Evaluating the Flexible Deployment of an ADS/B Infrastructure in the Newark Terminal Area

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Background

- Central Theme: Study the flexible deployment of an Automatic Dependent Surveillance/Broadcast (ADS/B) infrastructure in the Newark International Airport (EWR) terminal area via a differentiated service structure
  - Contrasts with the usual approach of adoption via mandate
  - “Fixed” design risks degraded performance if realized CDTI uptake does not conform to forecast uptake
- Concept: Users leverage ADS/B via Cockpit Display of Traffic Information (CDTI) equipage
  - Voluntary equipage is accomplished by providing competitive advantage: equipped aircraft can be processed through terminal area quicker, thus mitigating any delay costs
  - This deployment strategy consists of appropriately allocating terminal area resources between technology (CDTI) adopters and non-adopters. Thus, the two users are segregated and are subject to different levels of service, biased towards the adopters.
- Motivation: National Airspace System (NAS) demand has surpassed pre-9/11 levels, resulting in increased congestion and decreased system performance
  - Demand is predicted to grow exponentially
  - A meaningful increase in capacity at EWR can only be accomplished via the increased throughput offered by ADS/B (by virtue of decreased separation standards)

System Description

- Characteristics Included
  - Terminal Area traffic model of both arrival streams
  - Model of annual demand growth [*Source: Boeing*]
    - Assumption: Arrival traffic growth mirrors NAS growth
  - CDTI Uptake Schedule [*Source: FAA*]
- Characteristics Not Included
  - Departure traffic model
  - Any consideration of safety benefits

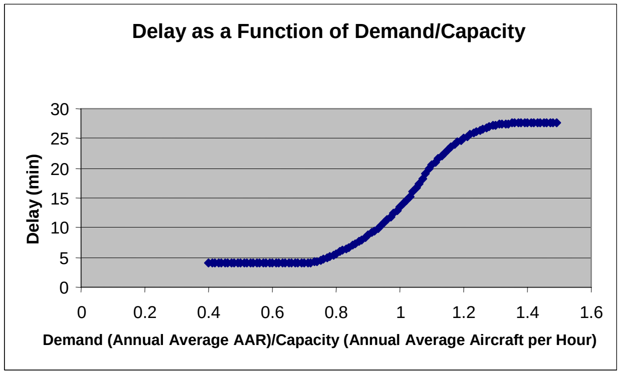


Figure 2. Terminal Area Demand as a Function of Demand and Capacity

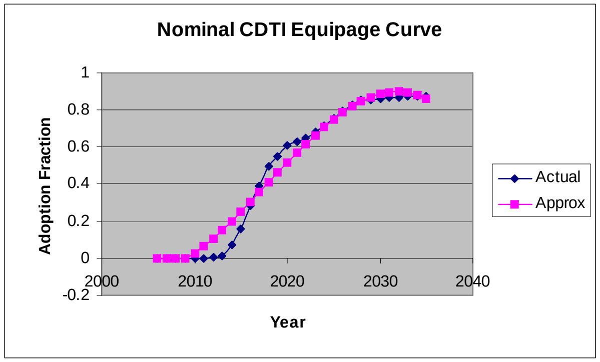


Figure 3. CDTI Equipage Curve [Source: ADS/B Program Office]

System Description (cont.)

- System Levers
  - Adjustment of service rate fraction
    - Determines the allocation of terminal area resources between two user types
  - Maximum allowable delay difference
    - Determines the minimum acceptable resource allocation for non-adopters
  - Equipage mandate
    - System managers reserve right to enforce equipage should actual adoption proceed too slowly
- System Tensions
  - "+" – Accommodating as many early adopters as possible results in increased throughput and increased landing fee revenues
  - "-" – Overly-aggressive allocation in favor of adopters increases non-adopter delays and results in lost capacity/revenue
- Benefits
  - Increased traffic/passenger throughput
  - Decreased delay and delay costs
  - Increased revenue from landing and ADS/B service fees

System Architecture Blueprint

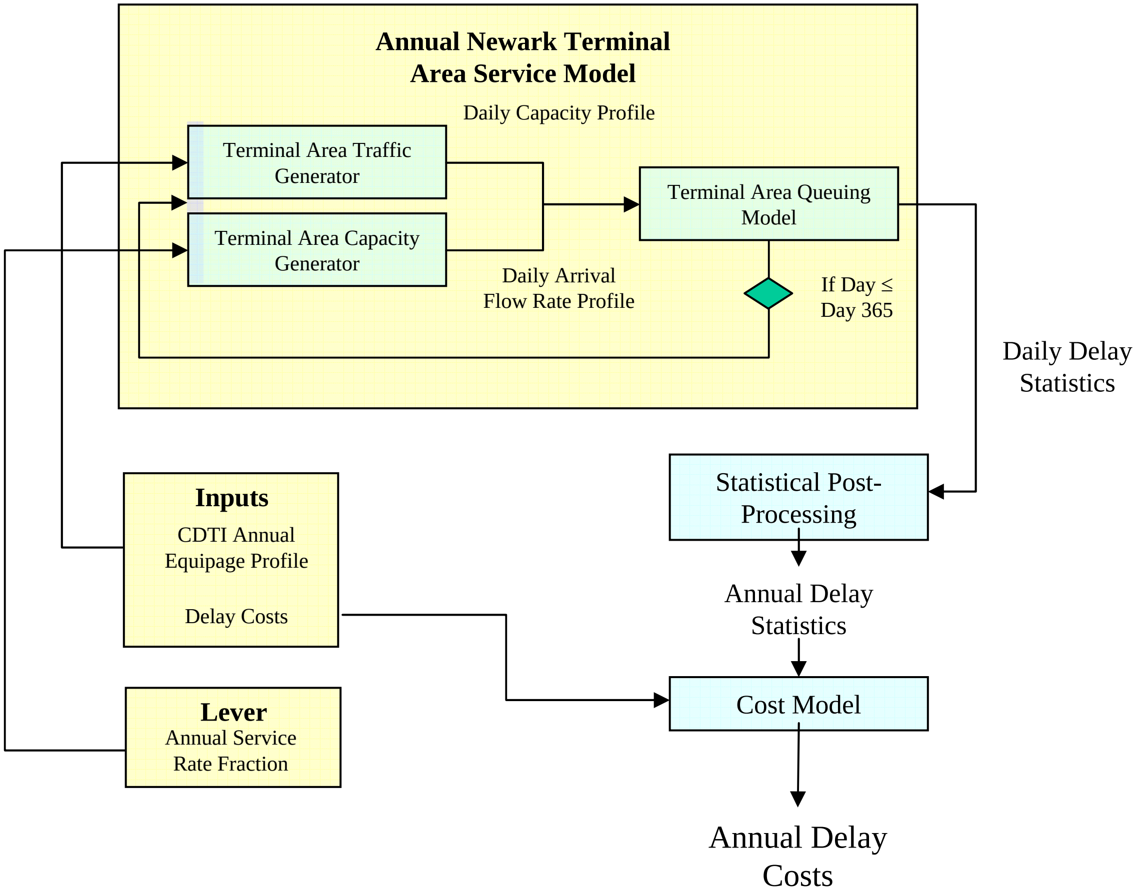


Figure 4. System Architecture Blueprint

Characterizing the Sources of Uncertainty

- Uncertainty is the source of risk
- Two major sources of uncertainty were identified
  - Terminal Area Demand Growth
    - The amount of arrival traffic expected in the EWR terminal area
    - Direct driver of system performance and the main source of uncertainty
  - ADS/B Implementation Date
    - A history of schedule slips for the majority of modernization products
    - Perceived slip is one barrier to early CDTI adoption since users unmotivated to adopt early

Uncertainty Source #1: Terminal Area Demand Growth

- Model: Mean Reverting Process [*Source: Miller and Clarke*]

$$dx = \eta\left(X - x\right)dt + \sigma dz,$$

where:

$X \equiv$ Mean value of growth

$\eta \equiv$ Speed of reversion

$\sigma \equiv$ Variation of demand

$dz \equiv$ Weiner process increment

- Forecast: Boeing 20 year forecast [*Source: Boeing*]

Table I: NAS Demand Statistics

Year	Demand	Total Growth	Annual Growth
-	RPK	%	%
1985	470.63	-	-
1990	589.06	25.16	5.03
1995	670.74	13.82	2.76
2000	857.47	27.89	5.58
2001	812.76	-5.21	-5.21
2002	783.48	-3.6	-3.6
2003	828.27	5.72	5.72
2004	925.18	11.7	11.7
2014	1273.26	37.62	3.76
2024	1856.81	45.83	4.58

- Parameter Estimation: Maximum Likelihood Estimation yields the necessary model parameters [*Source: Dixit & Pindyck*]

$$X_t - X_{t-1} = a + bX_{t-1} + e_t$$

where:

$e_t \equiv$ Standard Gaussian noise (i.e. N(0,1))

$$\eta = -\frac{a}{b} = 0.380$$

$$\sigma = \sqrt{\frac{2\ln\left(1+b\right)}{\left(1+b\right)^2 - 1}} = 0.496$$

Uncertainty Source #2: ADS/B Implementation Date

- Model: “Noisy,” monotonically decreasing stochastic process describing the estimated deployment date from the perspective of airspace users as a function of the actual deployment date.
  - Note: As defined, it is only useful when generating scenarios for use in a simulation.
- Statistics Source: GAO Report on Modernization Progress [*Source: GAO*]

$$\hat{T}(t) = \max\left[(T+S)+(T+S-t)\left(e_s\right), S_0 + t\right]$$

$$\hat{S}(t) = \hat{T}(t) - T$$

$where:$

$\hat{T}(t) =$ estimated deployment date at t

$T =$ targeted deployment date

$S =$ actual schedule slip

$\hat{S}(t) =$ estimated schedule slip at time t

$S_0 =$ minimum estimated schedule slip

$e_s =$ Standard Gaussian noise ~ N(0,1)

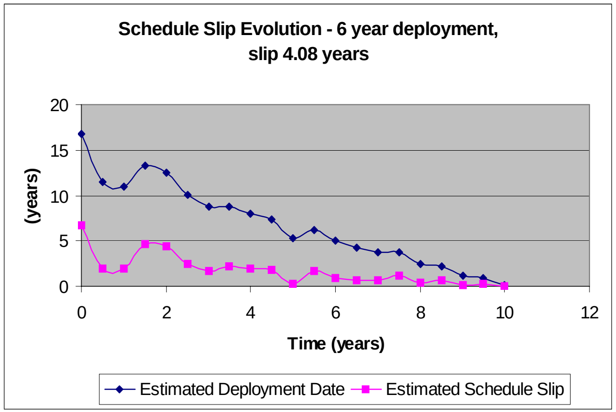


Figure 5. Example Schedule Slip Evolution

Table II: Schedule Slip Histogram for NAS Modernization Programs

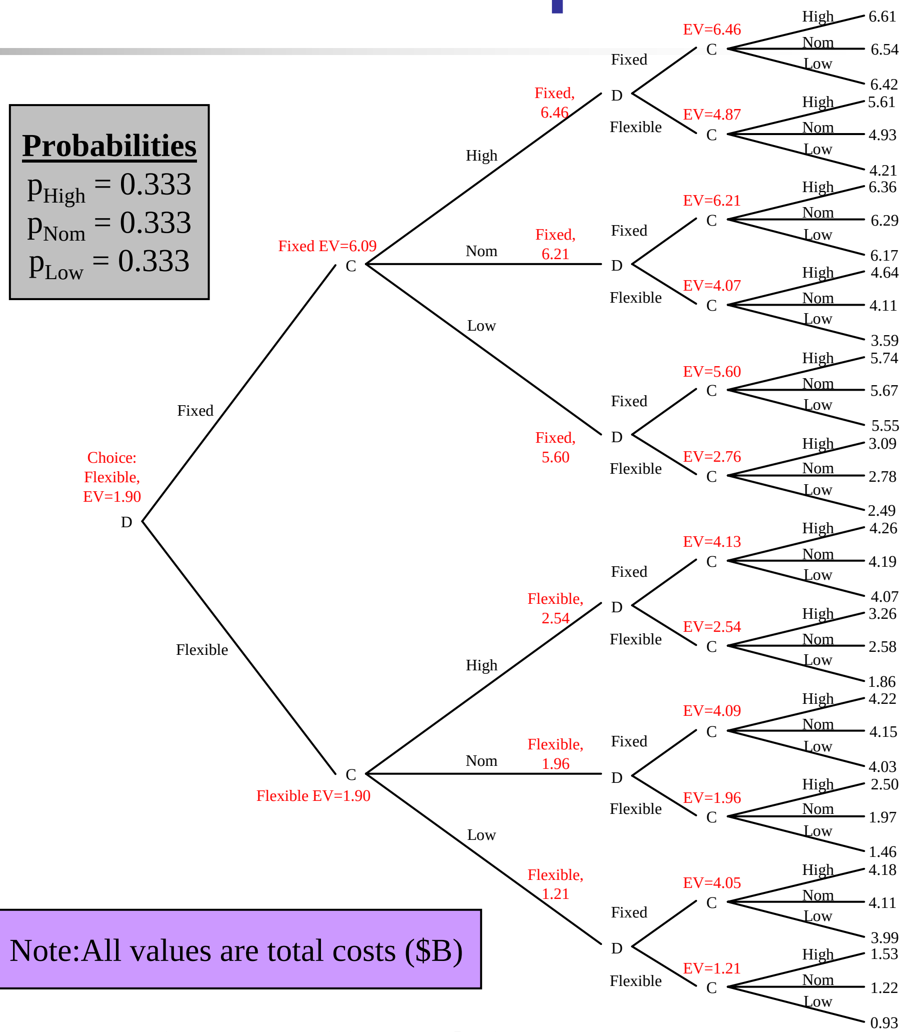
Schedule Slip	Number of Program Slips
Years	-
0	4
1	0
2	2
3	0
4	1
5	0
6	1
7	1
8	1
9	0
10	2

Defining System Concepts

- Objective: Conceive of two possible designs to provide a crude estimate of value flexibility in the face of uncertainty
- Timeframe: 2005-2020
  - Within the uptake time frame and before overwhelming adoption has transpired
- Concept #1: Base case design
  - Fixed service fraction for the foreseeable future (resources split evenly between categories of users)
- Concept #2: Flexible design
  - Active management of airspace is possible. System managers can adjust the service fraction at beginning of deployment (2005) and during deployment (2012)
- Source of Uncertainty: Terminal Area Demand Growth
  - 3 Possible Values of equal likelihood: Low Annual Growth (1%), Nominal Annual Growth (3.5%), High Annual Growth (5%)

Using Decision Analysis to Compare System Concepts

- Base Case Concept Costs = -$6.09B (2005 $)
- Flexible Case Concept Costs = -$1.09B (2005 $)
- Flexible Case results in cost mitigation of $4.19B (2005 $)
- Thus, it behooves management to actively manage terminal area capacity



Probabilities

$p_{High} = 0.333$
$p_{Nom} = 0.333$
$p_{Low} = 0.333$

Note:All values are total costs ($B)

Figure 6. Decision Analysis Tree

Using a Binomial Lattice to Represent Uncertainty

- Motivation: First step to a more robust analysis involves the development of the uncertainty within a more sophisticated representation
- Result: Use a Binomial Lattice to model the diffusion of the future possible states for the demand growth
- Model: Exponential demand growth starting in 1985 using the Boeing forecast

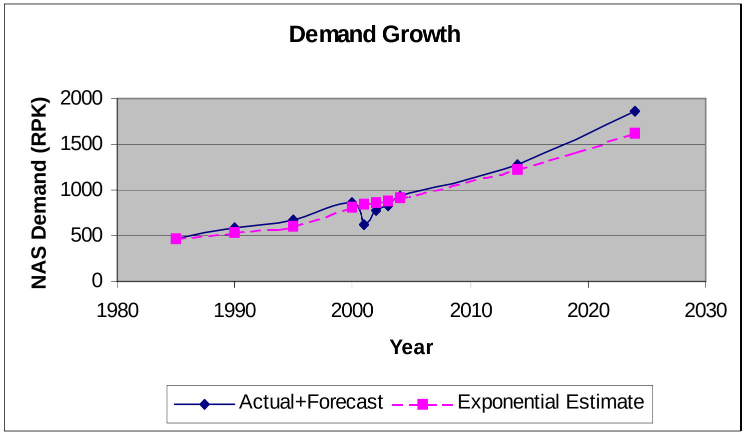


Figure 7. Exponential Curve Fit to NAS Demand Growth

$$u = e^{\sigma\sqrt{\Delta t}} = e^{0.02882/year\sqrt{1year}=1.167}$$

$$d = e^{-\sigma\sqrt{\Delta t}} = e^{-0.02882/year\sqrt{1year}=0.857}$$

$$p = 0.5 + 0.5\left(\frac{v}{d}\right)\sqrt{\Delta t} = 0.5 + 0.5\left(\frac{0.02882}{0.1542}\right)\sqrt{1year}$$

Using a Binomial Lattice to Represent Uncertainty (cont.)

- Results Include:
  - Demand Growth Diffusion Lattice
  - Probability Lattice
  - Demand Distribution at Final Year

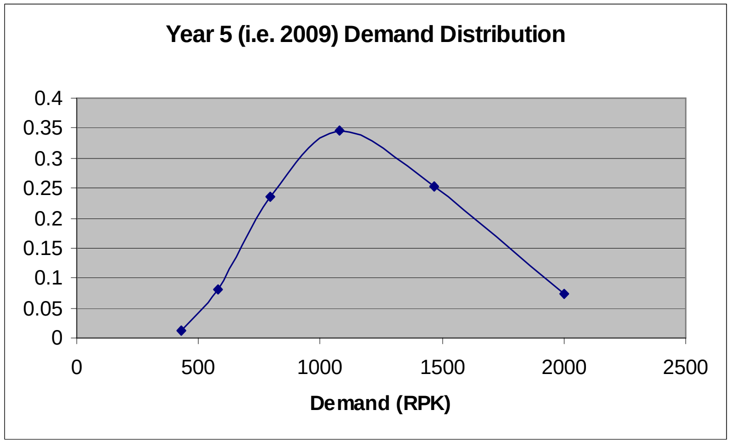


Figure 8. NAS Demand Distribution at Year 5 (2009)

Demand Growth Diffusion Lattice

2004	2005	2006	2007	2008	2009			
0	**1**	**2**	**3**	**4**	**5**	**Step**	**(u/d)^(step)**	**outcome/lowest**
925.18	1079.43	1259.39	1469.36	1714.34	2000.17	5	4.674	4.674
	792.97	925.18	1079.43	1259.39	1469.36	4	3.434	3.434
		679.65	792.97	925.18	1079.43	3	2.522	2.522
			582.53	679.65	792.97	2	1.853	1.853
				499.29	582.53	1	1.361	1.361
					427.94	0	1.000	1.000

Probability Lattice

	2004	2005	2006	2007	2008	2009
	0	**1**	**2**	**3**	**4**	**5**
	1	0.593	0.352	0.209	0.124	0.0736
		0.407	0.483	0.430	0.340	0.252
			0.165	0.294	0.349	0.345
				0.0672	0.160	0.237
					0.027	0.081
						0.011
sum	1	1	1	1	1	1

Decision Analysis: Part II

- Motivation: Conduct a more refined valuation of flexibility using the binomial lattice of demand growth uncertainty
- Mechanics: Backwards recursion from end of diffusion to the beginning
  - Value at each state is set to the maximum of: the value in adjusting the service fraction and the value in leaving the service fraction unchanged
  - Note: Since flexibility incurs no cost, the option to adjust the service fraction is only chosen when it reduces the cost by more efficiently allocating the airspace
  - Results:
    - 3 States exist where the option to adjust the service rate is exercised (highlighted in red)
    - Flexibility results in cost mitigation of $211M (2004 $)

Value Lattice w/o Flexibility (i.e. Base Case)
($ Million 2004)

ear	0	1	2	3	4	5	6
	$116	$77	$76	$83	$98	$117	$136
		$136	$116	$73	$74	$88	$102
			$132	$132	$113	$78	$79
				$111	$129	$138	$148
					$97	$116	$136
						$85	$100
							$73

Value Lattice w/ Flexibility
($ Million 2004)

Year	0	1	2	3	4	5
	$632	$518	$411	$327	$281	$214
		$602	$504	$366	$257	$193
			$492	$452	$342	$197
				$357	$343	$269
					$247	$215
						$155

Conclusions

- Flexibility has value!
- ADS/B infrastructure deployment should be designed so that managers can actively manage terminal area capacity
- Flexibility can be alternatively couched in the context of a real option
    - System managers have the right, but not the obligation to reallocate terminal area resources in order to cash in on the additional revenue realized by optimizing the system throughput

Future Work

- Next step should involve modeling and integration of the feedback mechanism detailing how the equipage is driven by the additional delay experienced by non-adopters
- Uncertainty in the actual deployment date of the ADS/B infrastructure should be incorporated into the analysis
- The costs associated with the airspace reconfiguration taking place every time the terminal area resources are reallocated should be incorporated into the analysis

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