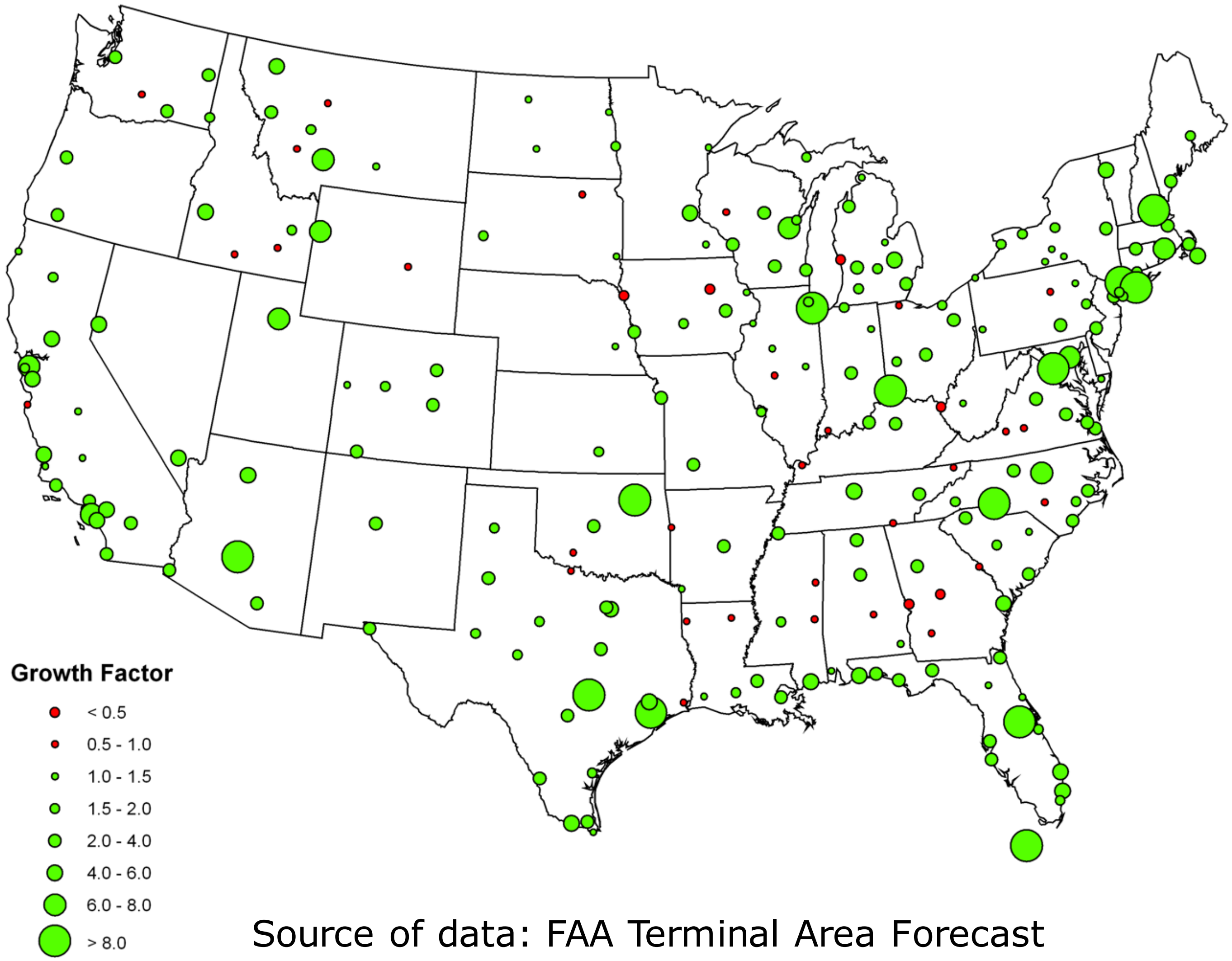
Historical Aviation Demand in the U.S.



Source of data: Bureau of Transportation Statistics

The number of passengers enplaned tripled between 1976 and 2006

Growth of Passenger Enplanements (1976 to 2006)



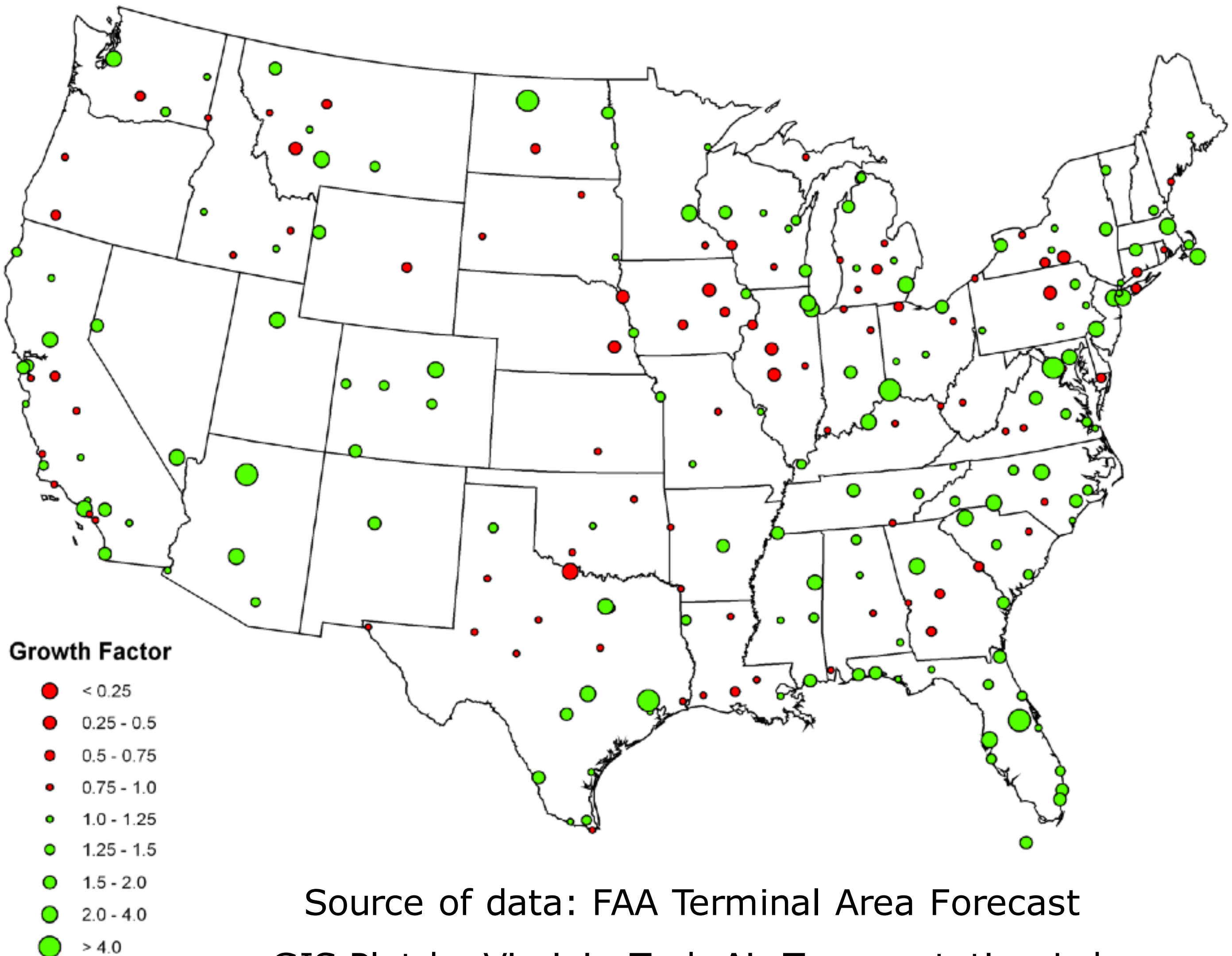
Source of data: FAA Terminal Area Forecast

Virginia Tech Air Transportation Lab

Observations (1976 to 2006)

- The figure shows observed enplanement growth factors for the top 287 airports in the U.S. between years 1976 and 2006
- Note that some airports in this figure show extremely high growth factors
- Chicago Midway (MDW) is an example of such growth
- In 1976 Midway had 12,624 enplanements with Chicago O'Hare experiencing robust traffic levels above 18 million enplaned passengers during the same year
- After the airline deregulation and with traffic pressures increasing at Chicago O'Hare, traffic at Midway increased to 191,946 enplanements by 1980 and soared to 8.6 million in 2006.

Growth in the Number of Operations - Flights (1976 to 2006)



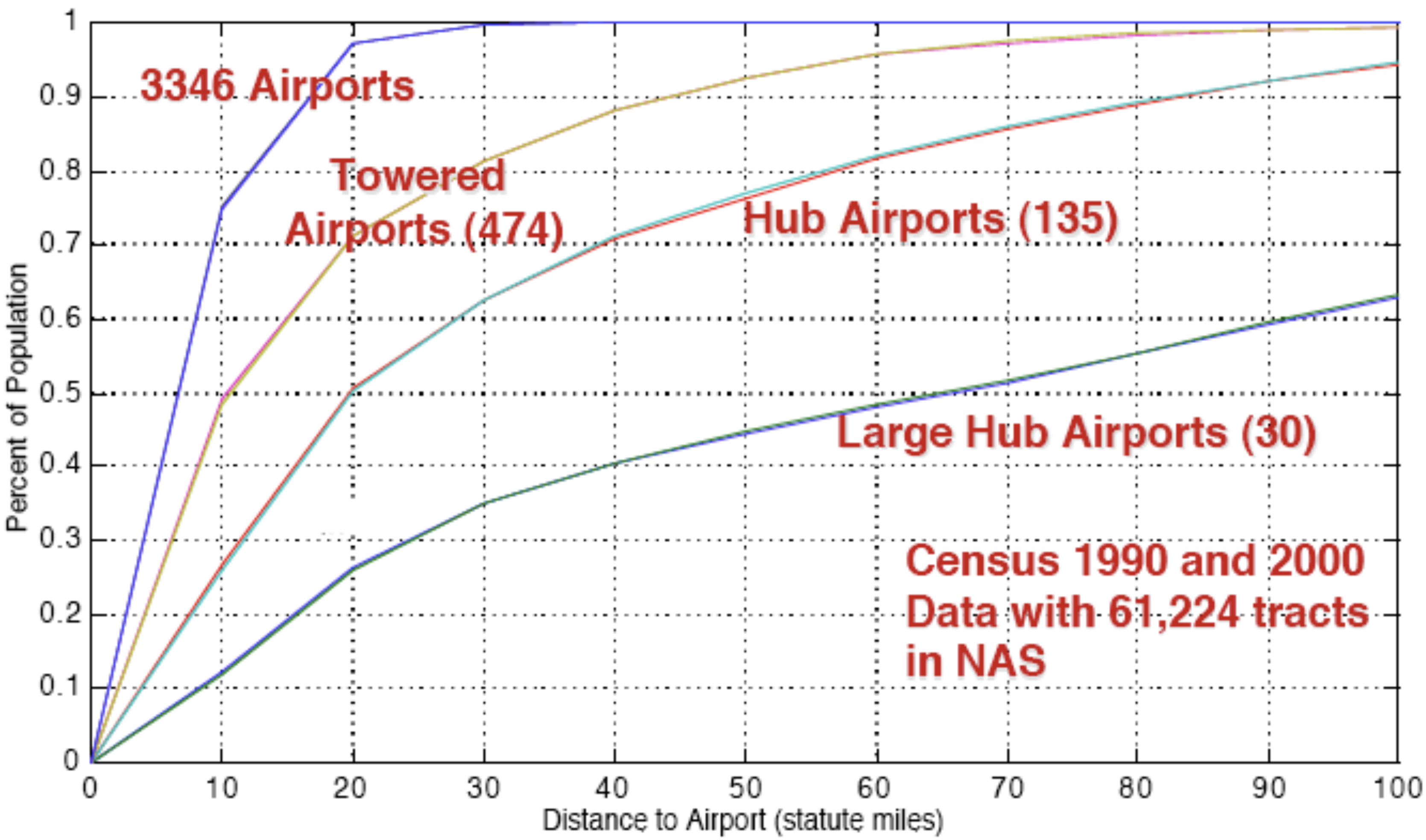
Source of data: FAA Terminal Area Forecast

GIS Plot by Virginia Tech Air Transportation Lab

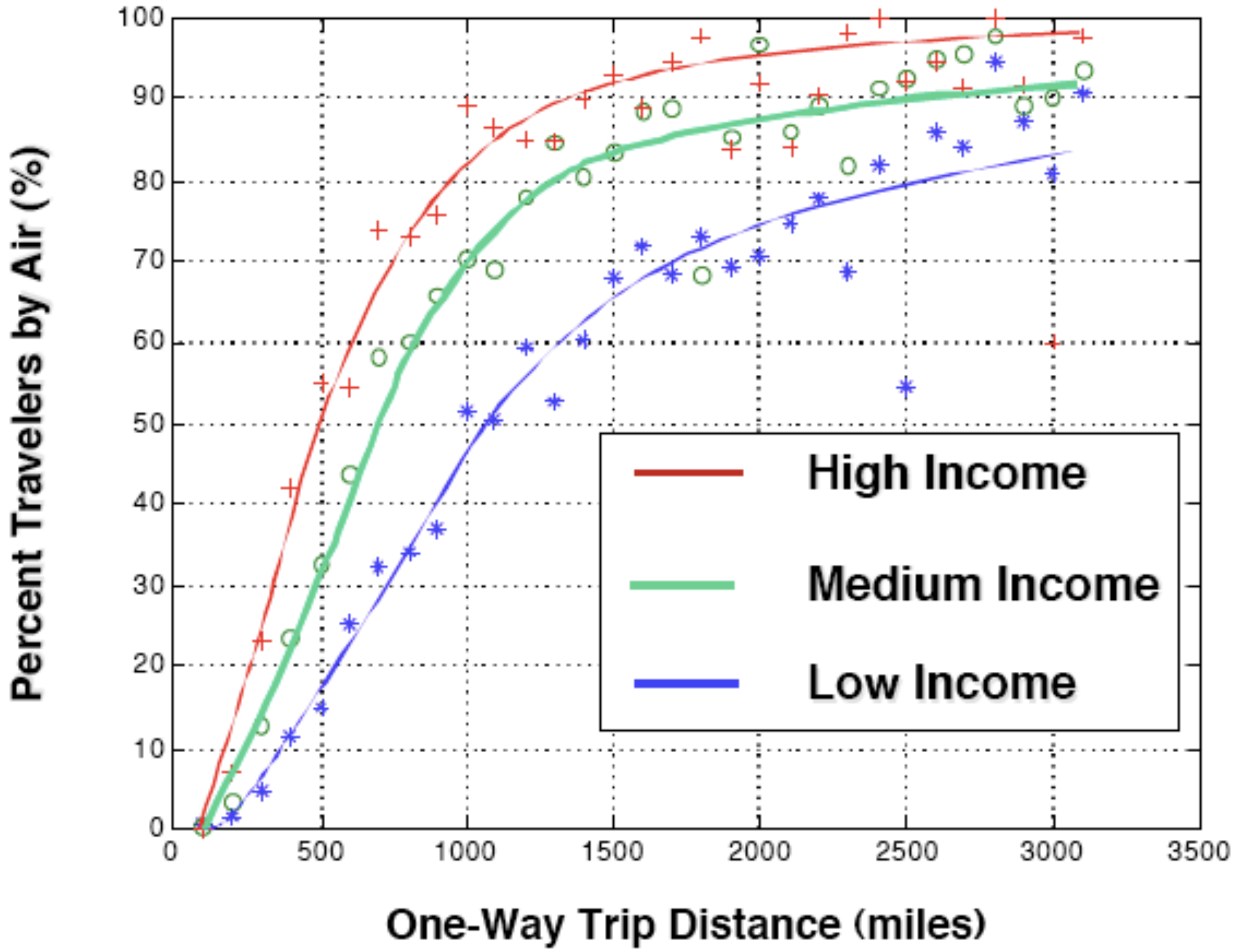
Some Observations (1976 to 2006)

- The figure illustrates the observed growth factors of the top 287 airports with commercial service between 1976 and 2006
- 50% of the airports experienced a decrease in flight operations (arrivals and departures) between 1976 and 2006
  - Twenty medium hub airports
  - Forty-five are small hubs
  - Ninety are non-hubs
- This trend has increased the volume-over-capacity ratio point at which such airports operate, thus increasing delays
- Large hub airports have achieved consolidation
- Consolidation trend:
  - In 1976 sixty three percent of the enplanements in the nation occurred at large hub airports
  - In 2006 that number rose to seventy percent according to FAA statistics

Location of Airports in the U.S. System



Results of Historical Travel Survey (American Travel Survey)

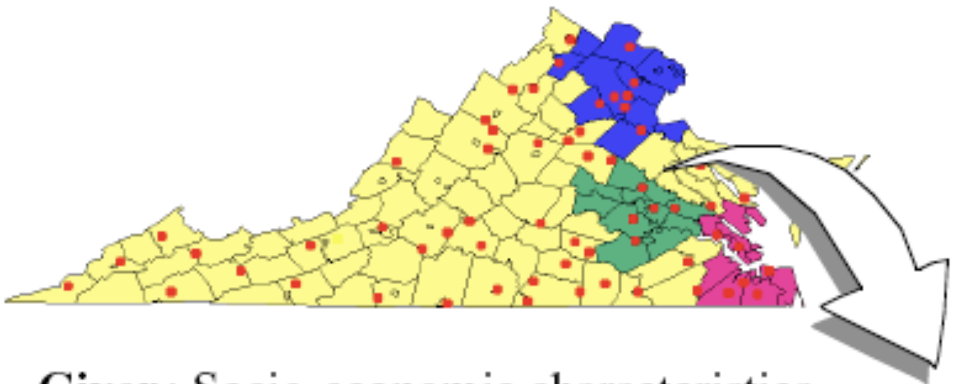


Travel Propensity with Time

Source of data: Bureau of Transportation Statistics

Analysis by Virginia Tech Air Transportation Lab (Henderson and Trani, 2006)

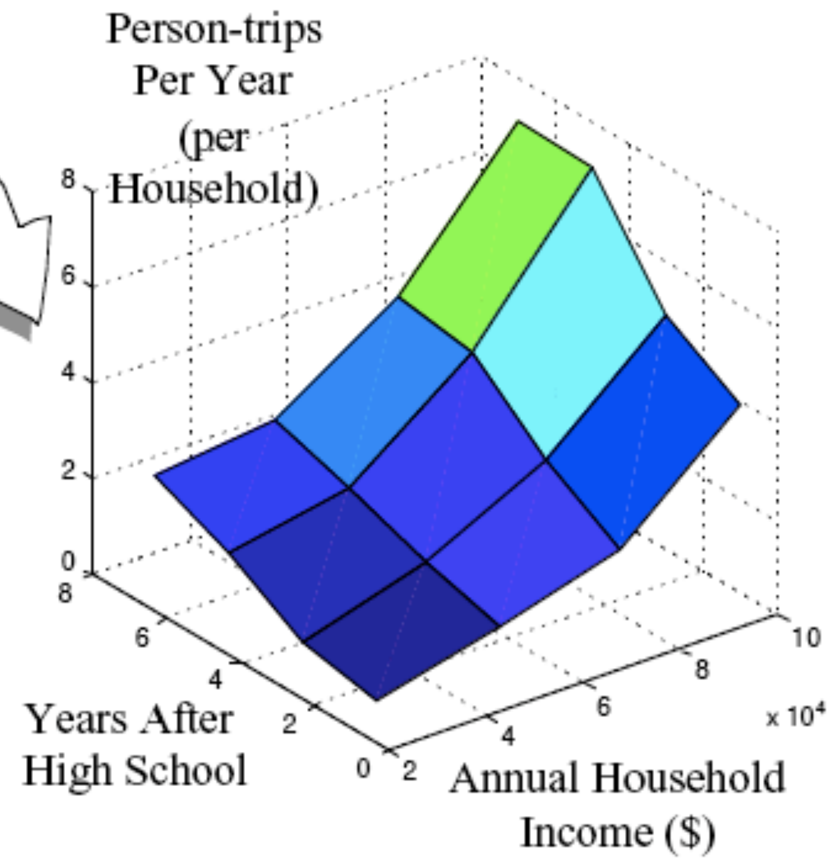
Travel Trends (>100 millas) (U.S. American Travel Survey)



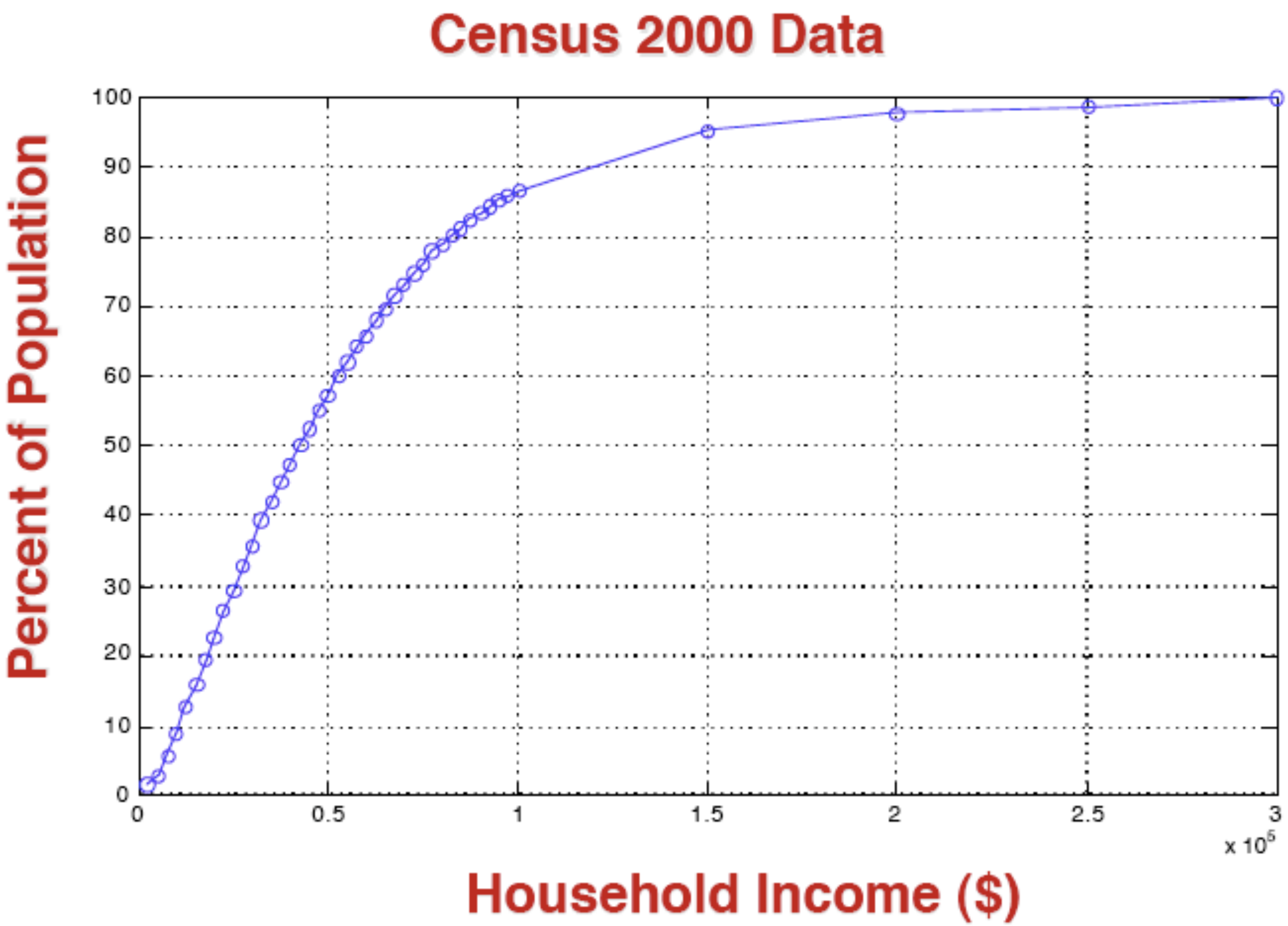
Given: Socio-economic characteristics
for each county (for all states)

Predict: a) Number of trips produced
per household/year
for various income levels
b) Trips attracted to a county

Use: Trip rate tables



Household Income Distribution in U.S.



Intercity Travel

- Aquellos de mas de 100 millas (de ida) distancia en ruta

	1995	2000	Annual Growth Rate[a] (%)
Total Trips (Person-Trips)	1,001,000,000	1,097,372,000	1.9
Business Trips	225,000,000	259,569,000	2.9
Non-Business Trips	776,000,000	837,803,000	1.5
Population (1000 People)[b]	262,761	281,422	1.4
GDP (billion dollars)[c]	7,543.3	9,224.0	4.1

a. Average annual growth rate of x between year t and year $t+n$ = $((x_{t+n}/x_t)^{1/n} - 1) \times 100$.

b. Available at http://factfinder.census.gov

c. Reference year is 1996. Available at http://www.bea.doc.gov

Our Final Objective

The main goal of the analysts and researchers was development of reliable models that can provide various information to decision makers related to some of the following questions:

- How many passengers will use air transportation for business and/or leisure trips at the airport?
- What is the expected number of operations (take offs and landings) at the airport?
- What is appropriate fleet size?
- What is appropriate aircraft mix in the fleet?
- What types of airport investments (new runways, air traffic control modernization, new aircraft types) will improve the regional, national system?

Demand Estimation Techniques

- **Aggregate Models -** use socio-economic variables such as (GDP) and fare to predict aviation demand
  - Causality between socio-economic factors and aviation demand
  - Examples are the FAA Terminal Area Forecast (TAF)
- **Individual choice modeling of travel demand**
  - People choose a mode (airline, GA, auto, rail bus, etc.) based on full price of travel, which includes:
    - Travel time
    - Out of pocket travel costs
    - Access time and cost
    - Trip purpose (business vs. non-business)
  - The TSAM mode choice model employs this framework

Aviation Forecast Techniques

- Expert opinion
- Extrapolation techniques
- Market share analysis
- Econometric models
- Competing mode models

Trend Extrapolation Techniques

- Use of regression models (linear and nonlinear) to assess the demand in the future
- Long-term trend behaviors are most frequently modeled using linear, quadratic or exponential functions

We denote time by t, and the number of air passengers that changes over time by $D(t)$. Trend models of the air transportation demand $D(t)$ in a period t are described mathematically by:

$$D(t) = a + b \cdot t$$ Linear model

$$D(t) = a \cdot b^{t}$$ Exponential Model

$$D(t) = k \cdot a^{b^{t}}$$ Gompertz Model

Trend Extrapolation Techniques (II)

$$D(t) = \frac{k}{1 + b \cdot e^{-at}}$$ Logistic Model

- These model can be calibrated using historical data about the airport facility or region. In most cases a tranformation using logarithms is needed to simplifythe analysis.
- Once a logarithmic transformation has been done we can use standard regression technqiues to the find coefficients of the model

Transforming Non-linear Models

Suppose that we have data of demands and time and would like to use the exponential model:

$$D(t) = a \cdot b^{t}$$

Apply a logarithmic transformation to get,

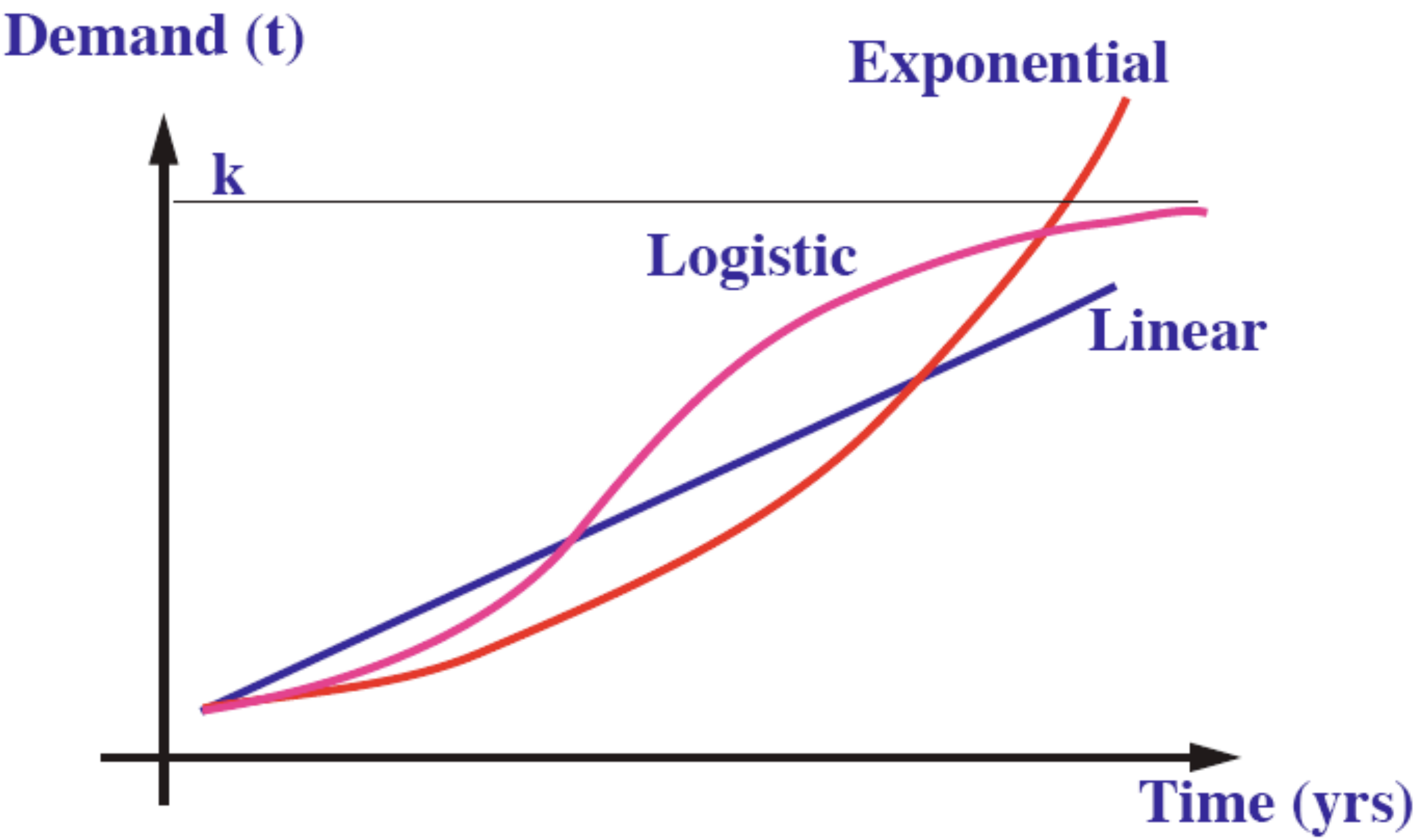
$$\log D(t) = \log(a) + t \cdot \log(b)$$

The new equation is a linear model of the form,

$$y = A + Bt$$

This new model can be studied easily using standard linear regression techniques

Trend Extrapolation Methods



General Observations

- The logistic model is perhaps the best for long-term behavior
- The capacity of the airport (or the system) can be stated in the logistic model
- The linear model can be used in short-term planning
- The exponential model can only be used for short to medium range forecasts

Example of a Logistic Model (I)

- Grilihes developed a logistic model to estimate the demand for passengers at Belgrade airport

$$D(t) = \frac{9,023,394}{1 + 39.88 \cdot e^{-0.176t}}$$

- Where: *D(t)* is he demand as a function of time (t) and t represents the time variable
- This model was derived using data from 1962 to 1978

Example of a Logistic Model (II)

- Lundtorp developed a model to estimate the number of leisure Danish passengers traveling to Portugal via air mode

$$AP = 13,000 + \frac{52,000}{1 + e^{-0.54 \cdot (t - 1986)}}$$

- Where: AP is the number of annual passengers traveling from Denmark to Portugal
- The model was derived using historical data from 1976 to 1986

Another Example for Us to Do

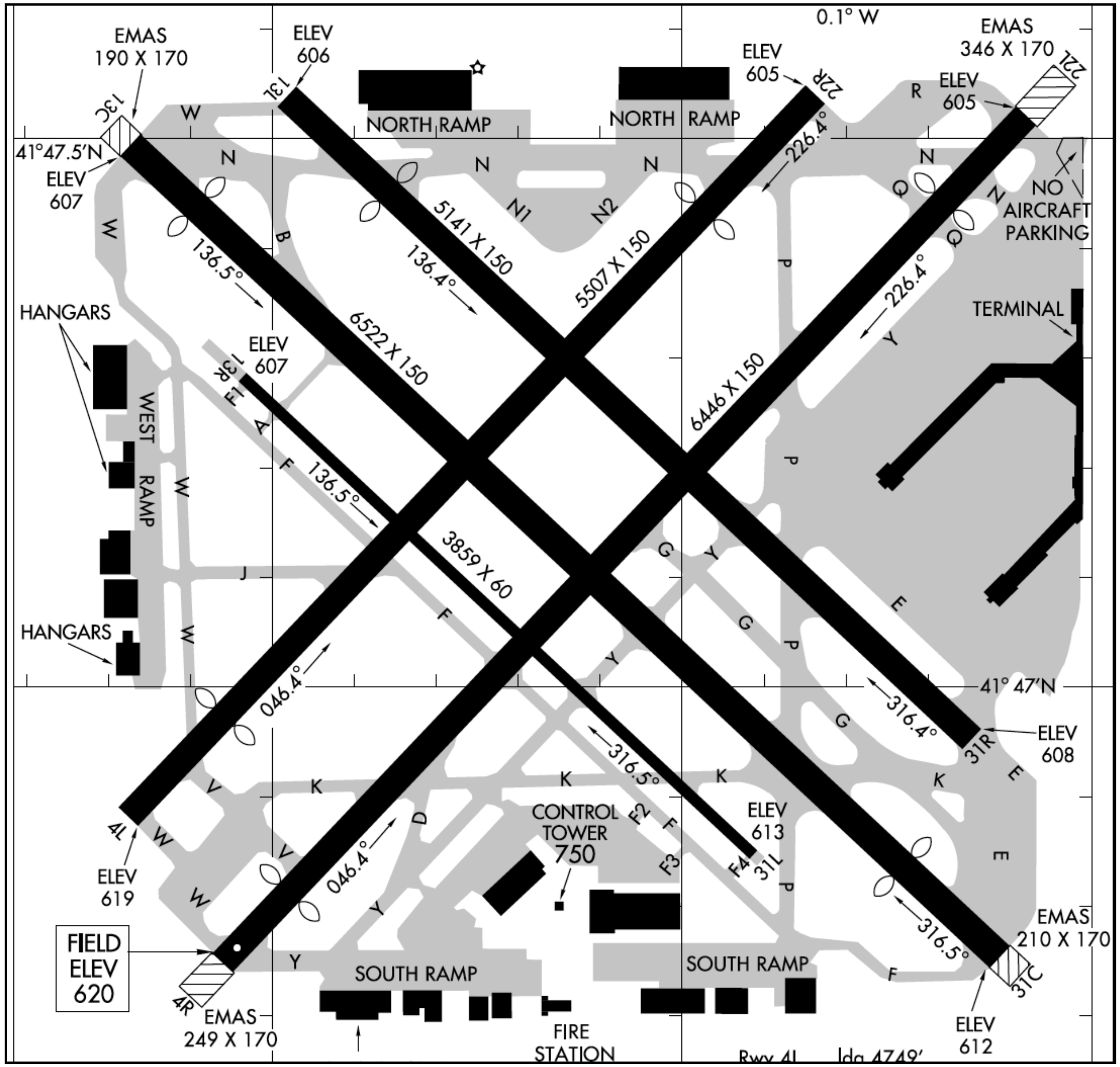
- Airport: Chicago Midway (MDW)
- Web Site for historical data: Terminal Area Forecast (available at): http://aspm.faa.gov/main/taf.asp
- Required software: Microsoft Excel Solver

Chicago Midway (MDW)

source: Google Earth ™

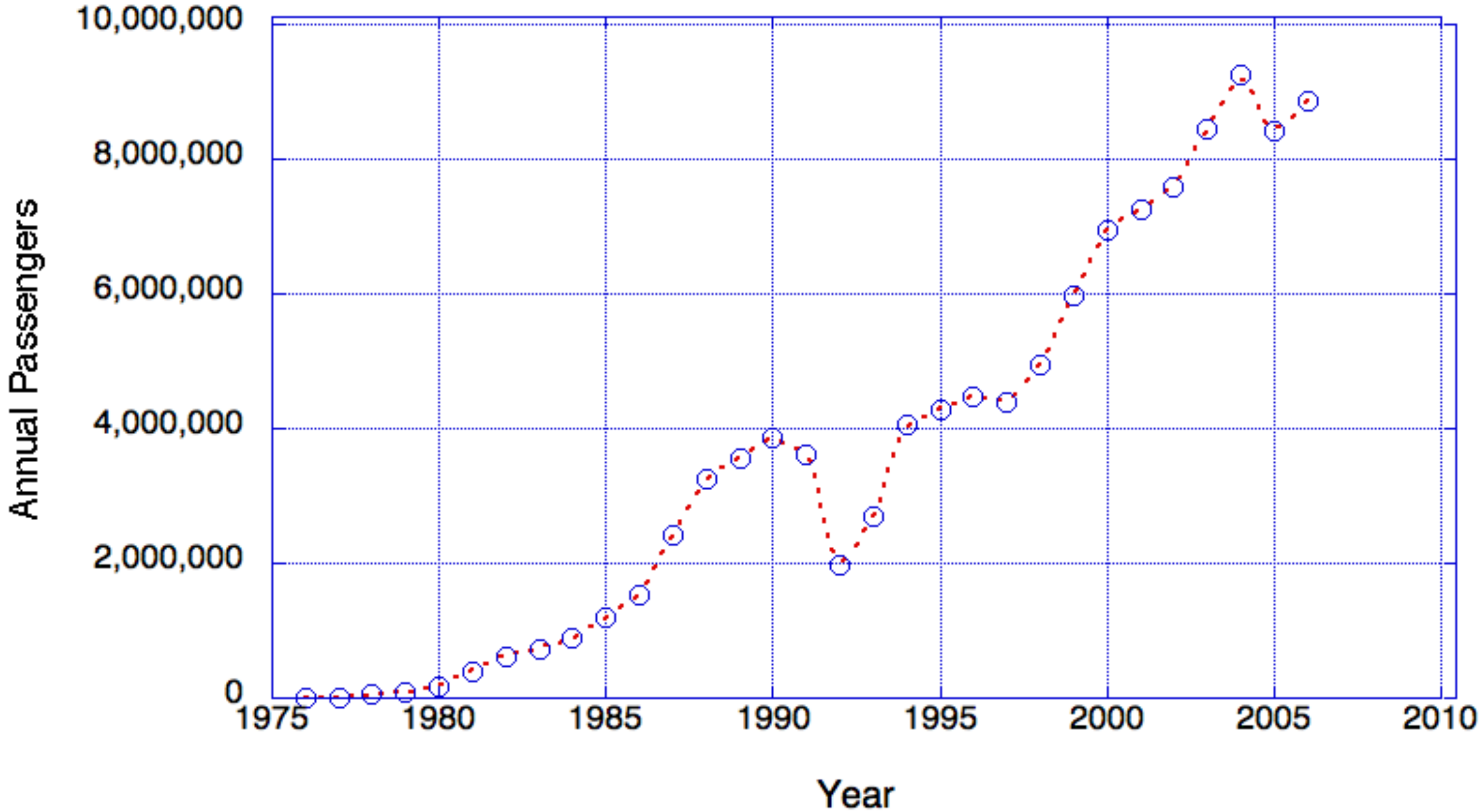
Layout of Midway Airport (MDW)

source: www.flightaware.com



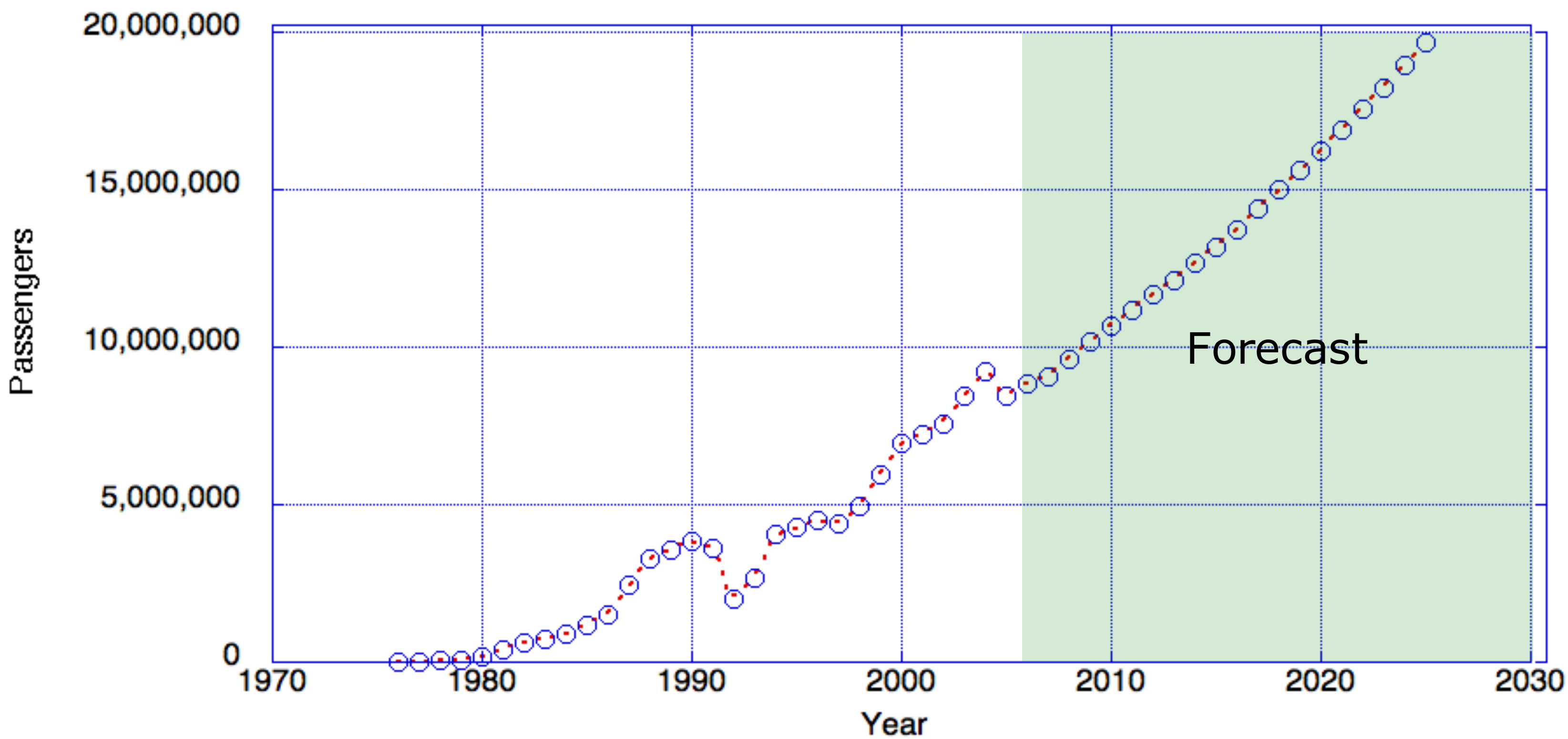
Chicago Midway (MDW)

- Historical data of annual passengers for Chicago MDW airport



Projection without Capacity Constraints

- The graph illustrates the unconstrained projection of the FAA Terminal Area Forecast (TAF)



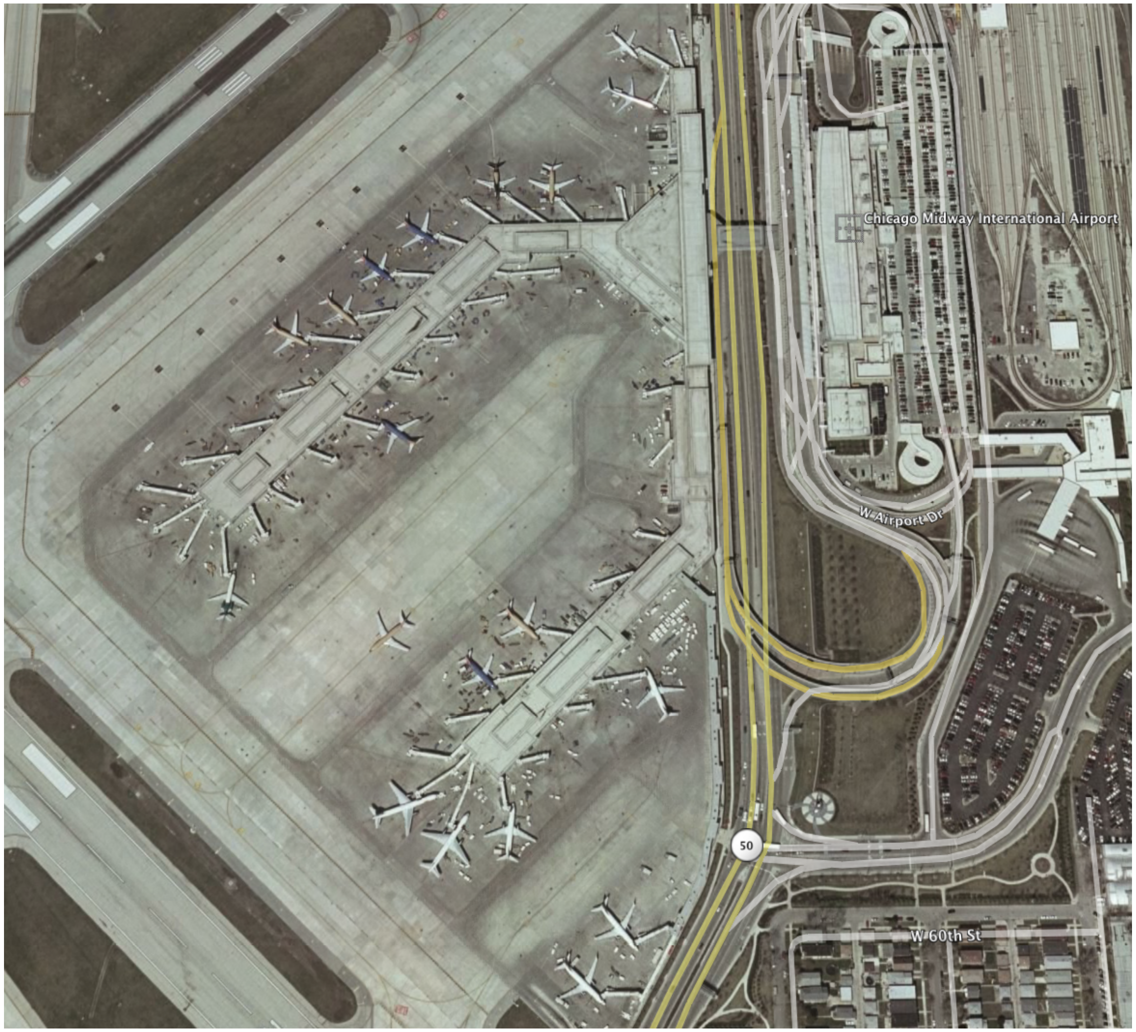
Observations for MDW Airport

- MDW demand has increased by orders of magnitude since 1976
- In 1976 MDW processed 12,626 passengers
- In 1984 MDW processed a million enplanements
- In 2006 MDW processed 8.8 millions enplanements

- Can the demand grow in the future to justify our investment?

Preliminary Analysis

- MDW has 42 gate boarding positions distributed into two terminals
- The airport has 4 runways with 6,500 pies in length (1,981 m.)



Analysis

- Due to the proximity of MDW and other New York airports (La Guardia and Kennedy), the airport might be open at night
- Suppose we want to project the future using the same model
- Where k is estimated to be 15 million passengers and D(t) is the demand in annual passengers

$$D(t) = \frac{k}{1 + b \cdot e^{-at}} \quad \text{Logistic Model}$$

The Idea Behind the Model

- To create a logistic model we need to find the values of *a, b y k so that the sum of square errors is minimized*
- The values of *a, b y k* can be found using Excel Solver or a dedicated statistical packages like Minitab, SAS, SPSS, etc.

$$D(t) = \frac{k}{1 + b \cdot e^{-at}} \quad \text{Logistic Model}$$

Analysis for Chicago MDW

- Historical data for MDW example (Excel)

Year	Year-1976	Passengers	Total Operations
1976	1	12,626	53,785
1977	2	12,950	54,426
1978	3	48,000	59,778
1979	4	86,000	66,324
1980	5	180,279	88,318
1981	6	406,434	98,084
1982	7	629,251	97,312
1983	8	737,423	109,593
1984	9	887,231	120,650
1985	10	1,191,276	131,398
1986	11	1,531,914	142,935
1987	12	2,424,358	187,692
1988	13	3,264,884	272,933
1989	14	3,560,521	332,575
1990	15	3,853,407	337,856

Analysis for MDW Airport

- Calculate the demaqnd according to the logistic model
- Initially assume any values for *a* and *b* (for example, assume *a* = 1 and *b* = 1)

A	B	C	D	E	F	G
Year	Year-1976	Passengers	Total Operations	Model	Error	Square Error
1976	1	12,626	53,785	459,583	446,957	199,770,737,243
1977	2	12,950	54,426	522,681	509,731	259,825,296,637
1978	3	48,000	59,778	594,087	546,087	298,210,898,870
1979	4	86,000	66,324	674,794	588,794	346,678,014,812
1980	5	180,279	88,318	765,882	585,603	342,930,437,270
1981	6	406,434	98,084	868,520	462,086	213,523,211,133
1982	7	629,251	97,312	983,962	354,711	125,819,763,493
1983	8	737,423	109,593	1,113,539	376,116	141,463,366,998

Model

Error (between Model and historical demand)

Sum of the square errors

I	J	K
Values of logistic model		
a	1	
b	1	
k	1.50E+07	Capacidad

Excel Formulas

A	B	C	D	E
Year	Year-1976	Passengers	Total Operations	Model
1976	1	12,626	53,785	=$J$9/(1+$J$8*EXP(-$J$7*(B2)))
1977	2	12,950	54,426	13,211,956
1978	3	48,000	59,778	14,288,612
1979	4	86,000	66,324	14,730,207
1980	5	180,279	88,318	14,899,607

$$D(t) = \frac{k}{1 + b \cdot e^{-at}}$$ Logistic Model

C	D	E	F
Passengers	Total Operations	Model	Error
12,626	53,785	10,965,879	=E2-C2
12,950	54,426	13,211,956	13,199,006
48,000	59,778	14,288,612	14,240,612
86,000	66,324	14,730,207	14,644,207
180,279	88,318	14,899,607	14,719,328

Error (difference between the Model and historical demand)

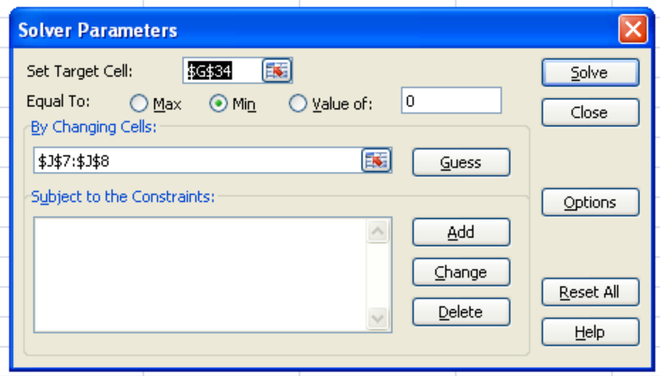
Complete Spreadsheet (to develop a logistic regression)

A	B	C	D	E	F	G	H	I	J
Year	Year-1976	Passengers	Total Operations	Model	Error	Square Error			
1976	1	12,626	53,785	10,965,879	10,953,253	119,973,744,259,880			
1977	2	12,950	54,426	13,211,956	13,199,006	174,213,763,866,940			
1978	3	48,000	59,778	14,288,612	14,240,612	202,795,027,352,968			
1979	4	86,000	66,324	14,730,207	14,644,207	214,452,794,282,241		Values of logistic model	
1980	5	180,279	88,318	14,899,607	14,719,328	216,658,623,723,103			
1981	6	406,434	98,084	14,962,911	14,556,477	211,891,012,539,158		a	1
1982	7	629,251	97,312	14,986,334	14,357,083	206,125,838,932,987		b	1
1983	8	737,423	109,593	14,994,970	14,257,547	203,277,639,272,632		k	1.50E+07
1984	9	887,231	120,650	14,998,149	14,110,918	199,118,009,098,858			
1985	10	1,191,276	131,398	14,999,319	13,808,043	190,662,052,372,720			
1986	11	1,531,914	142,935	14,999,749	13,467,835	181,382,592,480,584			
1987	12	2,424,358	187,692	14,999,908	12,575,550	158,144,453,712,452			
1988	13	3,264,884	272,933	14,999,966	11,735,082	137,712,151,779,571			
1989	14	3,560,521	332,575	14,999,988	11,439,467	130,861,394,424,174			
1990	15	3,853,407	337,856	14,999,995	11,146,588	124,246,433,214,641			
1991	16	3,624,349	320,071	14,999,998	11,375,649	129,405,397,268,982			
1992	17	1,980,046	198,349	14,999,999	13,019,953	169,519,185,991,577			
1993	18	2,688,354	202,481	15,000,000	12,311,646	151,576,621,604,133			
1994	19	4,046,580	269,394	15,000,000	10,953,420	119,977,407,855,307			
1995	20	4,278,735	287,069	15,000,000	10,721,265	114,945,522,537,280			
1996	21	4,480,680	278,327	15,000,000	10,519,320	110,656,093,023,110			
1997	22	4,403,637	298,161	15,000,000	10,596,363	112,282,908,739,094			
1998	23	4,954,796	333,553	15,000,000	10,045,204	100,906,123,370,691			
1999	24	5,975,096	376,095	15,000,000	9,024,904	81,448,892,198,995			
2000	25	6,957,336	338,886	15,000,000	8,042,664	64,684,444,213,545			
2001	26	7,244,552	292,897	15,000,000	7,755,448	60,146,973,679,515			
2002	27	7,585,834	305,208	15,000,000	7,414,166	54,969,857,475,138			
2003	28	8,450,042	331,485	15,000,000	6,549,958	42,901,949,801,628			
2004	29	9,252,314	348,269	15,000,000	5,747,686	33,035,894,354,552			
2005	30	8,429,362	268,329	15,000,000	6,570,638	43,173,283,727,026			
2006	31	8,864,959	298,407	15,000,000	6,135,041	37,638,728,071,675			
					Sum of Squared Errors	4,098,784,815,225,160			

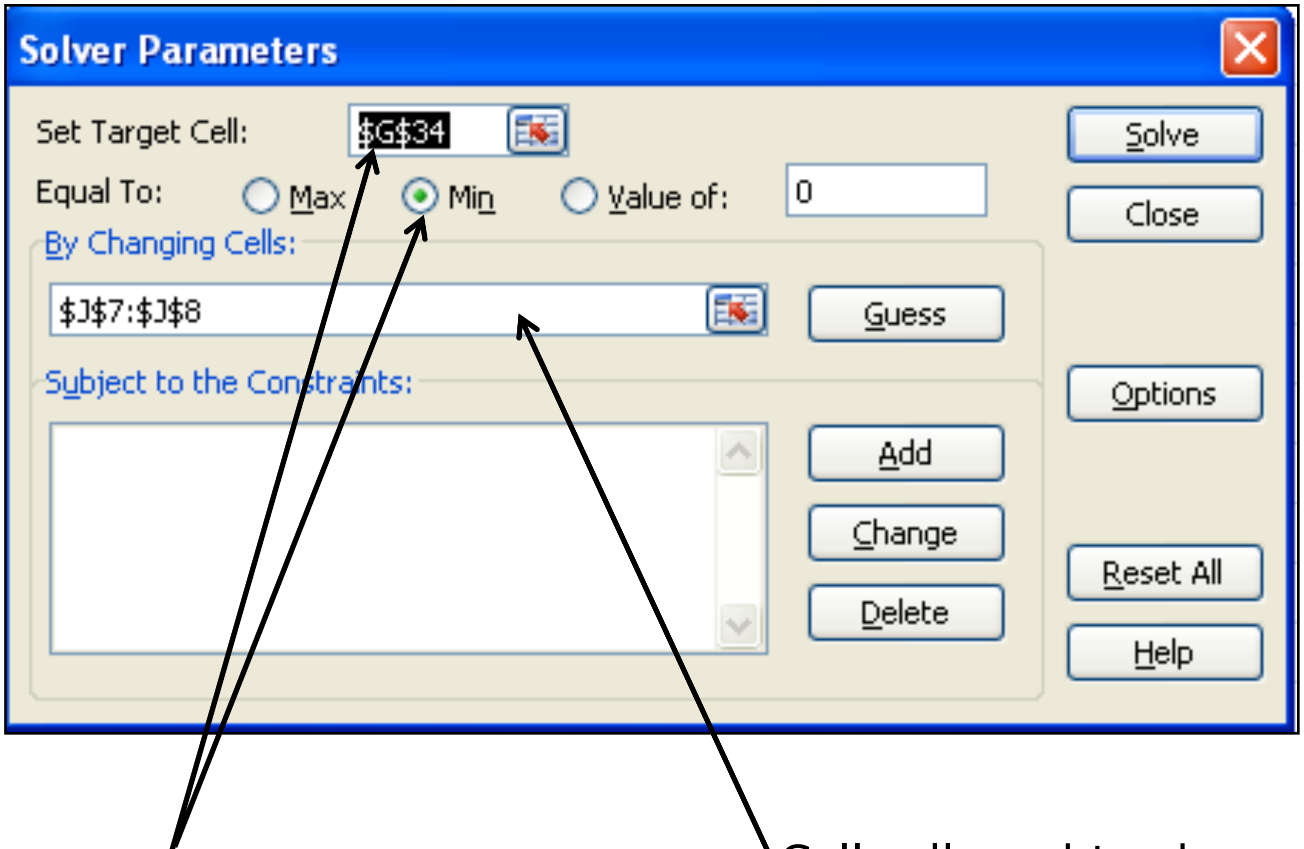
Sums of square errors

Excel Solver is Used to Estimate Parameters of the Demand Model

F	G	H	I	J	K
Error	Square Error				
10,953,253	119,973,744,259,880				
13,199,006	174,213,763,866,940				
14,240,612	202,795,027,352,968				
14,644,207	214,452,794,282,241		Values of logistic model		
14,719,328	216,658,623,723,103				
14,556,477	211,891,012,539,158		a	1	
14,357,083	206,125,838,932,987		b	1	
14,257,547	203,277,639,272,632		k	1.50E+07	Capacidad
14,110,918	199,118,009,098,858				
13,808,043	190,662,052,372,720				
13,467,835	181,382,592,480,584				
12,575,550	158,144,453,712,452				
11,735,082	137,712,151,779,571				
11,439,467	130,861,394,424,174				
11,146,588	124,246,433,214,641				
11,375,649	129,405,397,268,982				
13,019,953	169,519,185,991,577				
12,311,646	151,576,621,604,133				
10,953,420	119,977,407,855,307				
10,721,265	114,945,522,537,280				
10,519,320	110,656,093,023,110				
10,596,363	112,282,908,739,094				
10,045,204	100,906,123,370,691				
9,024,904	81,448,892,198,995				
8,042,664	64,684,444,213,545				
7,755,448	60,146,973,679,515				
7,414,166	54,969,857,475,138				
6,549,958	42,901,949,801,628				
5,747,686	33,035,894,354,552				
6,570,638	43,173,283,727,026				
6,135,041	37,638,728,071,675				
Sum of Squared Errors	4,098,784,815,225,160				



Graphic User Interface in Excel Solver



Minimize cell
G34
(least square method)

Cells allowed to change
(J7 y J8)

Final Solution with Excel Solver

Error	Square Error
448,605	201,246,786,260
511,518	261,650,316,469
548,018	300,324,179,414
590,874	349,132,165,893
587,835	345,549,573,887
464,470	215,732,475,928
357,246	127,624,482,911
378,796	143,486,777,648
374,234	140,051,142,388
232,396	54,008,087,539
72,388	5,239,988,502
-619,556	383,849,628,554
-1,238,315	1,533,423,501,466
-1,289,624	1,663,131,033,668
-1,314,491	1,727,886,710,377
-792,818	628,559,817,872
1,169,302	1,367,267,018,253
804,244	646,808,696,709
-185,509	34,413,733,419
-24,689	609,533,898
189,569	35,936,424,863
704,180	495,868,939,387
609,501	371,491,926,072
61,582	3,792,365,995
-435,891	190,001,040,844
-229,877	52,843,536,649
-73,677	5,428,358,108
-440,511	194,049,512,696
-749,870	562,304,654,308
557,333	310,619,663,620
593,418	352,145,218,804
Sum of Squared Errors	12,704,477,292,397

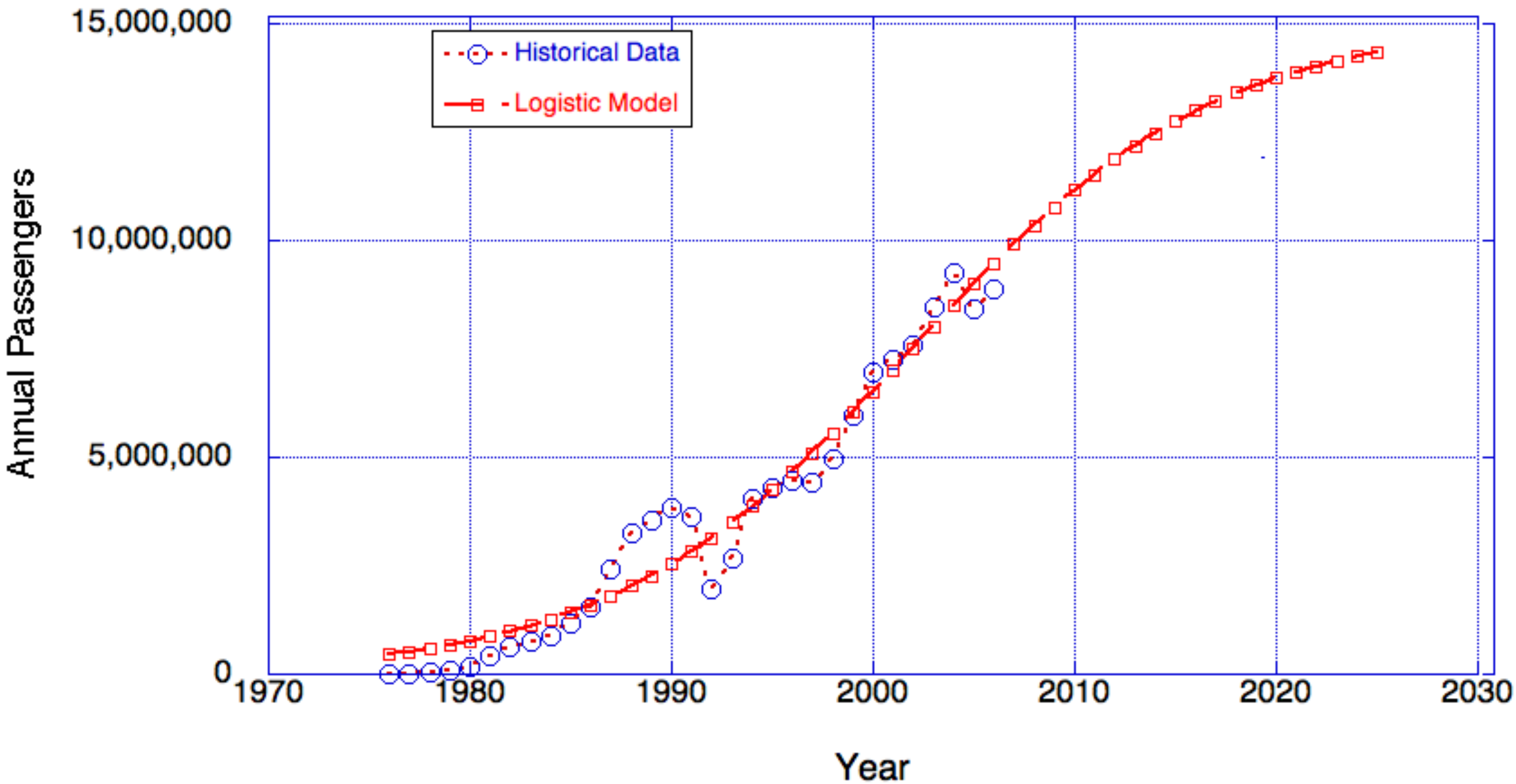
Values of logistic model

a	0.1328429
b	35.999936
k	1.50E+07

Final values of Coefficientes a y b

NOTE: the value k represents the ultimate capacity of the airport

Validation of Model (Model vs Historical Data)



Market Share Models

- Start with a national-level picture of the share of an airport
- Assume that over time, share of passengers can change or remain the same as before
- For example:
  - Atlanta handles 5% of the enplanements of the US per year (695 million in 2000)
  - if the number of enplanements in the US is estimated, then ATL would continue capturing 5% of the total
- These have to use stated preference surveys when studying multi-airport systems

Econometric Models

- Use of economic variables to predict demand
- **SE** – set of socio-economic variables (population (current and forecasted), income, employment, volume of trade, average level of education,...)
- **LOS** – set of level-of-service variables (service frequencies, total travel times, departure and arrival schedule, routing, waiting times, fares, travel costs, schedule reliability, perceived level of comfort, perceived level of safety, carrier reputation,...)

Definition of Econometric Models

- A general model where demand is a function of socio-economic characteristics and the characteristics of the transportation system can be written in the following general form:

- $$D(t) = a\prod_{i=1}^{m} S_{it}^{b_i}$$

- $$D(t) = a \cdot \prod_{i=1}^{m} S_{it}^{b_i} \cdot \prod_{j=1}^{n} T_{jt}^{c_j}$$

- where:
- m - the total number of socio-economic characteristics,
- n- the total number of transportation system characteristics,
- D(t) – the number of air passenger in year t

Econometric Models

- S_{it} - the value otf the *i*-th socio-economic characteristics in year *t*
- T_{jt} - the value of the j-th transportation system characteristics in year *t*
- a, b_i, c_j, - parameters to be estimated

Econometric Models

$$D(t) = a \cdot \prod_{i=1}^{m} S_{it}^{\;b_i} \cdot \prod_{i=1}^{n} T_{jt}^{\;c_j}$$

where:

m - the total number of socio-economic characteristics,

n- the total number of transportation system characteristics,

$D(t)$ – the number of air passenger in year t

S_{it} - the value of the i-th socio-economic characteristic in year t

T_{jt} - the value of the j-th transportation system characteristic in year t

a, b_i, c_j - parameters to be estimated

Sample of an Econometric Model (Gohbrial y Kanafani, 1995)

$$T_{ij} = \alpha \cdot P_{ij}^{\beta} \cdot I_{ij}^{\gamma} \cdot FR_{ij}^{\phi} \cdot FP_{ij}^{\mu} \cdot FO_{ij}^{\eta} \cdot SP_{ij}^{\lambda} \cdot SO_{ij}^{\varphi} \cdot TM_{ij}^{\theta} \cdot h_{ij}$$

where:

$$h_{ij} = \exp(\omega \cdot TR_{ij} + \psi \cdot HUB_{ij}) \cdot \varepsilon$$

$$\forall FP_{ij} > 0 \qquad \forall FO_{ij} > 0$$

where:

T_{ij} - daily passenger demand who fly directly in market i, j

P_{ij} - product of populations of cities i and j

I_{ij} - product of income per capita of cities i and j

FR_{ij} - weighted average airfare by class type in market i, j

FP_{ij} - number of daily direct flights between city i and city j during peak periods

Sample of an Econometric Model (Gohbrial y Kanafani, 1995)

FO_{ij} - number of daily direct off-peak flights between city i and city j

SP_{ij} - weighted average aircraft size (number of seats) during peak periods between city i and city j

SO_{ij} - weighted average aircraft size (number of seats) during off-peak periods between city i and city j

TM_{ij} - average travel time in hours between cities i and j

TR_{ij} - a dummy variable for tourist markets (equal to one if city i or j is located in Florida, Hawaii, or Las Vegas; equal to zero otherwise)

HUB_{ij} – a dummy variable for capacity constrained airport (equal to one if city i or j is capacity constrained airport (O'Hare, La Guardia, Logan, etc); equal to zero otherwise)

$\alpha, \beta, \gamma, \Phi, \mu, \eta, \lambda, \varphi, \sigma, \omega, \psi$ - coefficients to be estimated

ε - error term of estimation

Sample of an Econometric Model (Gohbrial y Kanafani, 1995)

Variable	Coefficient	Estimated coefficient
Constant	α	11.180
Population	β	0.116
Per income capita	γ	0.139
Airfare	φ	-1.314
Peak flights	μ	0.436
Off-peak flights	η	0.296
Peak aircraft size	λ	0.786
Off-peak aircraft size	ϕ	0.700
Travel time	σ	0.359
Dummy for tourist markets	ω	0.058
Dummy for congested hubs	ψ	-0.231

Other Models

Forecasts by the FAA and Boeing

FAA National Level Model

- Domestic traffic and revenue
- Reconcile TAF and national level model (TAF should be within 0.5% of national level forecast)
- Top-Down model
  - Inputs: GDP, PCE, Unemployment rate, ticket tax, real oil price, 911 dummy, post 911 dummy, segment fee)
  - Assume based on trends: passenger trip length, load factors
  - Outputs: RPMs, ASMs, real yield, enplanements, unit costs
- Perform the analysis for legacy, low cost and regional carriers (definitions of these are unknown)

Internacional Markets

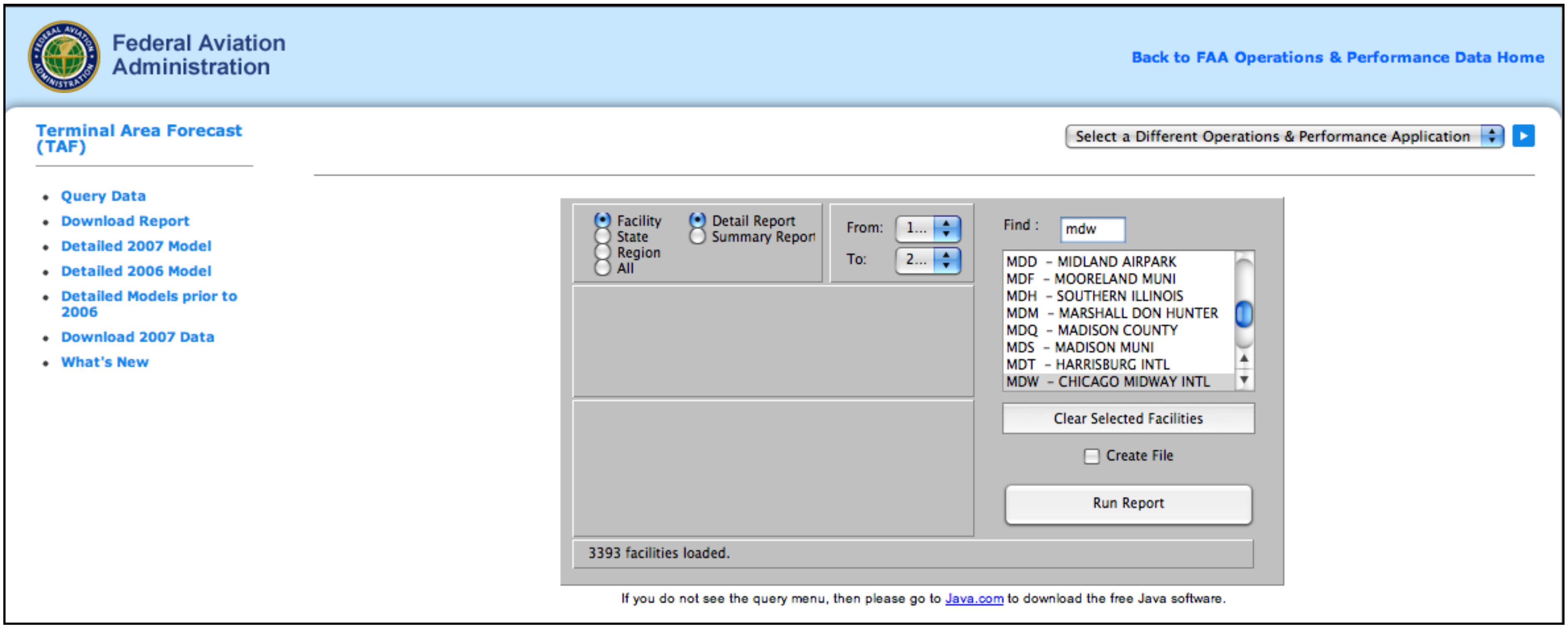
- By region of the world
- Explanatory variables vary by region
- For example:
- North Atlantic Traffic = f(US and Europe GDP, Gulf War dummy, passengers (t-1))

- Once demand is estimated, the FAA predicts:

- ASM, aircraft stage length, seats/aircraft, departures

FAA Terminal Area Forecast (TAF)

- Predicts the number of passengers across all NPIAS airports



- Web site: http://aspm.faa.gov/main/taf.asp

Sample TAF Information for MDW (Chicago Midway – MDW)

MDW

				AIRCRAFT OPERATIONS										
	Enplanements			Itinerant Operations					Local Operations					
Fiscal Year	AC	Comm.	Total	AC	AT & Comm.	GA	Mil	Total	GA	Mil	Total	Total OPS	Total Inst.OPS	Based Aircraft
2006	8596151	268808	8864959	190436	47194	56803	1021	295454	180	9	189	295643	298407	71
2007*	8771643	272840	9044483	199052	49019	55974	974	305019	276	10	286	305305	312075	70
2008*	9205515	400529	9606044	205979	60194	47074	974	314221	278	10	288	314509	321218	67
2009*	9756402	408940	10165342	216483	60495	39590	972	317540	280	10	290	317830	324541	66
2010*	10275211	417527	10692738	225856	60797	33295	970	320918	282	10	292	321210	327967	65
2011*	10765484	426712	11192196	234370	61101	28001	968	324440	284	10	294	324734	331581	64
2012*	11219133	436099	11655232	241916	61407	23549	968	327840	286	10	296	328136	335100	63
2013*	11691902	445693	12137595	249705	61714	19804	966	332189	288	10	298	332487	339598	62
2014*	12198528	455943	12654471	258020	62022	16655	964	337661	290	10	300	337961	345225	61
2015*	12727109	466429	13193538	266612	62332	14007	964	343915	292	10	302	344217	351645	61
2016*	13263432	477156	13740588	275196	62644	11780	962	350582	294	10	304	350886	358487	59
2017*	13896110	488607	14384717	285873	62957	9907	960	359697	296	10	306	360003	367786	58
2018*	14481700	500333	14982033	295078	63272	8331	958	367639	298	10	308	367947	375922	58
2019*	15091971	511840	15603811	304579	63588	7007	958	376132	300	10	310	376442	384616	57
2020*	15727963	523612	16251575	314386	63906	5892	956	385140	302	10	312	385452	393833	56

Behind an analytical mind, there is always room for keeping over the weekend

Boeing Commercial Outlook (BCO)

- 20 year forecast
- 3-level forecast
- All jets 30 seats and over

- Boeing forecasts RPKs (Revenue Passenger Kilometers)

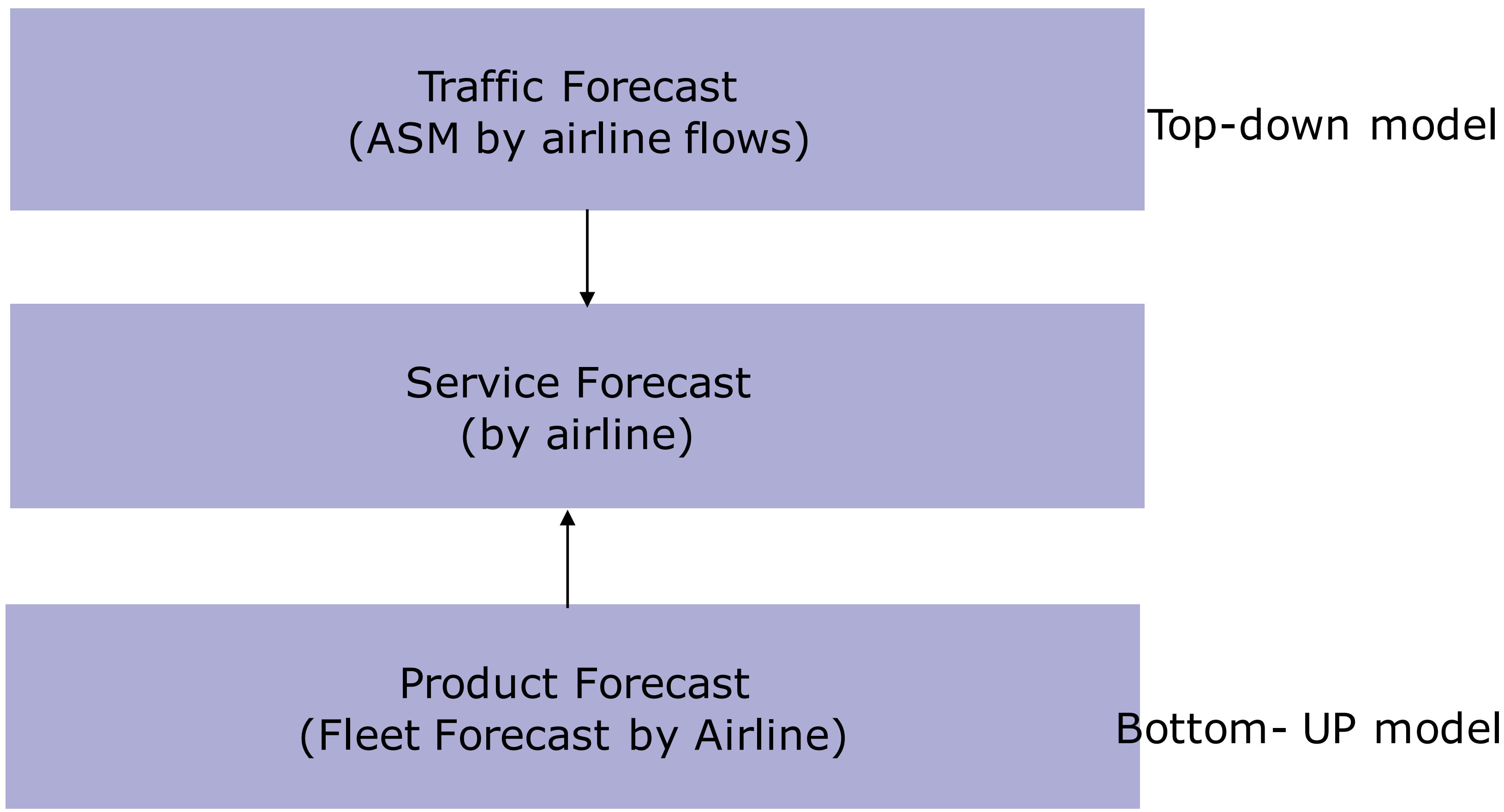
BCO Methodology

- Forecast matches traffic derived from GDP growth
- Considers network and airline fleet plans

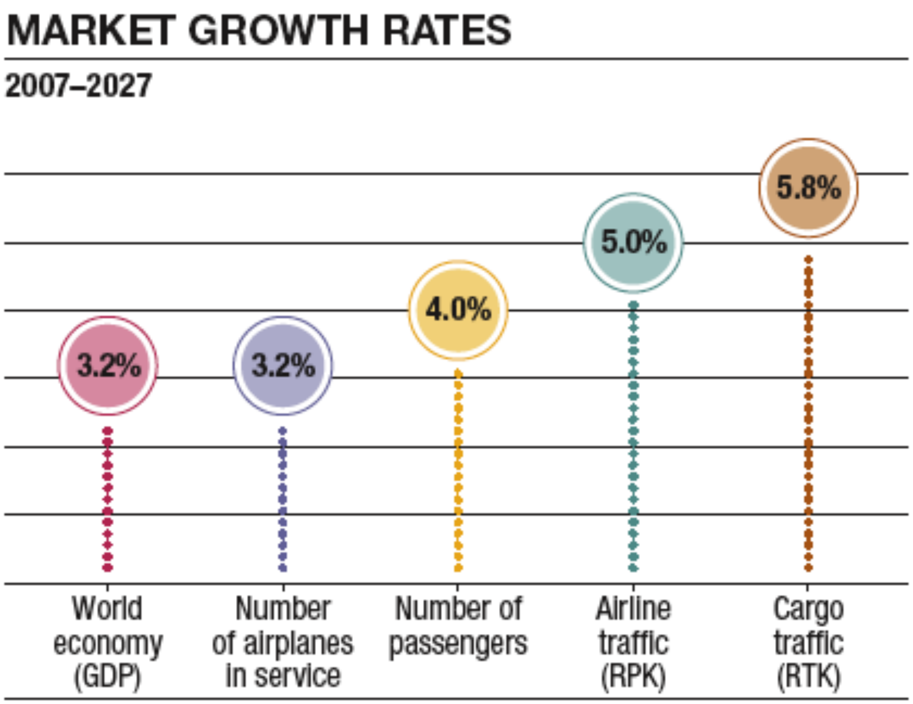
- 142 airlines modeled individually
- Includes cargo, charter and LCC

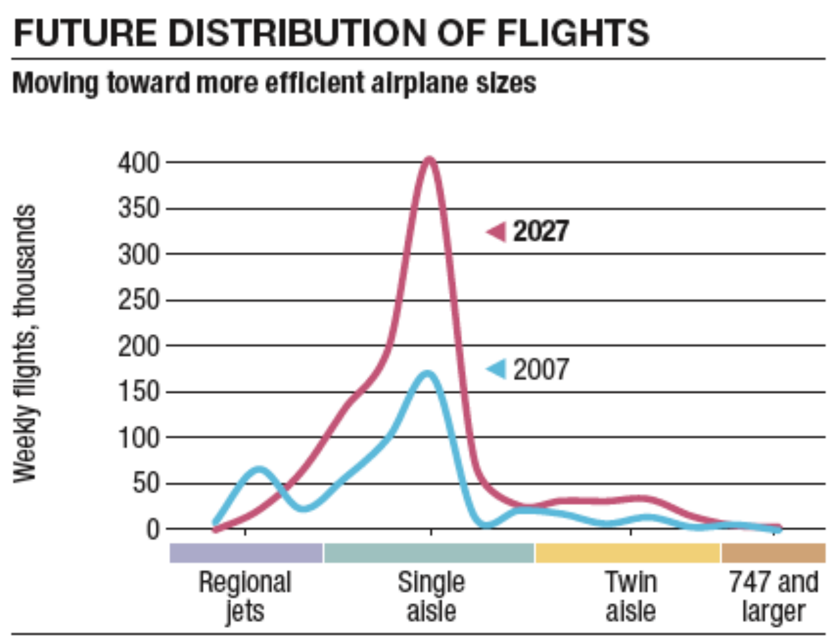
- 64 traffic flows
- 14 generic aircraft sizes are models
- International traffic considers all city pairs > 3000 miles
- 12 world regions

BCO Methodology



Results with BCO (Boeing)





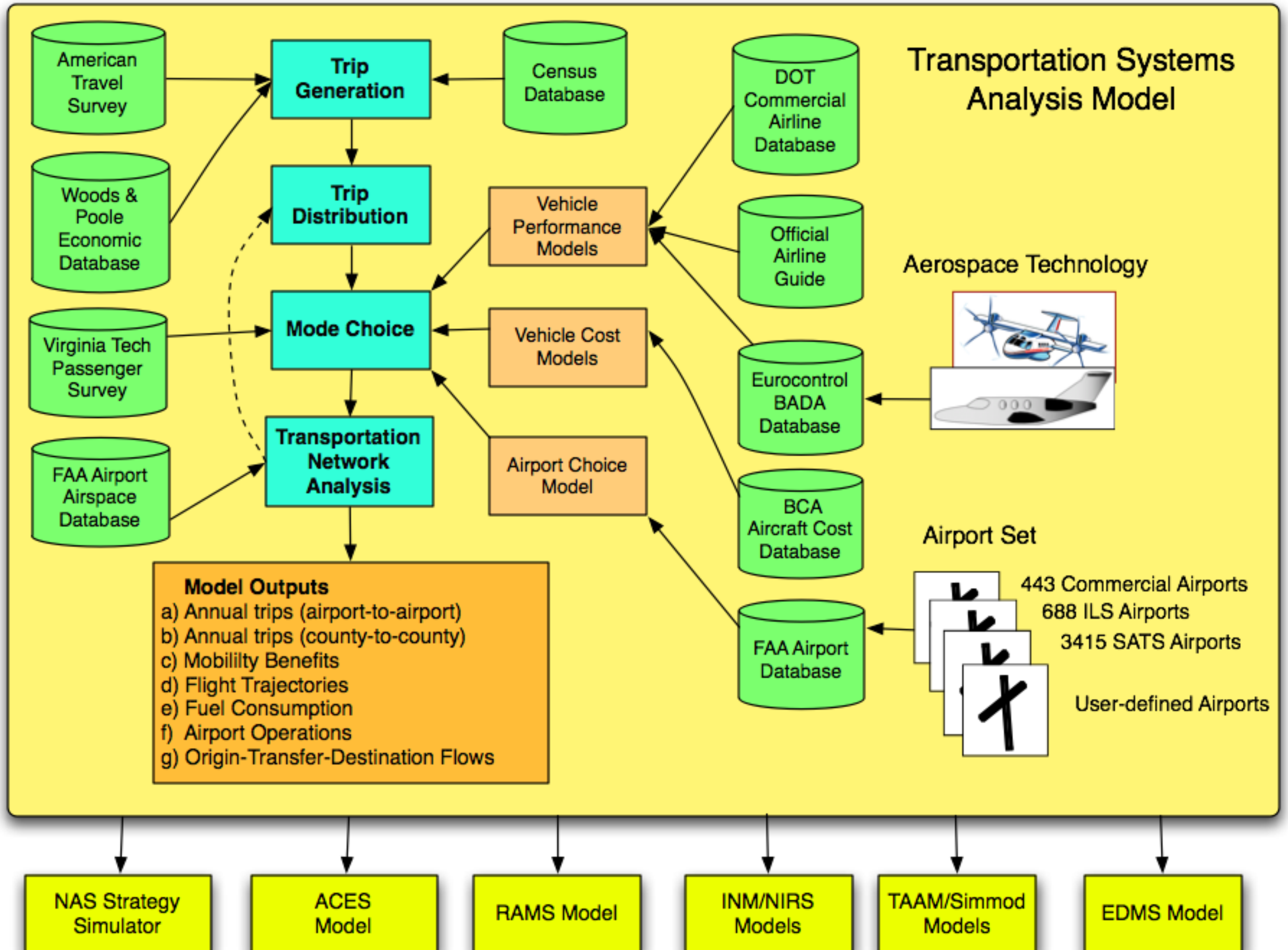
Forecast methods with Competition

- Required to baseline and measure the performance of the existing system
- Requires an assessment of the cost and travel time of the competing models
- Can be used to predict local, regional and national-level effects
- Can include competition among multi-airports

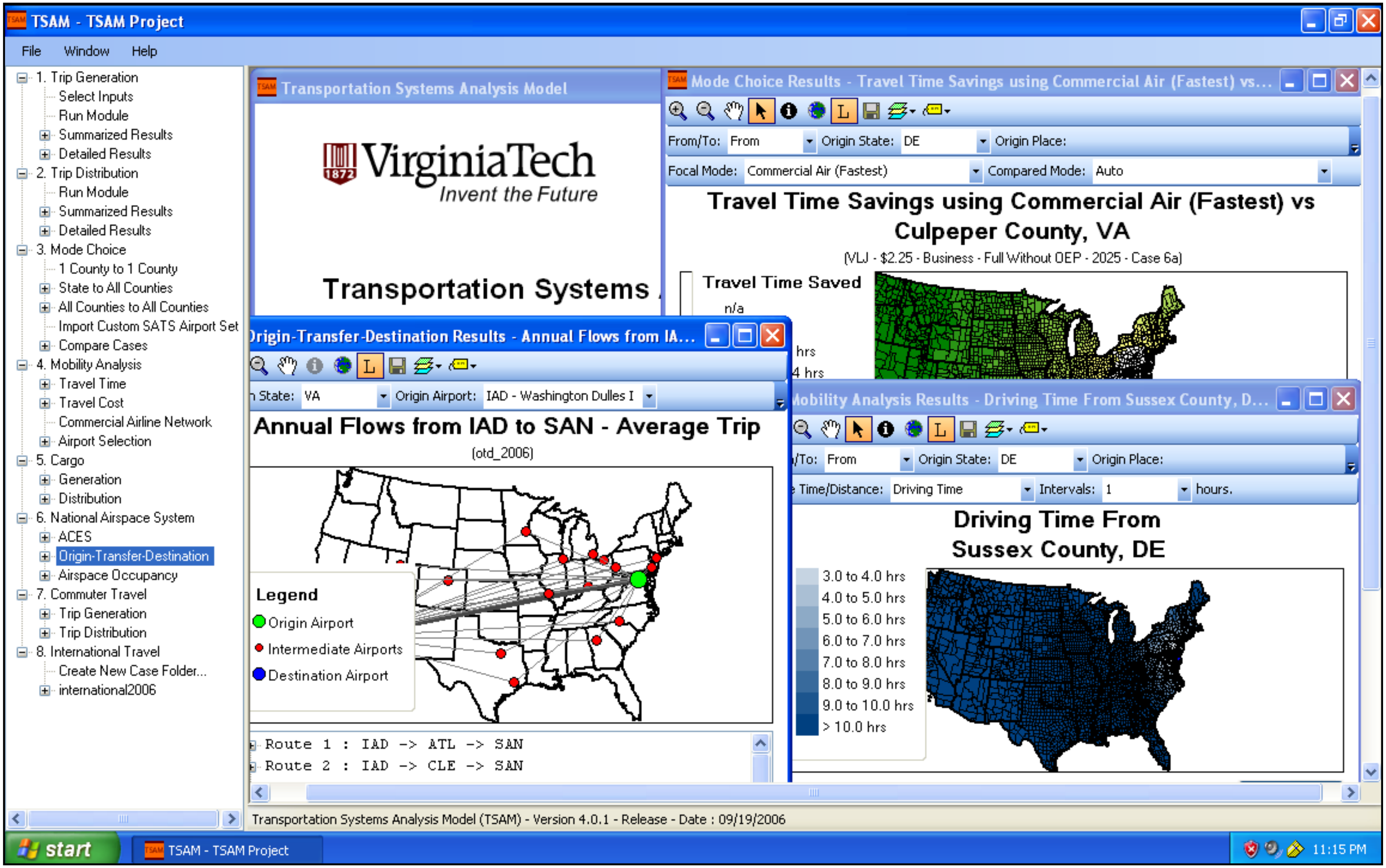
Methodology (TSAM Model)

- A multi-mode intercity trip demand model that predicts long distance travel (one-way route distance greater that 100 miles) in the continental U.S.
- Employs a multi-step, multi-modal transportation planning framework where trips are:
  - produced,
  - distributed,
  - split into modes, and
  - assigned to routes
- TSAM model can predict intercity travel in the presence of multi-mode alternatives (auto, commercial air, and new aviation modes)
- Mode choice of travelers based on trip characteristics (business and noon-business) and traveler demographics (income level)
- Mode choice is sensitive to vehicle performance, level of service and supply cost characteristics
- County-to-county spatial model
- Accepts any user-defined airport sets

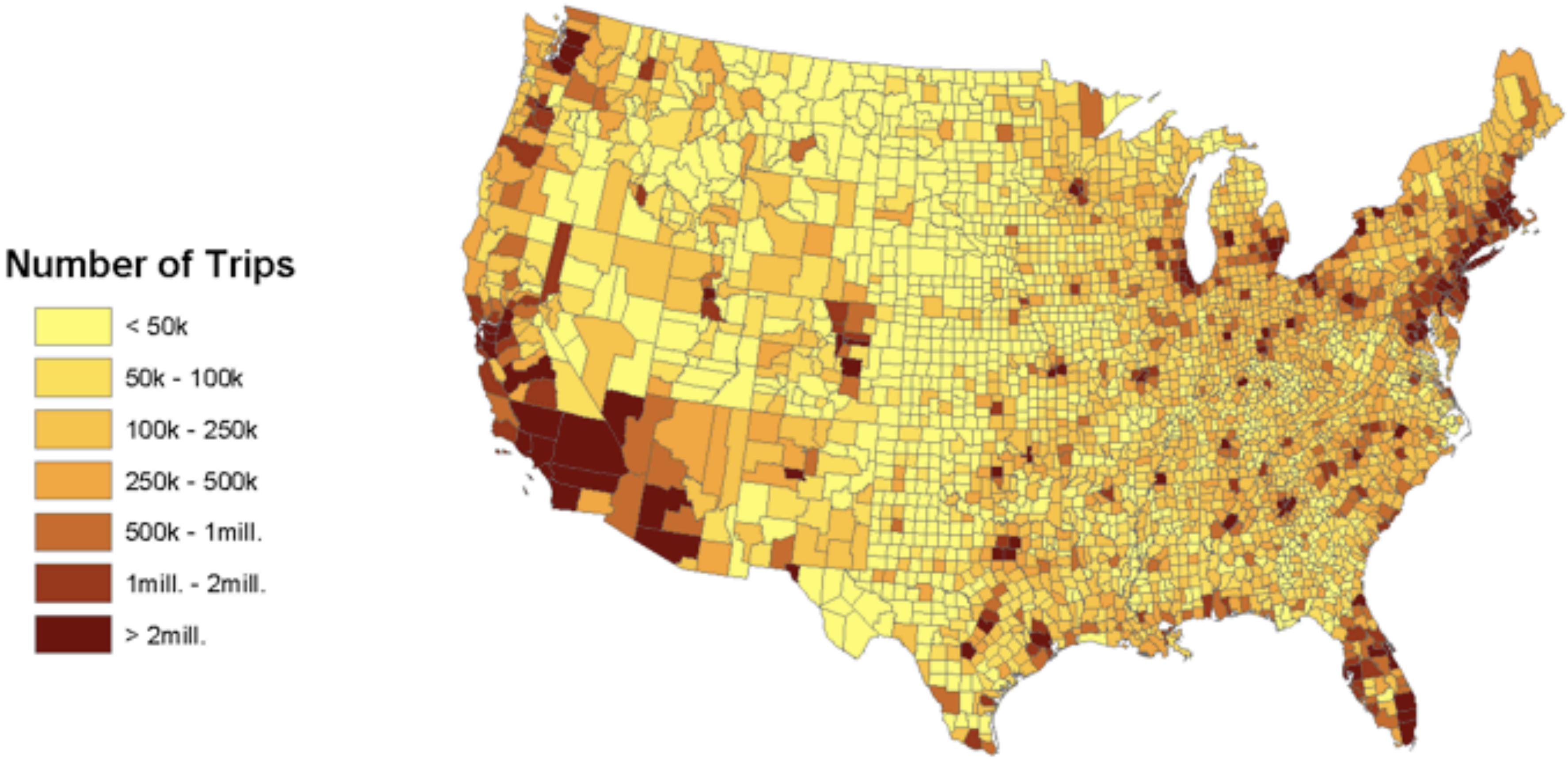
The TSAM Model



TSAM is an Application

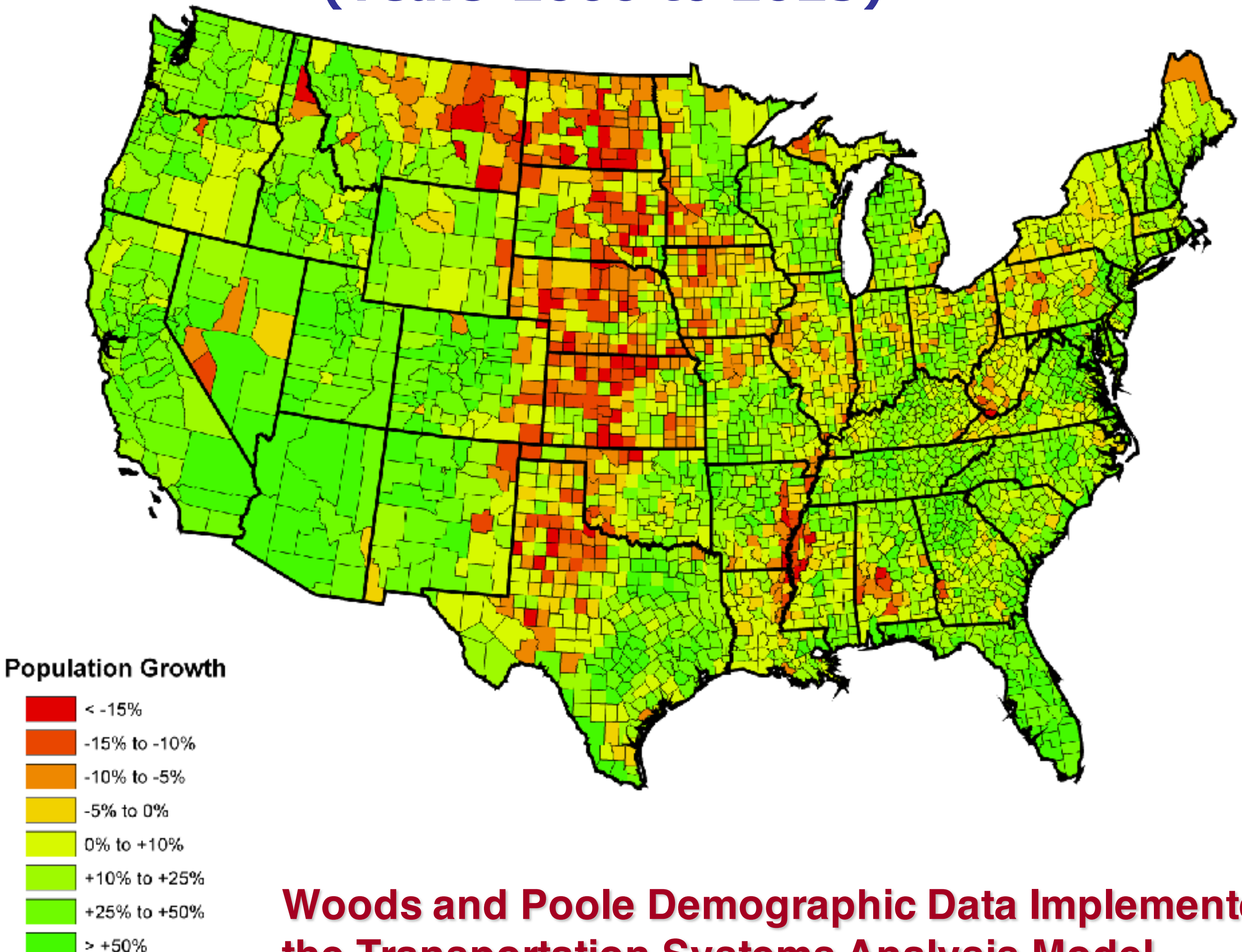


Trip Generation Trends



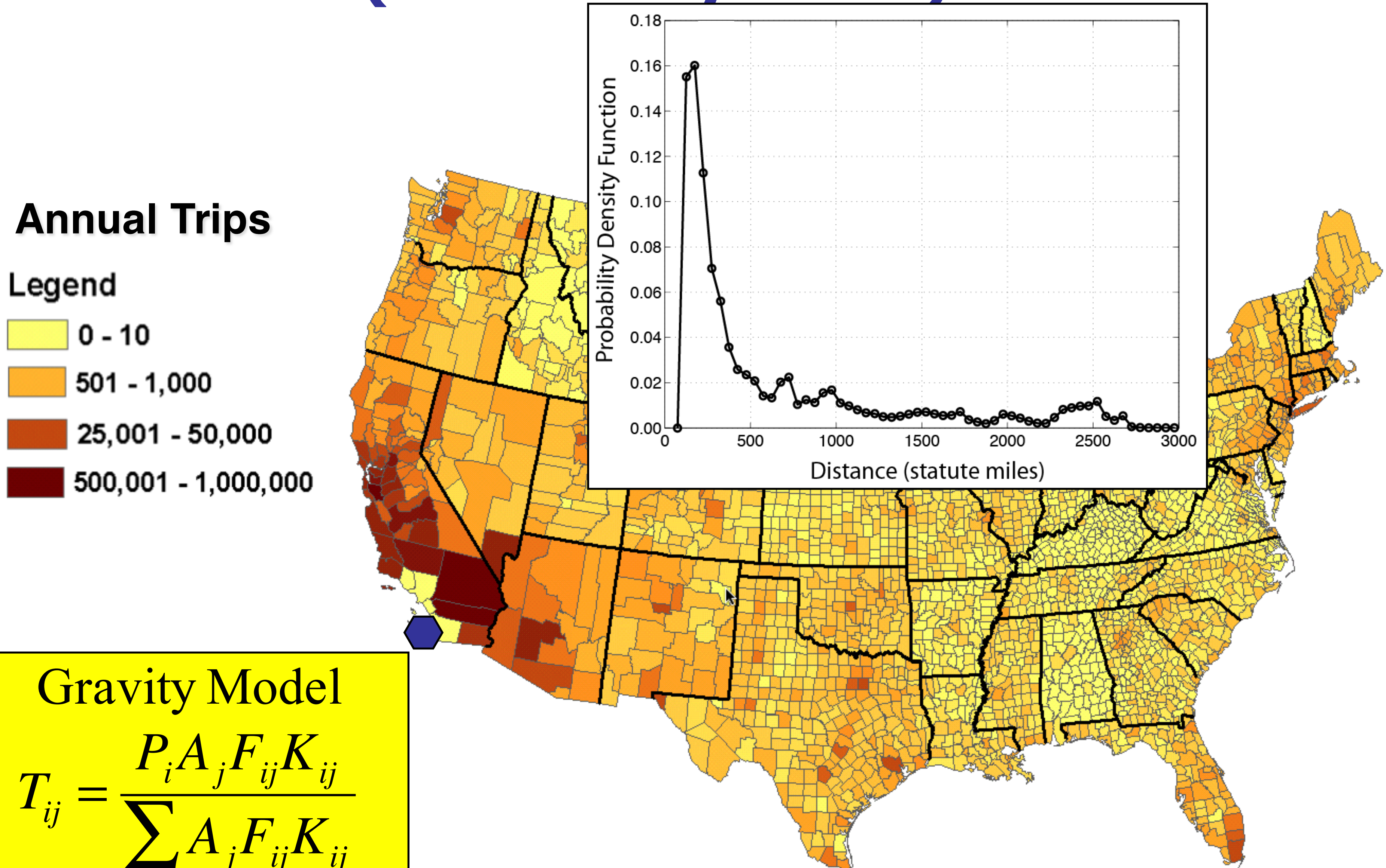
Total Intercity Trips Generated by County (Business + Non-Business Trips)

Changes in the U.S. Population
(Years 2000 to 2025)



Woods and Poole Demographic Data Implemented in the Transportation Systems Analysis Model

Distribution of Trips (LA County to all)



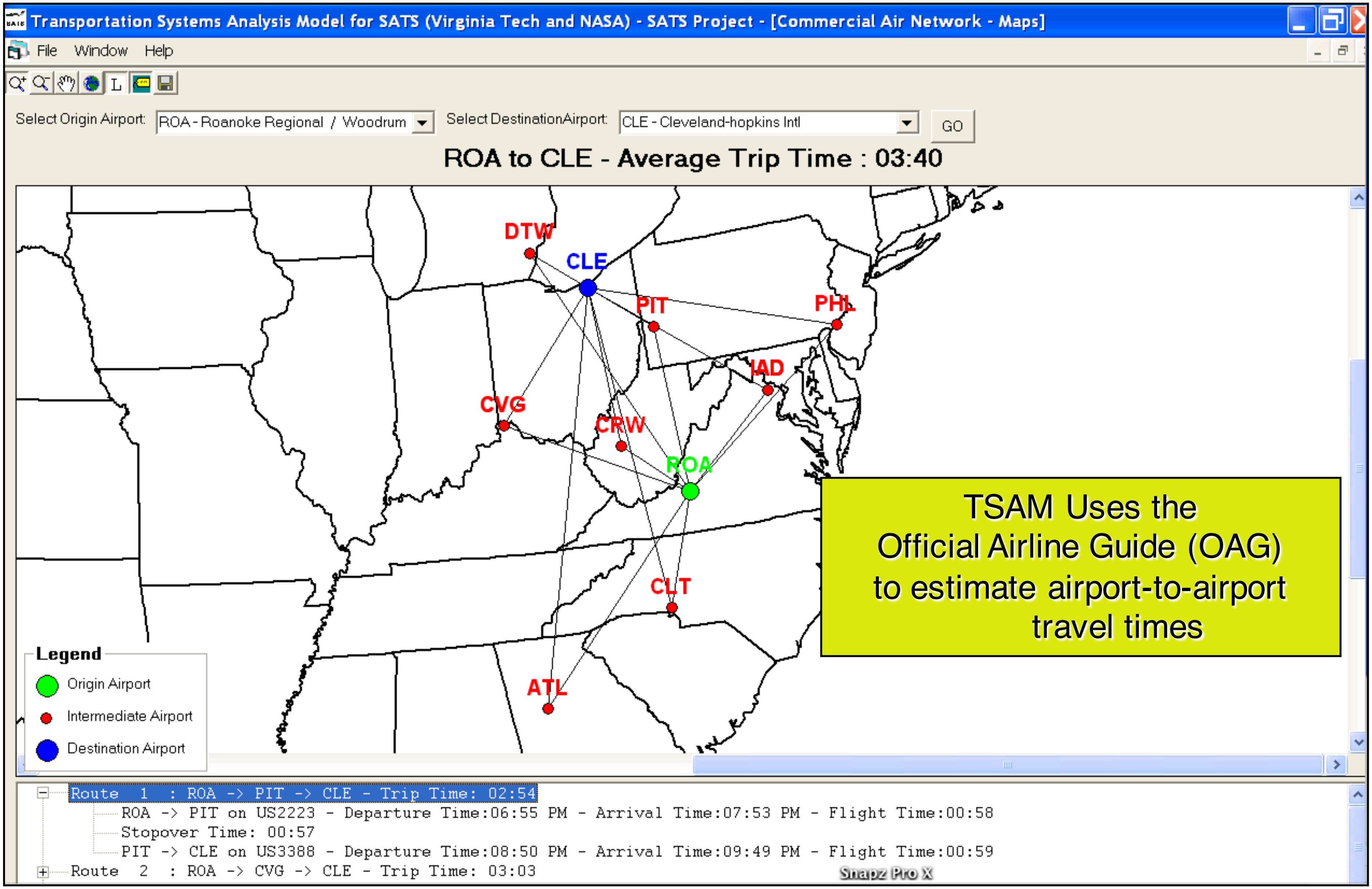
Gravity Model

$$T_{ij} = \frac{P_i A_j F_{ij} K_{ij}}{\sum_j A_j F_{ij} K_{ij}}$$

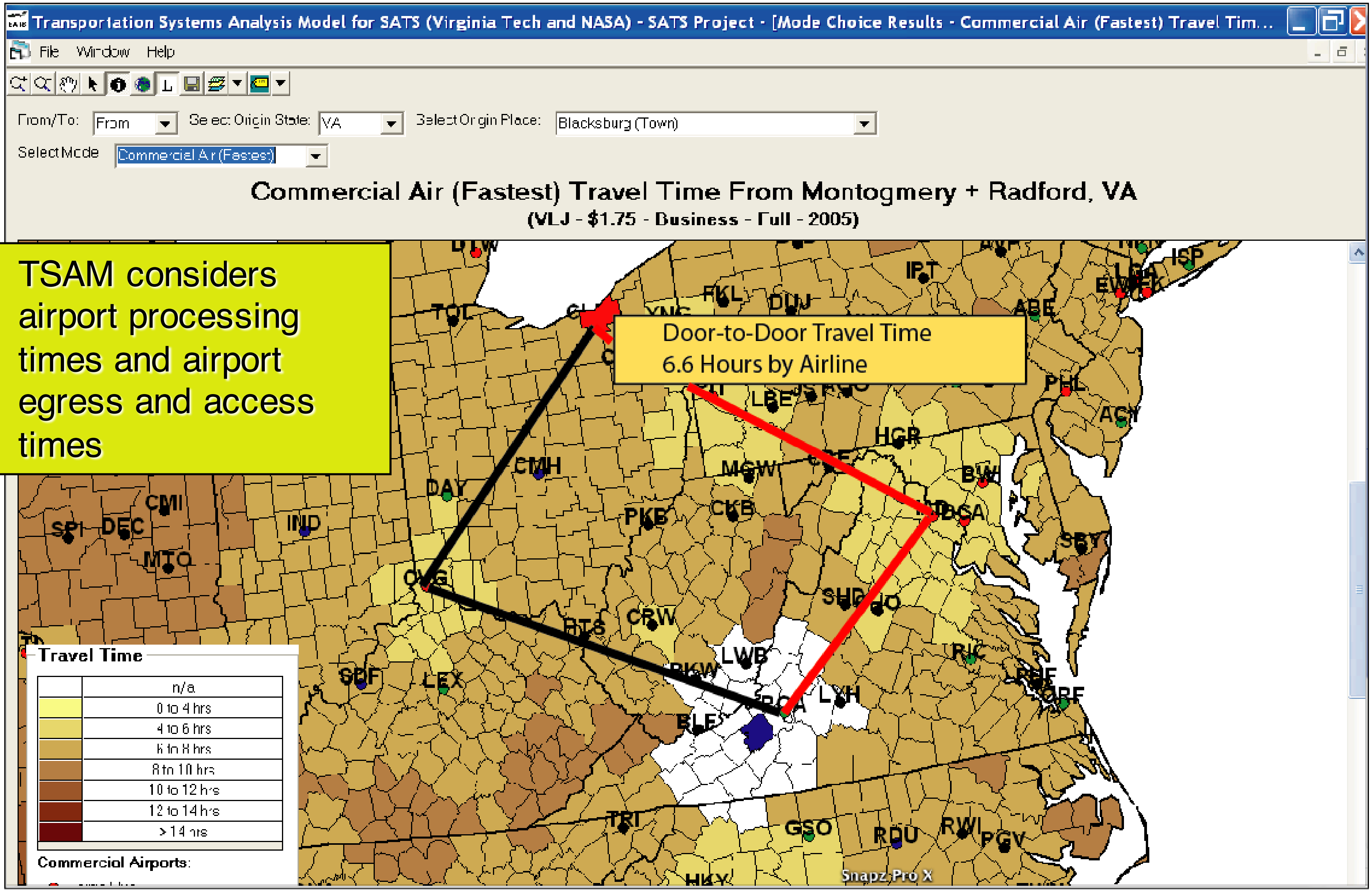
Business Travel
Blacksburg, Virginia to Cleveland, Ohio

- Suppose three alternatives are available:
  - Auto
  - Commercial Air
  - On-demand service using VLJ aircraft (future NAS)
- To make a mode selection a user might consider:
  - Travel time
  - Travel cost (including lodging and rentals)
  - Duration of stay
  - Value of time

Multi-route Mode Choice Model

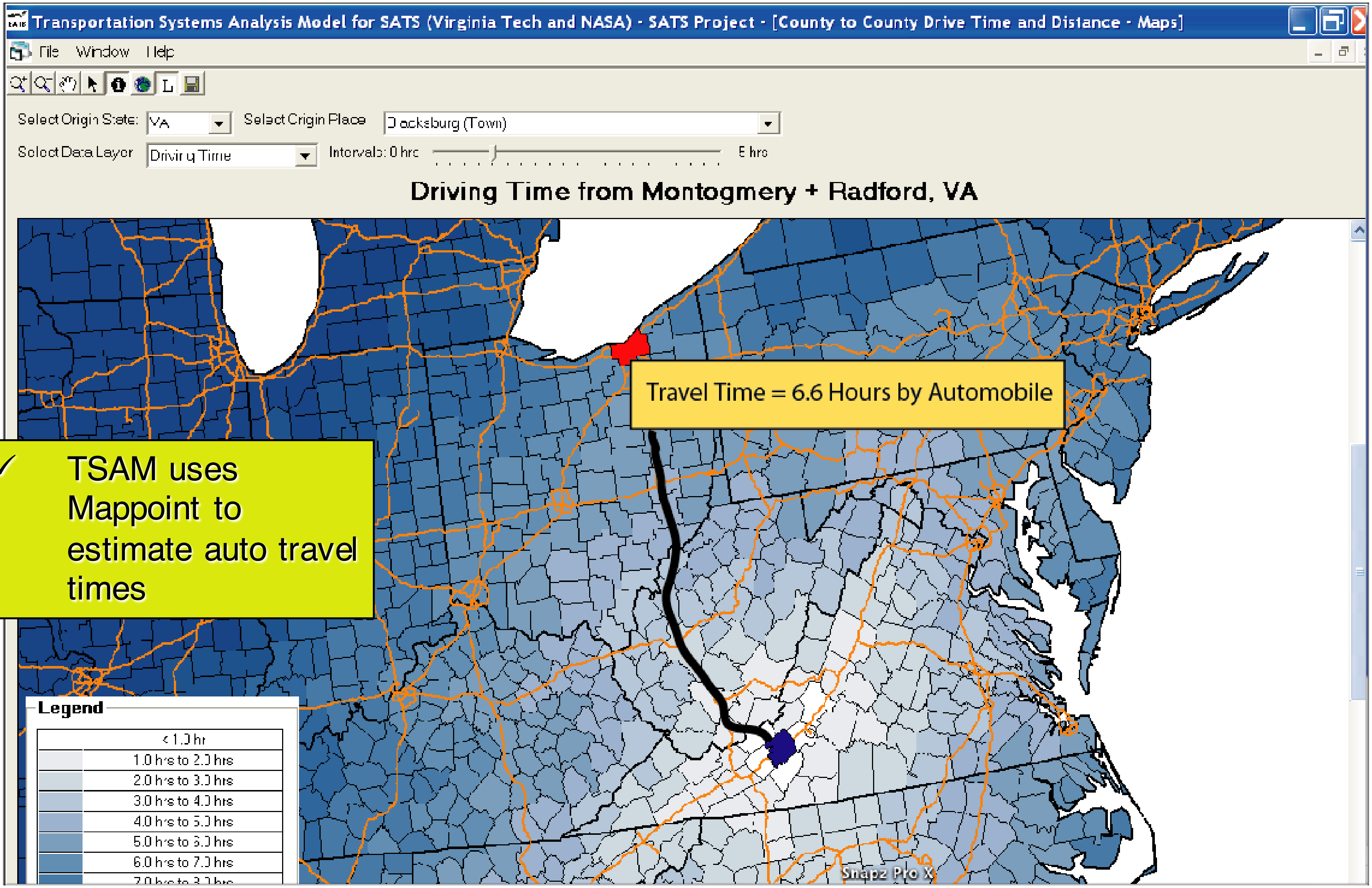


Multi-mode Choice Model (Door-to-Door Commercial Air Travel Time)



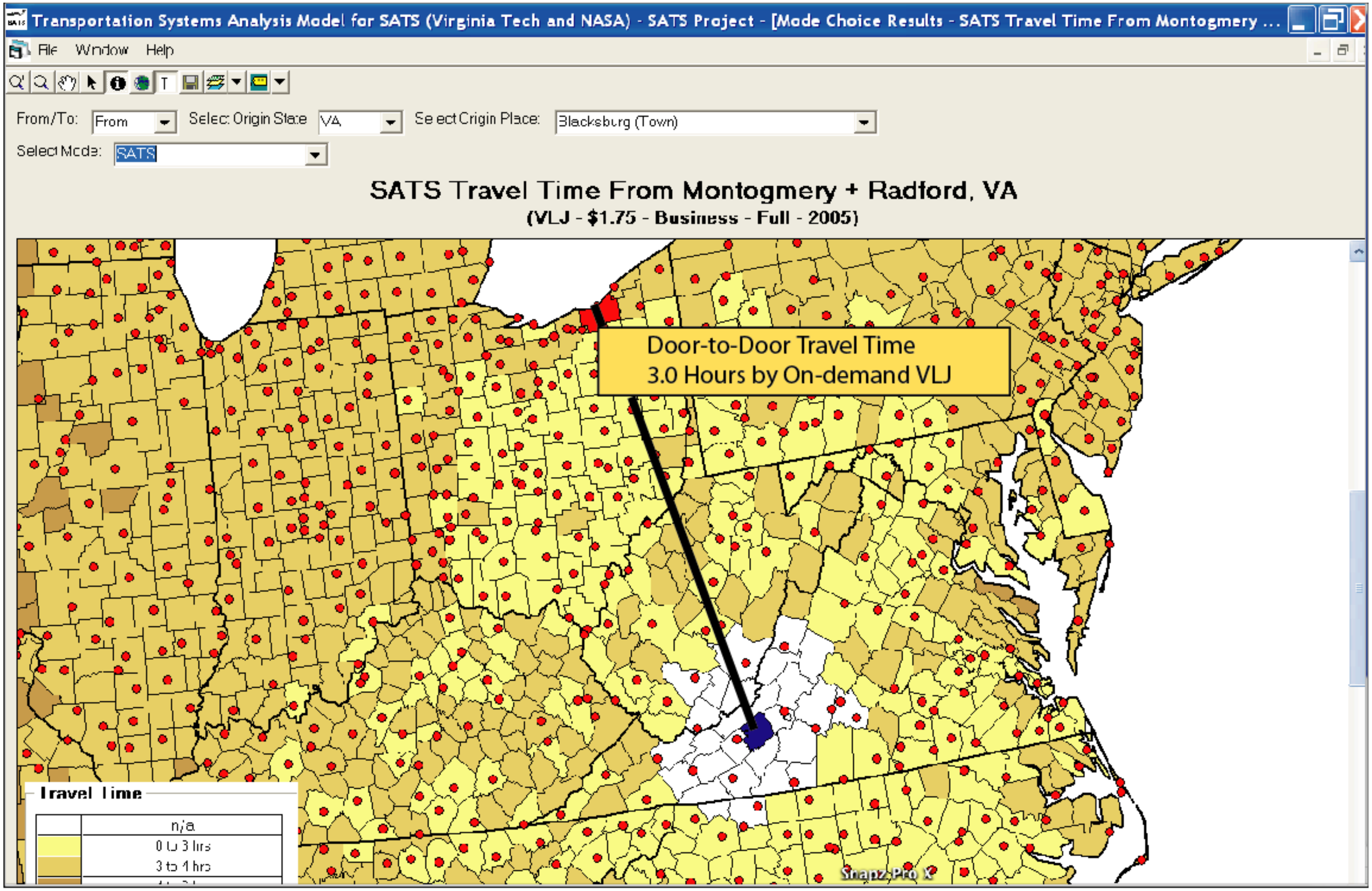
✓ TSAM considers airport processing times and airport egress and access times

Multi-mode Choice Model (Auto)



- ✓ TSAM uses Mappoint to estimate auto travel times

Multi-mode Choice Model (GA)



Summary Trip Information

From Blacksburg, VA To Cleveland, OH (391 miles)

Roundtrip Travel Time Savings Using	7 hrs 2 min + 2 extra nights compared to automobile
	7 hrs 16 min + 1 extra night compared to fastest airline route

SATS Trip Details

	Origin Airport	Destination Airport	Travel Time (Outbound)	Travel Time (Return)	Travel Cost (Roundtrip)	Average Travel Speed	Cost for Speed	Nights Away
SATS	BCB, Virginia Tech / Montgomery Executive, Blacksburg, VA	BKL, Burke Lakefront, Cleveland, OH	2 hrs 59 min	2 hrs 59 min	$1,093	131 mph	$8.33/mph	0

Car Trip Details

	Origin	Destination	Travel Time (Outbound)	Travel Time (Return)	Travel Cost (Roundtrip)	Average Travel Speed	Cost for Speed	Nights Away
Auto	Blacksburg, VA	Cleveland, OH	6 hrs 30 min	6 hrs 30 min	$493	60 mph	$5.20/mph	2

Commercial Air Trip Details

	Origin Airport	Destination Airport	Travel Time (Outbound)	Travel Time (Return)	Travel Cost (Roundtrip)	Average Travel Speed	Cost for Speed	Nights Away
Route 1	ROA, Roanoke, VA	CLE, Cleveland, OH	6 hrs 37 min	6 hrs 36 min	$526	59 mph	$7.39/mph	1
Route 2	ROA, Roanoke, VA	CAK, Akron, OH	6 hrs 50 min	7 hrs 15 min	$528	57 mph	$7.65/mph	1
Route 3	CLT, Charlotte, NC	CLE, Cleveland, OH	7 hrs 38 min	7 hrs 12 min	$638	51 mph	$10.71/mph	1

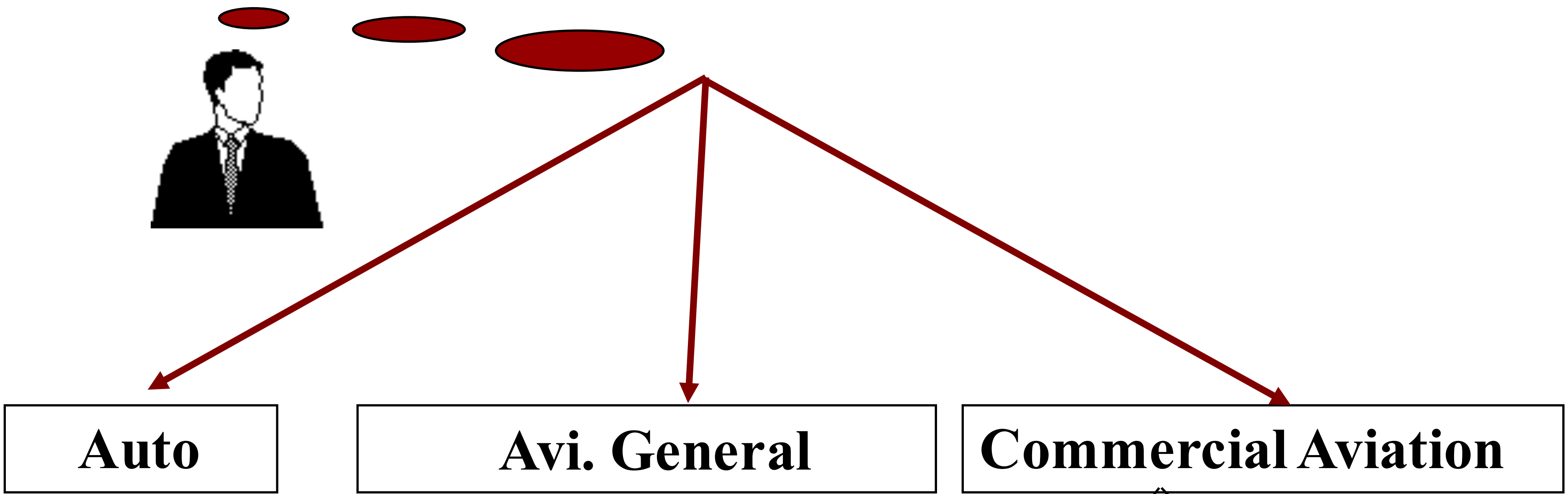
Market Share Details*

Household Income Group	<$30K	$30K - $60K	$60K - $100K	$100K - $150K	>$150K
Auto	82 %	76 %	64 %	53 %	51 %
Airline	18 %	24 %	30 %	32 %	31 %
SATS	0 %	0 %	5 %	16 %	18 %

*Numbers rounded to nearest percent.

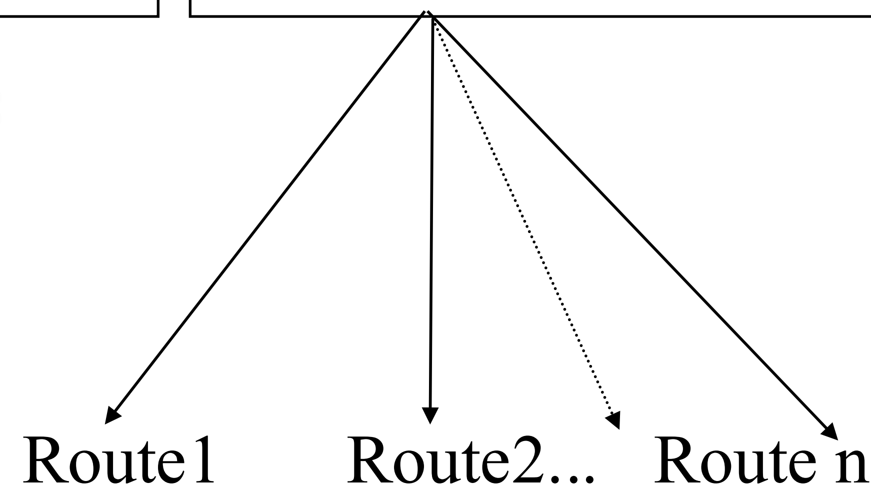
Print Results | Close

Analysis of Travel Bahavior



Factors considered in mode split:

- Travel time
- Travel cost
- Value of time
- Route convenience
- Trip type



Includes Airport Choice

TSAM employs a family of Logit Models (mixed and nested)

Logit Models used in TSAM

- Logit model

$$P_i = \frac{e^{U_i}}{\sum_i e^{U_i}}$$

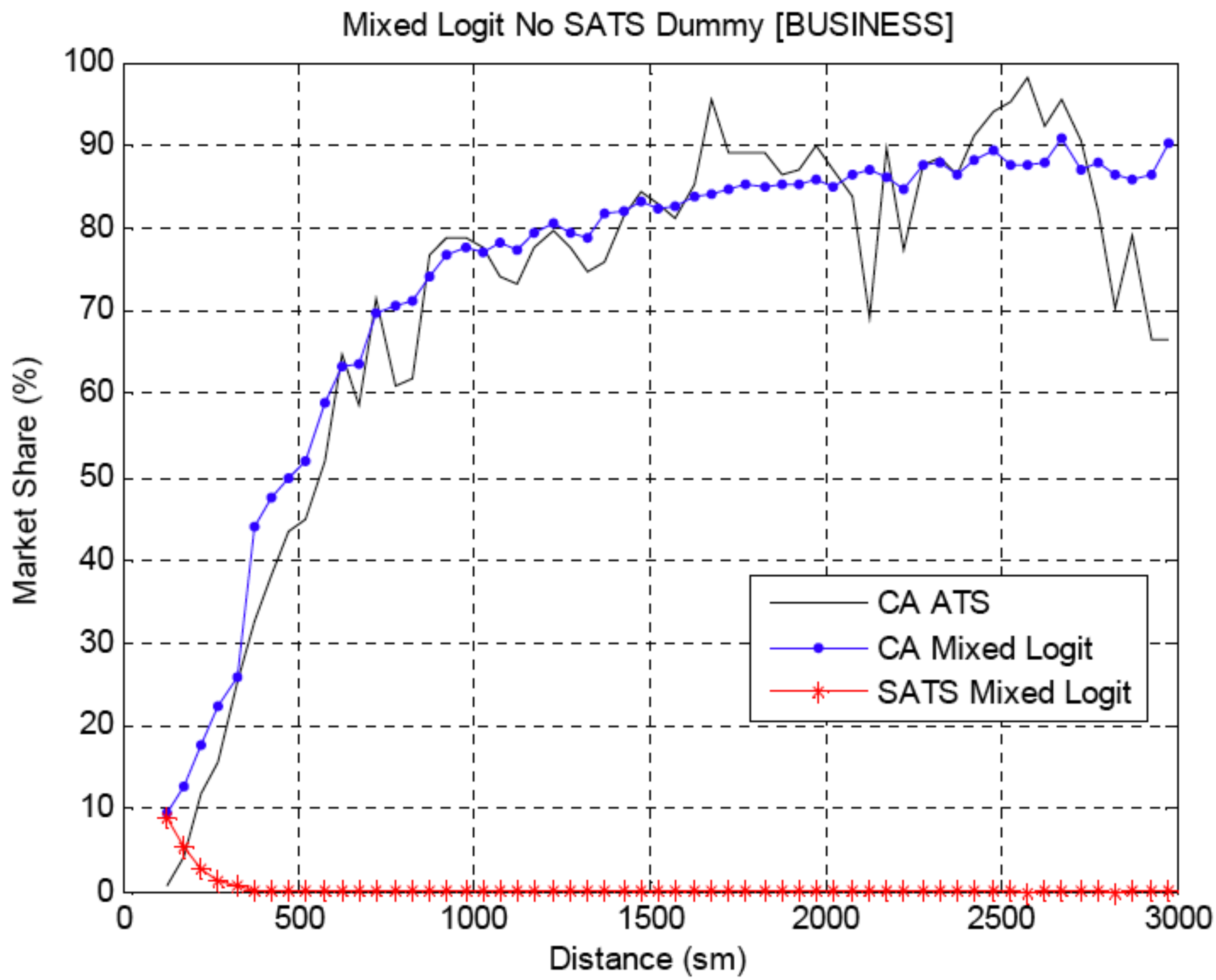
- Nested logit utility function

$$U_{ij}^{kl} = \alpha_0\ Travel\ Time_{ij}^{k} + \alpha_1\ Travel\ Cost_{ij}^{k1} + \alpha_2\ Travel\ Cost_{ij}^{k2} + \alpha_3\ Travel\ Cost_{ij}^{k3}$$
$$+ \alpha_4\ Travel\ Cost_{ij}^{k4} + \alpha_5\ Travel\ Cost_{ij}^{k5} + \alpha_6 shortTripDummy_{ij}^{m} + regionDummy_{ij}^{k}$$

- Mixed logit utility function

$$U_{ij}^{klm} = \alpha_0\ Travel\ Time_{ij}^{k} + \alpha_0^{'} + \alpha_1\ Travel\ Cost_{ij}^{k1} + \alpha_2\ Travel\ Cost_{ij}^{k2} + \alpha_3\ Travel\ Cost_{ij}^{k3} \ldots$$
$$+ \alpha_4\ Travel\ Cost_{ij}^{k4} + \alpha_5\ Travel\ Cost_{ij}^{k5} + \alpha_6 shortTripDummy_{ij}^{m}$$

Calibration of the Model



CA = commercial airline, SATS = VLJ vehicle

Sample Studies Using the TSAM Model

- Advanced aircraft concepts developed by NASA (ADS-B, Datalink, etc.)
- Parametric studies of advanced vehicle technology (tiltrotors, supersonic jets)
- Studies to predict aviation demand when significant changes occur (i.e., high fuel costs)

Constrained Demand

- Aviation demand can be constrained due to multiple reasons:
- No service to a given community (essential air servcice in the U.S.)
- Service exists but is out of my pocked
- The aviation service is not offered because 1) good capacidad aeroportuaria, 2) pollution, political will, and others)

Example 1 : Restrictions at DCA

- National (Reagan, DCA) airport does not offer flights > 1,250 miles (called perimeter rule)
- This is to discourage competition with Dulles (IAD). This last one was designed for large aircraft and longer stage lengths
- The availability of high-performance aircraft such as the Boeing 737-700/800 and Airbus A319/318 allows medium-range operations with a decent payload form DCA today

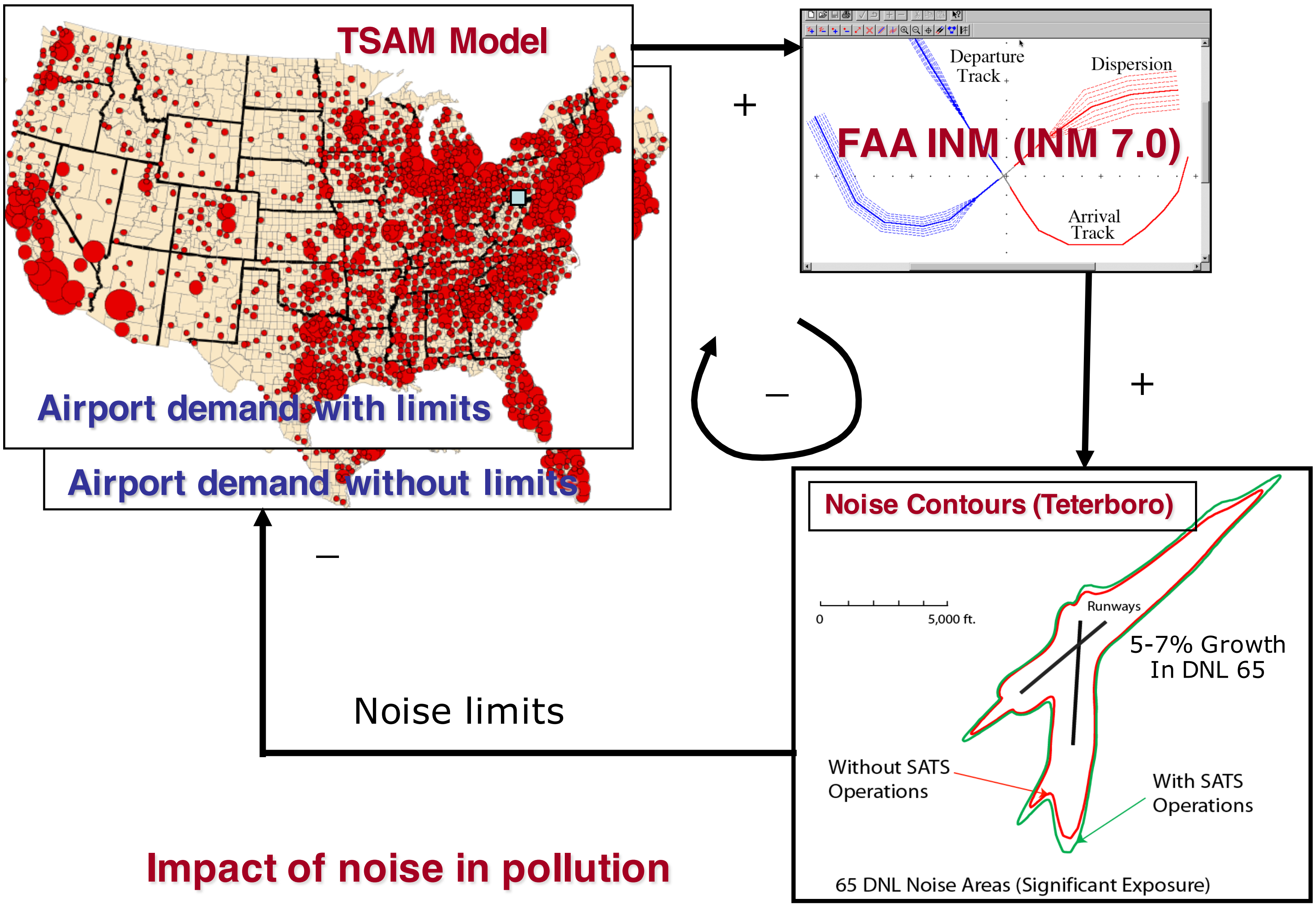
Example 2: Long Beach, California

- The Long Beach airport should have more demand
- Local regulations limit the number of flights to 60 per day
- Long Beach is located near Los Angeles (LAX) and serves one of the largest markets in the U.S.

Runway General Features

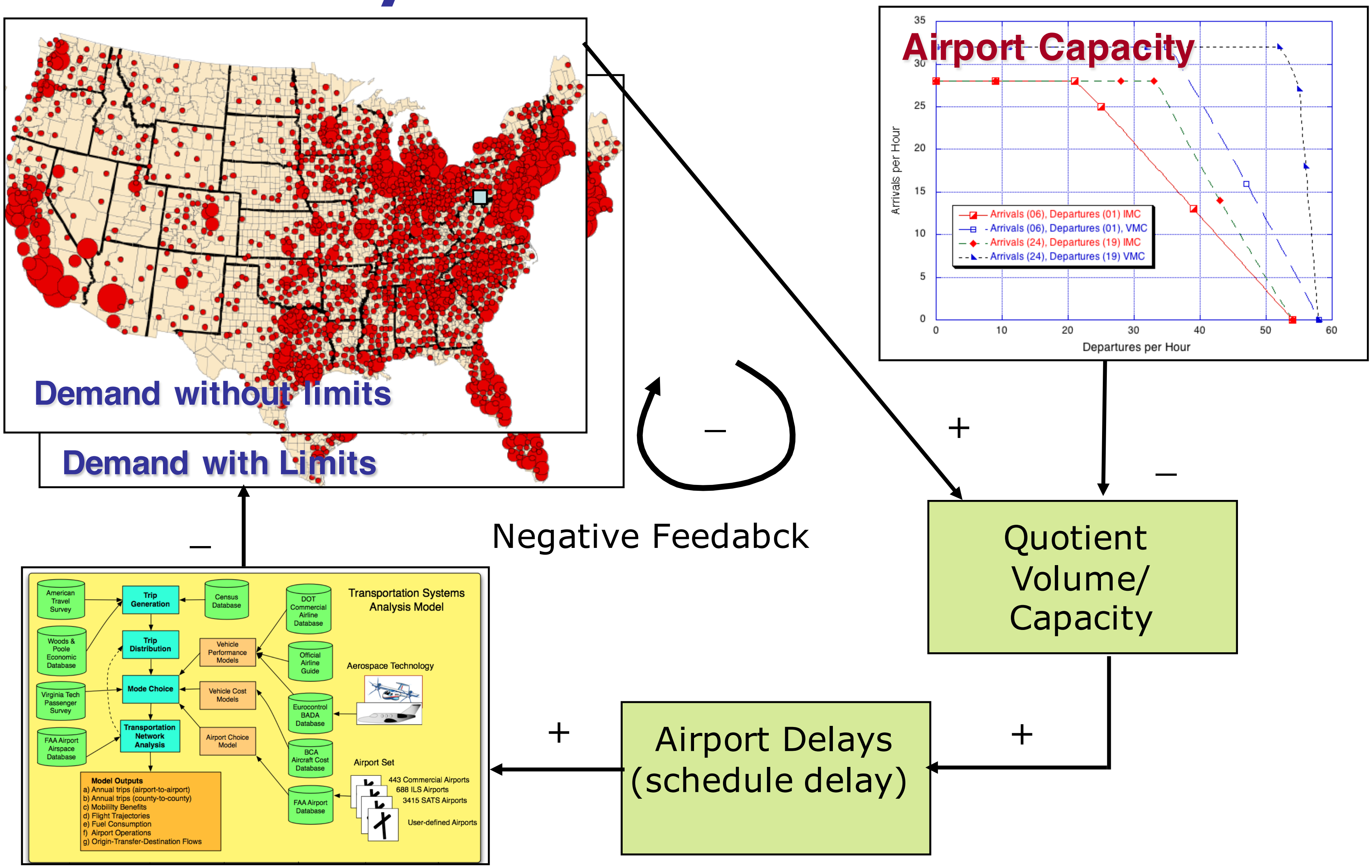
Runway Designation	Runway Length (ft.)	Runway Width (ft.)	Runway Surface
07L/25R	6192	150	ASPH-F
07L/25R	6192	150	ASPH-F
07R/25L	5423	150	ASPH-G
07R/25L	5423	150	ASPH-G
12/30	10000	200	ASPH-G
12/30	10000	200	ASPH-G
16L/34R	4267	75	ASPH-G
16L/34R	4267	75	ASPH-G
16R/34L	4470	75	ASPH-G
16R/34L	4470	75	ASPH-G

Constrained Demand due to Noise



Impact of noise in pollution

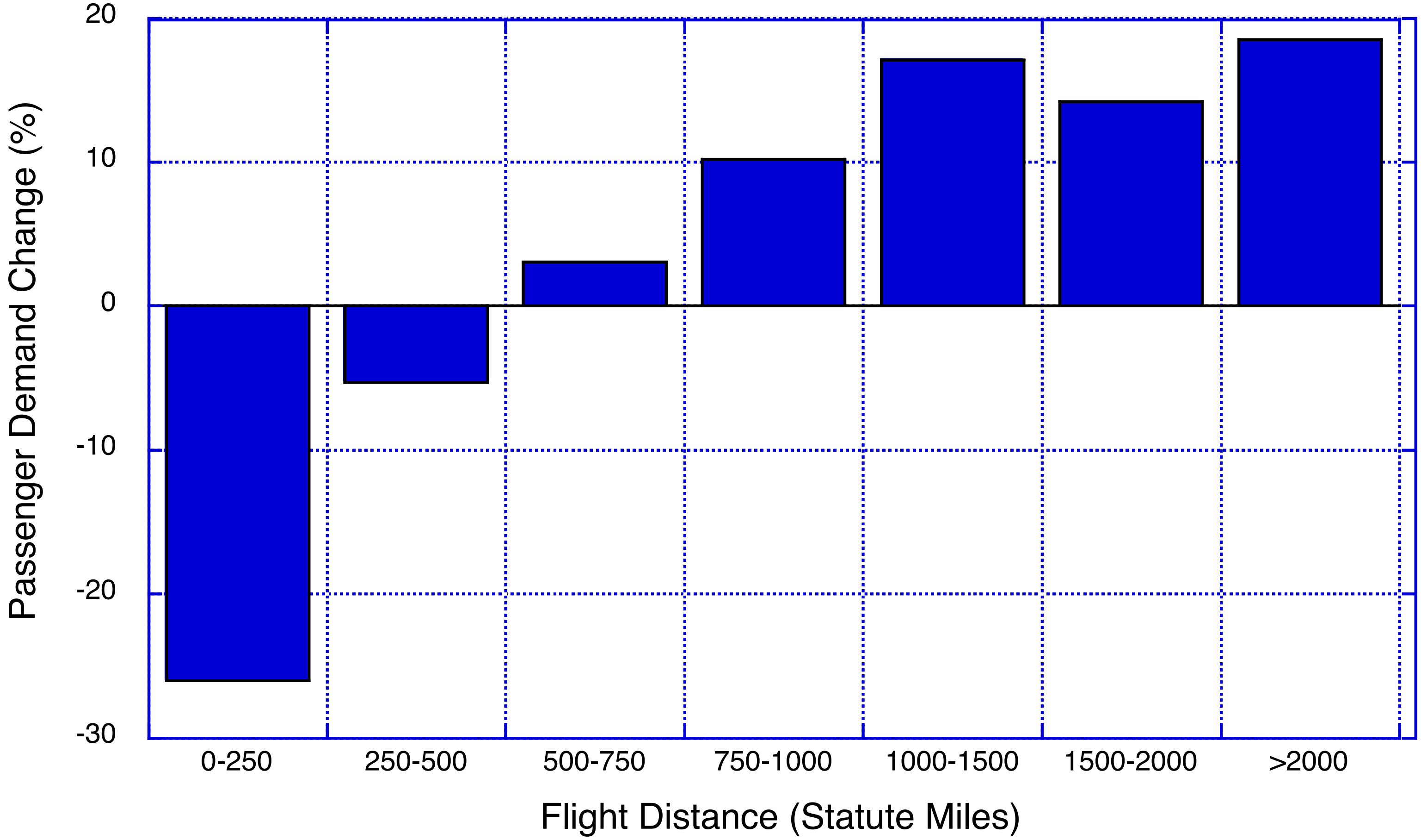
Airport Capacity
Delays and Level of Service



Demand Changes due to Events of Septiembre 11, 2001

- After 911 airports developed new procedures to screen passengers for security reasons
- Airport transit times increased from 1.4 to 2.0 hours for the average departing passenger
- This created an incentive to drive for shorter trips due to added airport transit times

Real Data (9/11 Effects in Demand)



Source of data: Bureau of Transportation Statistics

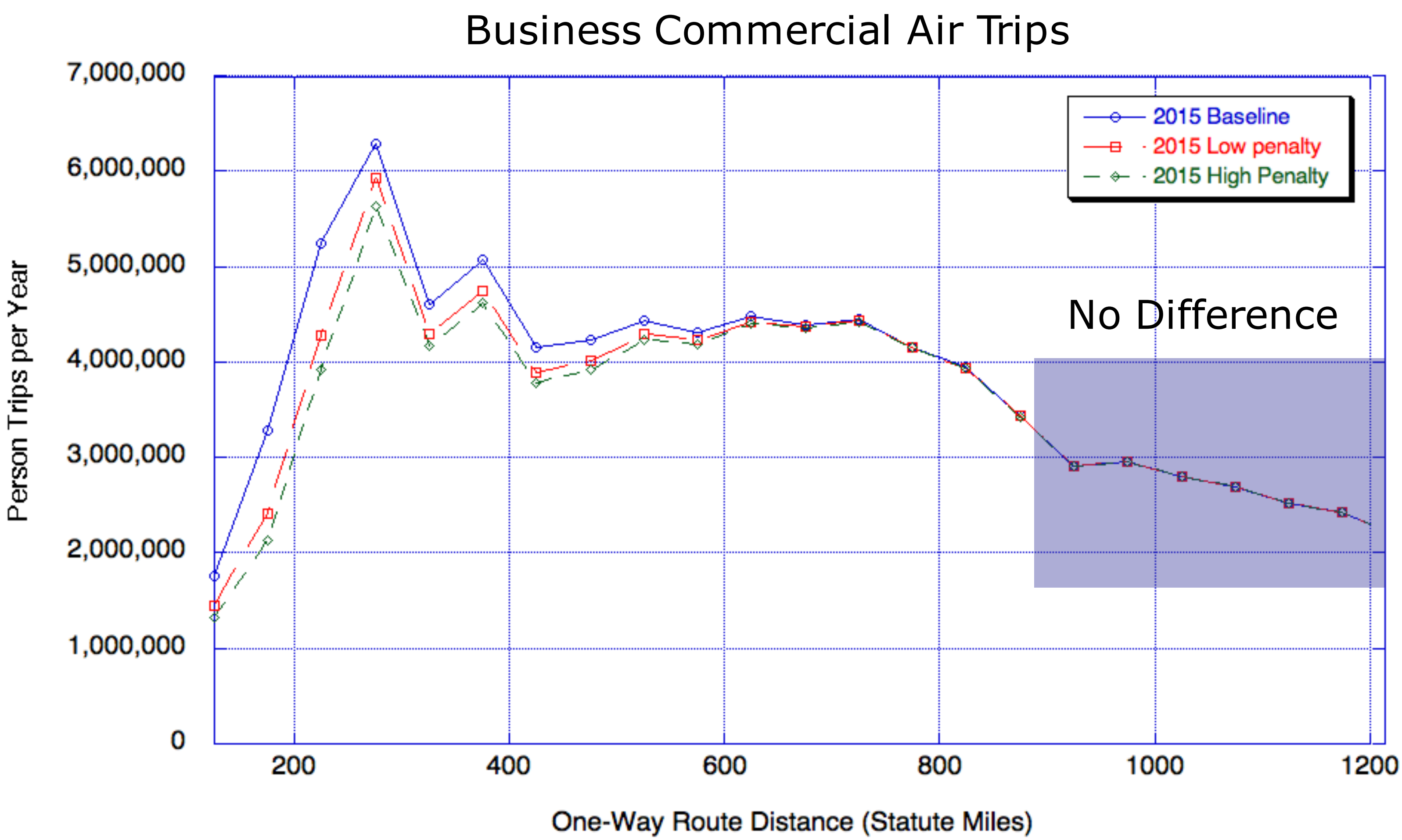
Analysis by Eclat Consulting (2005)

Study of New Security Regulations in the U.S.

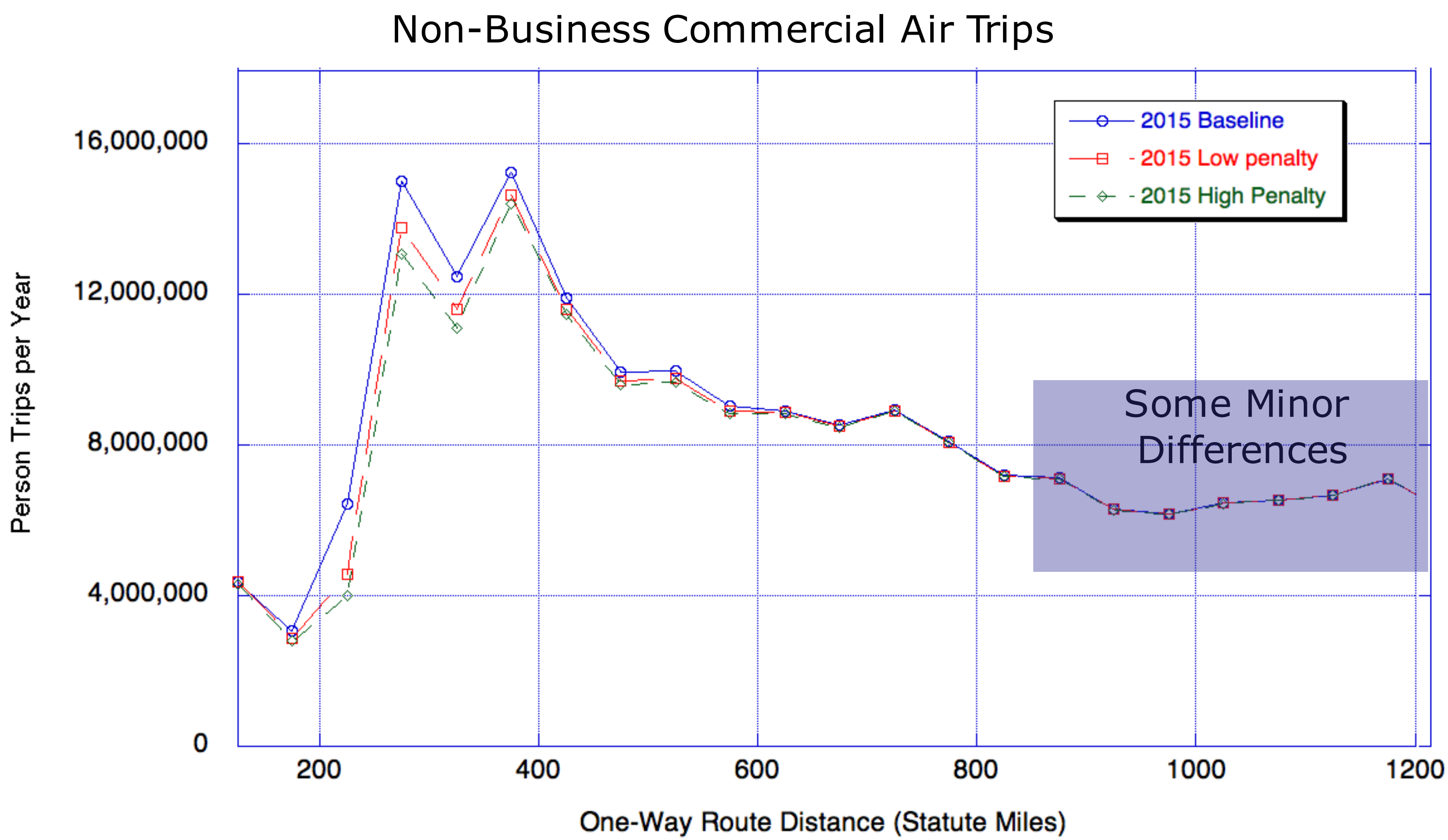
Scenarios Investigated

- Two cases reflecting added processing times at origin and ending airports
- Only domestic air transportation demand studied
- Cases are labeled low and high penalty scenarios
- The following airport processing times are added to the baseline airport times in TSAM
  - Low penalty scenario
    - 20 minutes are added to passengers using large hub airports
    - 15 minutes to medium hub airports
    - 10 minutes to small hub and non-hub airports
  - High penalty scenario
    - 30 minutes are added to passengers using large hub airports
    - 20 minutes to medium hub airports
    - 15 minutes to small hub and non-hub airports
- Results obtained for years 2015 and 2025 (consistent with NextGen analyses)

Increased Travel Times have an Impact in Short-Range Business Travel



Increased Travel Times have a Negative Impact in Short-Range Non-Business Travel



Results

- 2.6% of the nationwide commercial airline person trips are lost in the low penalty scenario
  - 3.4% of business trips lost
  - 2.3% of non-business trips lost
- 3.8% of the commercial airline person trips are lost in the high penalty scenario
  - 4.8% of business trips
  - 3.3% of non-business trips
- Short commercial air trips are affected the most (see graphs)
- Business trips using commercial airlines are unaffected beyond 700 miles