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Satellite Navigation

Investment Analysis Report

September 25, 1999

Mission Need Statement #50
Application of Satellite Navigation Capability for Civil Aviation

DCN: R90170-02

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Investment Analysis Team

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Background

The FAA's policy to transition from the current ground-based navigation and landing system to a satellite-based system has been stated in several FAA documents. These include the *FAA Strategic Plan*, the *FAA's Plan for Transition to Global Positioning System (GPS)-Based Navigation and Landing Guidance, July 1996*, and the *NAS Architecture (Version 4.0)*. According to this policy, the Wide Area Augmentation System (WAAS) will provide the National Airspace System (NAS) with satellite-based en route and terminal navigation, as well as a precision approach capability. The Local Area Augmentation System (LAAS) will complete the transition to satellite-based navigation by providing Category (CAT) II/III precision approach and landing service. CAT II is a precision approach with a decision height of less than 200 feet, but not less than 100 feet. CAT III is a precision approach with a decision height of less than 100 feet. LAAS will also provide CAT I service at a number of sites where WAAS does not provide coverage, cannot meet availability requirements, or at major airports where dual Instrument Landing System (ILS) or LAAS coverage is desirable to guarantee precision approach services. CAT I is a precision approach with decision height not less than 200 feet.

GPS alone does not satisfy all requirements for civil air navigation. Mission Need Statement (MNS) #50, *Application of Satellite Navigation Capability for Civil Aviation* identified the following deficiencies with respect to precision approach capabilities:

> "Some qualifying airports for which service has been requested do not have an approach aid capable of providing the appropriate level of service. Current systems cannot be sited due to terrain constraints, lack of real estate or, in many cases, financial reasons. There is a backlog of approximately 600 precision approaches due to cost and logistics. More runways would qualify for this capability with lower cost of service."

To meet the requirements identified in the MNS, the Agency has created the WAAS and LAAS programs to improve the integrity, accuracy, availability, and continuity of GPS by using special equipment that constantly monitors the GPS. The programs use Geostationary Satellite Transponder (GST) broadcast signals. The WAAS determines integrity and corrections for GPS satellites and the ionosphere, then broadcasts this data to the user via the GSTs. This broadcast data enables users to improve their position accuracy and to determine when GPS satellites should not be used. LAAS does the same, only using a very high frequency (VHF) data broadcast medium.

In January 1998, the FAA's Joint Resources Council (JRC) approved the Satellite Navigation (SatNav) Acquisition Program Baselines (APBs) for the WAAS and LAAS programs. An APB presents the yearly costs, benefits, schedule, and performance capabilities for a program. The baseline was prepared for the JRC by an Investment Analysis Team (IAT) that met from November 1997 through January 1998. The results of its efforts are documented in an Investment Analysis Report (IAR) dated January 9, 1998.

The General Accounting Office (GAO) completed a report on FAA SatNav programs in April 1998 that examined the IAR and did some sensitivity studies on the benefits analysis including the

Agency's use of passenger value of time (PVT) savings. The result showed that while benefits would decrease if the agency discontinued measuring PVT, the benefit to cost (B/C) ratio would still exceed 2.0. Another analysis showed that the B/C ratio was also greater than 1.0 even if no decommissioning of ground-based navigational aids (NAVAIDs) occurred. GAO recommended that the Agency revalidate its benefits analysis, especially its admitted soft estimates of large direct routing benefits, and the Agency agreed to perform this analysis in FY 1999.

Meanwhile, the WAAS program began to experience some difficulties with its procurement of leased satellites, schedule, and costs. In response to these difficulties, the GPS program manager briefed the Administrator on the problems and issues in September 1998. This precipitated a request by FAA senior managers and the Acquisition Executive that another investment analysis be conducted for the SatNav programs. That effort began in October 1998, and concludes with the JRC of September 2, 1999. The IAT was asked to rebaseline the WAAS and LAAS programs and to respond to later congressional language that asked the FAA to conduct a "Lease versus Buy" analysis of the WAAS satellites.

Approach

The approach of this investment analysis focused on the following main goals:

- To involve all the stakeholders inside and outside the FAA to the largest possible extent in the conduct of the investment analysis and to keep the process as open to public scrutiny as possible,
- To consider all viable alternatives in the analysis and to make use of all major studies including a major study by Johns Hopkins University/Applied Physics Laboratory (JHU/APL) on the risks of SatNav, and
- To focus on risk reduction strategies in considering which alternative to recommend.

The IAT consisted of representatives from the sponsoring office (AVR- the Office of Regulation and Certification), the GPS Integrated Product Team (IPT), the Architecture and System Engineering Office, airports, Air Traffic Services, the investment analysis staff, and the Center for Advanced Aviation Systems Development (CAASD), a part of the MITRE Corporation. The Department's Office of Inspector General (OIG), as well as GAO staff sat in on many of the team meetings. Representatives from the Department of Defense (DoD) were involved in meetings and briefings.

The investment analysis can best be understood by considering it to occur in three phases. The first phase, Alternatives Development, culminated in the first public meeting on February 25, 1999, where the Agency revealed the four basic alternatives it proposed to consider. The four basic alternatives identified were based on different levels of investment in WAAS. Each had several sub-variations depending on the extent of roles for LAAS and ground-based NAVAIDs including Loran-C.
During the second phase, the IAT performed a technical evaluation of the alternatives. The results were briefed at the second public meeting on April 6, 1999. Studies of availability and accuracy were briefed and twelve sub-alternatives were identified as worthy of further economic analysis.

During the third phase, the team conducted an economic analysis, developing estimates of FAA and user costs and benefits for each alternative and also conducting a risk assessment. The team went offsite to review the data collected and the analysis and then held a third public meeting on July 7, 1999, to discuss the user estimates on cost, benefits, and user equipage received.

The team then completed its economic analysis, including its cost-benefit analysis and the "lease versus buy" study for the WAAS satellites. Since the alternatives included different quantities of ground-based NAVAIDs, both maintained and decommissioned, the economic analysis included costs for both the maintenance of existing ground-based NAVAIDs and the decommissioning costs of those that would not be kept beyond the life of the study (2000-2020).

The decision criteria that were used to choose the alternative were: (1) Mission Effectiveness: to what extent the alternative improves mission performance for the external and internal customers of the Agency; (2) Return on Investment: value of the alternative in economic terms to the FAA and the users of the airspace we control; (3) Risk: how much risk the alternative has in terms of uncertainty and magnitude of the possible outcomes; and (4) Strategic Alignment: the extent to which the proposed alternative supports strategic organizational objectives such as the Agency's System Architecture and International Commitments.

Alternatives

Four primary SatNav architectures were developed, all meeting a "minimum" set of operational navigational performance requirements but ranging in the degree of user and FAA investments in both ground- and satellite-based NAVAID assets. Key minimum requirements for each architecture are as follows:

- The navigation and landing service must meet the accuracy, integrity, availability, and continuity of service performance levels of existing systems.
- The navigation service must be global and seamless.
- The navigation service must permit area navigation (RNAV) and Free Flight operations.
- Instrument approaches with vertical guidance in the form of precision approach or non-precision approach with vertical guidance (NPA) service must be extended to each instrument flight rules (IFR) runway.
- The navigation and landing service must be extended to the airport surface. The navigation service must support a terrain avoidance warning system for IFR-equipped aircraft.

Eight variations of the four baseline navigation architecture alternatives were developed and analyzed for technical feasibility. The twelve alternatives were recommended for detailed analysis by the cost analysis team, benefits analysis team, and risk analysis team.

The potential role of Loran-C to complement the SatNav services involves its use as a NAVAID during possible SatNav service outages. Loran-C is currently used as a supplemental navigation system for en route and terminal operations, but there are currently no NPAs approved for Loran-

C. The primary role for Loran-C explored in this analysis is to supplement the backup capability of a minimum operational network (MON) or basic backup network (BBN) infrastructure of VHF Omni-directional Range/Distance Measuring Equipment (VOR/DME).

See Figure ES-1 for an illustration of the alternatives considered.

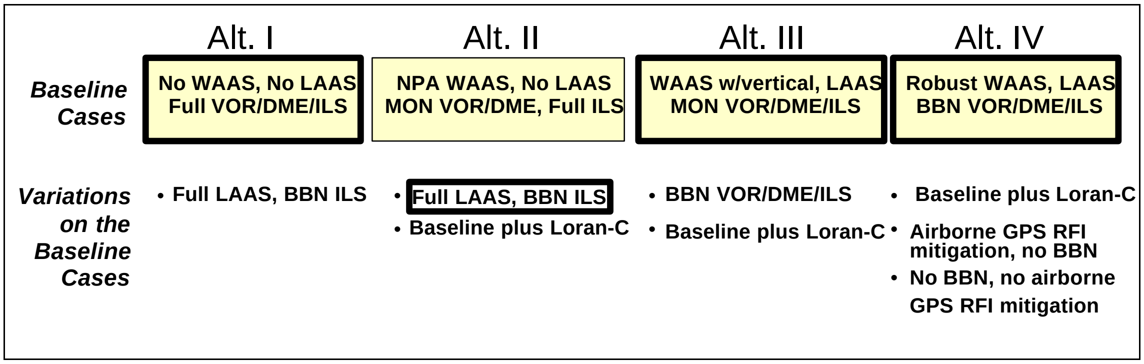

Figure ES-1. Alternatives Recommended for Detailed Economic Analysis

In order to more efficiently utilize the available resources, the cost team requested that the IAT narrow the list of 12 alternatives to a more manageable number that represented the most viable solutions from an operations perspective. Based on the three decision criteria of Mission Effectiveness, Risk, and Strategic Alignment, the IAT chose one alternative from each of the main alternative types. These are shown in bold in Figure ES-2, Alternatives Selected for Detailed Economic Analysis. Figure ES-2 shows the relationship between the amount of SatNav and the number of ground-based NAVAIDs in greater detail than Figure ES-1.

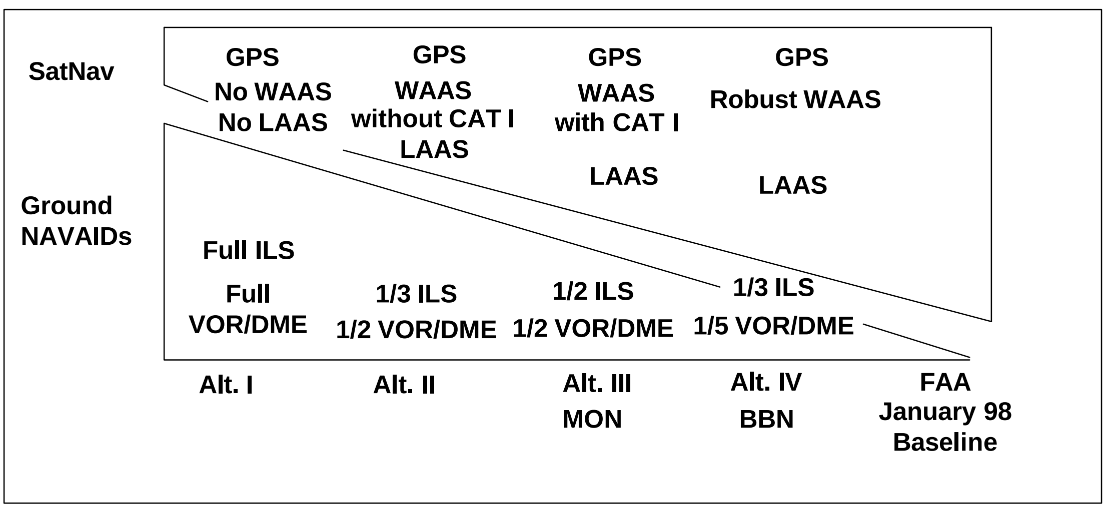

Figure ES-2. Alternatives Selected for Detailed Economic Analysis

Alternative I uses the DoD-provided GPS without FAA augmentation, and retains the entire ground-based NAVAID infrastructure including growth to accommodate demand. Alternatives II and III (MON) take advantage of the WAAS assets currently being fielded and provide an operational capability by adding one more geostationary (GEO) satellite to the existing two Inmarsat3 geostationary satellites to eliminate the single point of failure that exists with the Inmarsat3s alone, which covers about 3/4 of the continental United States (CONUS). Alternative IV (BBN) adds two more geostationary satellites to permit continued, unrestricted operations after a single geostationary satellite failure, and supplements the number of WAAS Reference Stations (WRSs) to provide complete CAT I coverage throughout the service volume.

Based on the four decision criteria mentioned above, the IAT determined that Alternative IV offered the best mission effectiveness, strategic alignment, and return on investment if users equip early. The IAT wanted to craft an approach to Alternative IV (BBN) that would reduce risks by allowing the FAA to make incremental changes and provide for time to capture and evaluate data such as user equipage (i.e., user acceptance) and data on interference and security before making additional investments and proceeding to the next step.

The IAT restructured Alternative IV (BBN) to allow time to gain experience and confidence in SatNav, while proceeding towards full SatNav capability. Figure ES-3 shows the implementation schedule for WAAS and LAAS, along with decommissioning ground-based NAVAIDs for the preferred alternative, which is a reduced risk path to Alternative IV (BBN). This path has the option of stopping at Alternative III (MON) depending on user acceptance and system performance, in essence, putting checkpoints along the way.

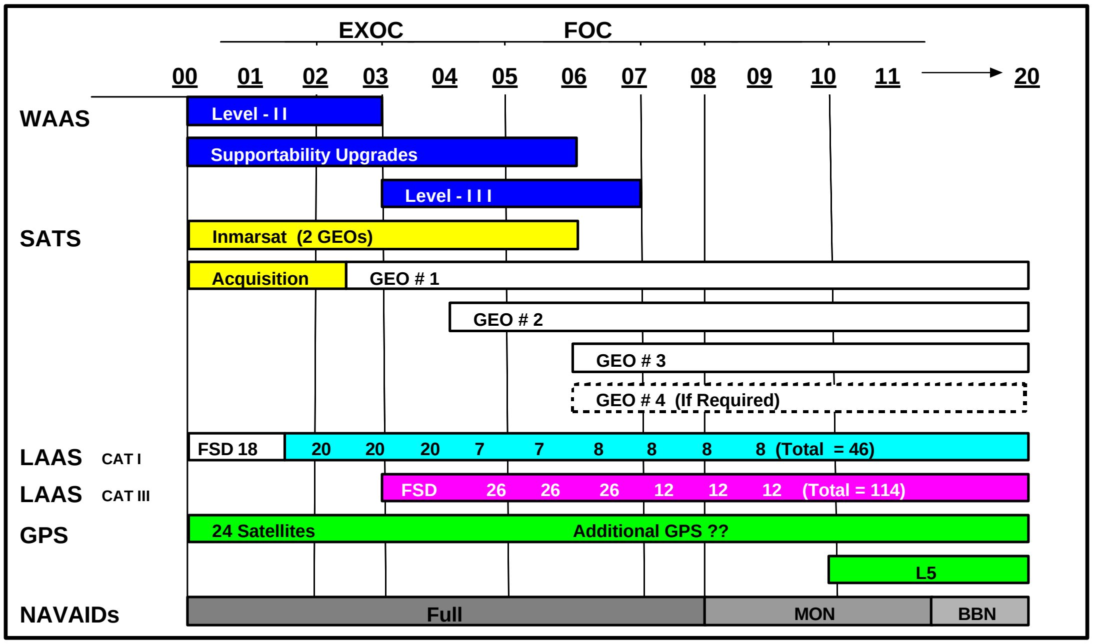

Figure ES-3. Restructured Alternative IV (BBN) Timeline

The 1998 LAAS baseline is not compatible with the WAAS schedule for user equipage. The air carriers have been clear that they do not want to invest twice. They want to buy one box for LAAS and WAAS in one purchase. The existing baseline does not have LAAS deployment until FY04 to FY06. To make LAAS consistent and compatible with WAAS precision approach capability, the

FAA could deploy additional LAAS stations earlier and update some of the algorithms in the system to meet Category III (i.e., all weather landing) requirement. The implementation schedule above reflects a two-year shift to the left in LAAS deployment.

Economic Analysis

Table ES-1 and Figure ES-4 summarize the life cycle costs (LCCs) for the alternatives selected and crafted by the IAT for detailed economic analysis. The years 2000 – 2020 were used to reflect the 21-year LCC estimates for the alternatives. LCCs represent the most likely costs for acquisition (including Facility & Equipment (F&E)), transition, operation and maintenance (O&M), technical refresh, and disposition in then-year dollars. Alternative IV (BBN) was identified as the alternative with the best B/C ratio. The most likely costs shown below for the preferred alternative were risk adjusted later for inclusion into the APB for WAAS and LAAS.

Table ES-1. Most Likely LCCs for the Alternatives (Then-Year $M)

	Ref. Case	Alt. I-v0	Alt. II-v1	Alt. III (MON)	Alt. IV (BBN)
Total Costs	$11,359	$12,795	$17,453	$15,716	$15,803
F&E	1506	2223	4988	4216	4768
O&M	3994	4714	4290	4020	3776
User Costs	5859	5859	8174	7479	7259

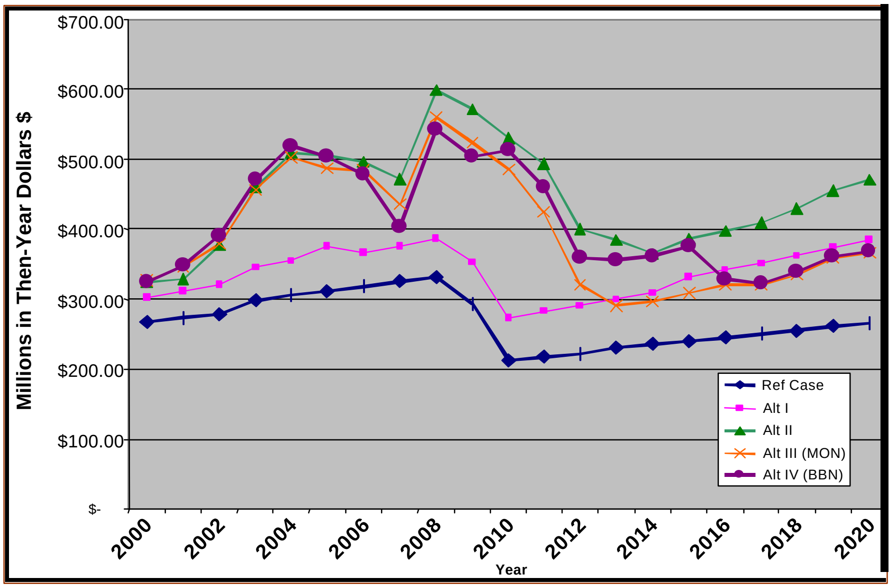

Figure ES-4. Comparison of FAA Most Likely Costs by Year

SatNav generates a wide range of aviation benefits in the general categories of: 1) increased safety, 2) increased efficiency, and 3) strategic alignment. The major effects that result from augmented SatNav operations are:

Safety

- Reduces approach accidents
  - Safer Skies recommendation: eliminate NPAs
  - There is an overall safety improvement from precision approaches
  - Precision approach will be added to over 3,000 runway ends
- Reduces Controlled-Flight-Into-Terrain (CFIT) accidents
  - Provides robust positioning to support terrain awareness and warning systems
- Reduces surface accidents
  - Provides positioning to help reduce runway incursions

    (Major benefits come when coupled with future technologies)

Efficiency

- Provides reliable RNAV capability throughout the NAS at all altitudes
  - Increased access to airports and reduced number of disruptions
  - More direct routing
  - More efficient terminal arrivals and departures
- Supports direct and dynamic routing; an essential element of Free Flight
- Supports expansion of air commerce to smaller communities
- Lowers future cost of overall navigation infrastructure (ground and satellite)

Strategic

- Essential part of the NAS Architecture
- International leadership
  - ➢ Promotes precision approach globally
  - ➢ Promotes international acceptance of GPS
  - ➢ Promotes U.S. leadership in trade

In many cases, benefits were not captured due to the absence of verifiable data. These include:

- Enables many non-aviation benefits (e.g., agriculture and environmental)
- Expansion of regional jet services into new airports (e.g., Southwest paradigm)
- Helicopter benefits (e.g., precision approaches for medical services, oil rigs, new routes)
- Noise mitigation (e.g., Minneapolis/St. Paul airport study)
- Terminal area efficiencies (e.g., approach into Newark without interfering with John F. Kennedy airport)
- Parallel approach operations (e.g., San Francisco and St. Louis)
- Allow general aviation traffic to fly into smaller airports; relieving congestion at major airports
- Surface navigation in low-visibility conditions

Figure ES-5 illustrates the total benefits by alternative on an annual basis. The benefits have been discounted by the 7% discount rate mandated by the Office of Management and Budget (OMB).

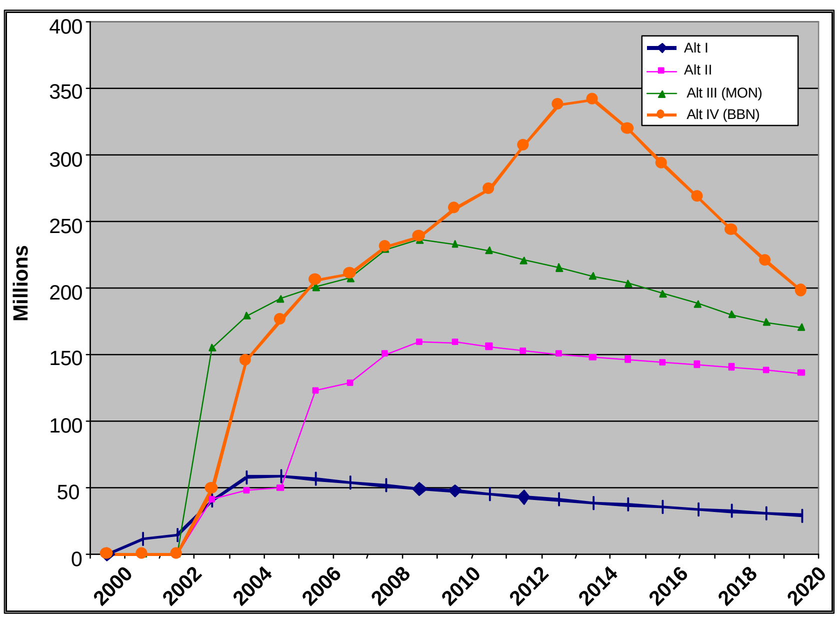

Figure ES-5. Annual Discounted Benefits by Alternative

The cumulative return on the FAA's investment is shown below in Figure ES-6. As the figure indicates, the Net Present Value (NPV) of Alternative IV (BBN) starts to slope upward in the year 2006 with a positive cumulative return on investment reached in the year 2008, the break-even point. From the year 2008 to the end of the life cycle, the slope of the curve increases dramatically indicating cumulative quantifiable benefits far exceeding cumulative costs. In comparison, Alternative I achieves a positive return on investment in the 2005 timeframe, but does not offer the same degree of quantifiable benefits in relation to its cost over the life cycle of the alternative. The factor that drives the benefit is the rate of user equipage. The projected rate for each alternative was obtained through meetings with the user community (i.e., airlines, AOPA).

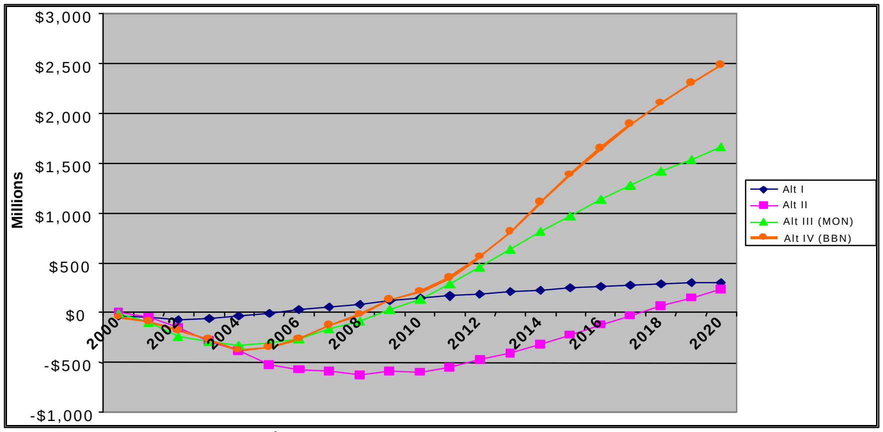

Figure ES-6. Return on Investment

By Department of Transportation (DOT) policy, all benefits are calculated assuming that time savings to passengers can be given a dollar benefit, i.e., PVT. The GAO requested, and the Agency agreed to show the sensitivity of our economic analysis if PVT was not counted as a benefit.

Figure ES-7 below indicates that without PVT, Alternative IV (BBN) is the only alternative to achieve a positive return on investment.

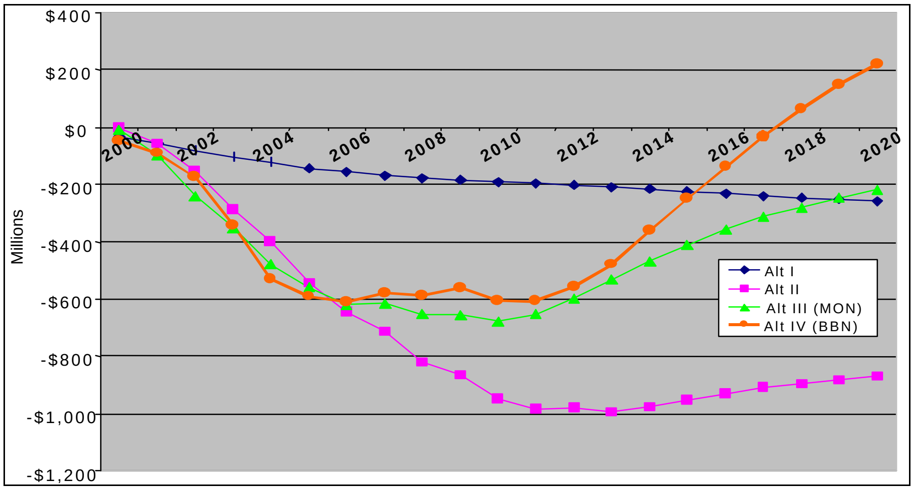

Figure ES-7. Return on Investment (without PVT)

The economic analysis of the alternatives considered the following criteria: FAA LCCs, user LCCs, user benefits, NPV, and B/C ratio. The economic summary of the alternatives, Table ES-2, shows that the preferred Alternative IV (BBN) is the best choice from an economic perspective.

Table ES-2. Economic Summary of Alternatives

Most Likely	Net Present Value ($M)*	Benefit/Cost Ratio
Alternative I	280	1.5**
Alternative II	94	1.0**
Alternative III (MON)	1,857	2.1**
Alternative IV (BBN)	2,493	2.4

Range Estimates for Alternative IV (BBN) (with and without PVT)

	Range	Conservative Estimate***	Range	Conservative Estimate***
With PVT	1,995 - 4,245	2,469	2.1 - 3.3	2.4****
Without PVT	0 - 840	72	1.0 - 1.5	1.1****

* NPV is the difference between benefits and costs, (discounted to present value)
** These alternatives have B/C ratio <1 if PVT is not counted.
*** The conservative estimate is the high-confidence 80/20 estimate.
**** See updated B/C ratio and NPV in Appendix C of this report.

Table ES-3/Table 4-12 (in Section 4) provides a comparison between the January 9, 1998, baseline and the proposed September 2, 1999, baseline. Overall cost growth in the new APB is primarily due to an increased IA life cycle through the year 2020.

Table ES-3. Comparison with January 1998 SatNav Investment Analysis (Then-Year $M)

WAAS	Prior	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total 1999-16	Total Prior-16	Total Prior-20
1999 IA																										
F&E	406	88	111	114	135	136	165	155	157	90	110	106	108	107	96	115	105	110	111	103	113	118	119	2,119	2,525	2,978
O&M	-	-	1	1	10	19	23	25	32	33	37	39	40	40	41	42	43	44	45	46	47	48	49	515	515	704
Total	406	88	112	115	146	155	188	181	190	123	146	145	148	148	137	157	148	154	156	148	159	166	168	2,634	3,040	3,682
1998 IA																										
F&E	406	138	136	124	39	10	10	10	35	31	-	-	-	34	35	-	-	-	-	-	-	-	-	600	1,007	1,007
O&M	-	33	36	41	121	122	125	126	129	127	121	122	124	128	130	134	137	140	147	-	-	-	-	2,043	2,043	2,043
Total	406	170	173	164	160	132	135	136	164	158	121	122	124	162	165	134	137	140	147	-	-	-	-	2,643	3,049	3,049
Difference																										
F&E	0	(50)	(25)	(10)	97	126	155	145	123	59	110	106	108	73	61	115	105	110	111	103	113	118	119	1,519	1,519	1,971
O&M	0	(33)	(35)	(40)	(111)	(103)	(102)	(101)	(97)	(94)	(85)	(83)	(84)	(87)	(89)	(92)	(94)	(96)	(102)	46	47	48	49	(1,528)	(1,528)	(1,339)
Total	0	(83)	(61)	(49)	(14)	22	53	45	26	(35)	25	23	24	(14)	(28)	23	12	14	9	148	159	166	168	(9)	(9)	633

LAAS	Prior	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total 1999-16	Total Prior-16	Total Prior-20
1999 IA																										
F&E	13	11	5	21	31	55	68	51	41	41	38	38	37	19	20	20	22	24	30	31	33	35	37	572	585	720
O&M	-	-	-	-	-	2	4	5	7	8	10	10	12	14	16	16	16	16	17	17	17	18	18	153	153	224
Total	13	11	5	21	31	58	72	56	48	49	48	48	49	33	36	36	38	40	47	48	50	52	55	726	738	943
1998 IA																										
F&E	7	7	4	7	7	82	85	91	88	1	1	10	10	10	11	11	11	12	12	12	13	13	13	459	466	516
O&M	-	-	-	-	0	0	3	7	10	14	16	16	17	17	18	18	18	19	19	20	20	21	21	192	192	274
Total	7	7	4	7	7	82	89	97	99	14	16	26	27	28	28	29	30	30	31	32	33	34	34	651	658	791
Difference																										
F&E	6	5	1	14	24	(27)	(17)	(40)	(47)	40	38	28	27	8	9	9	11	12	18	19	20	22	23	113	119	203
O&M	0	0	0	0	(0)	2	0	(1)	(3)	(6)	(6)	(6)	(5)	(3)	(1)	(2)	(2)	(3)	(3)	(3)	(3)	(3)	(3)	(39)	(39)	(51)
Total	6	5	1	14	24	(25)	(17)	(41)	(50)	35	31	22	22	5	8	7	8	10	16	16	17	18	21	74	80	153

Risk Assessment

A risk assessment of the original 12 alternative variants was conducted. Additionally, the hybrid "preferred alternative" combining Alternatives III (MON) and IV (BBN) was assessed after it was developed. This assessment was accomplished primarily to provide a risk rating to be used in evaluating the overall attractiveness of the alternatives, since risk is one of the four criteria to be evaluated. Additionally, the risk assessment identified the greatest risk areas, which in turn were used to adjust the most likely cost and benefit estimates to an 80% confidence level.

- Risk is not a significant discriminator in choosing among alternatives, i.e., there is no compelling case for selection or elimination of alternatives solely on the basis of their risk scores. The alternatives are all "moderate risk" with middle-of-the-road scores (ranging from 3.3 (lowest) to 5.7 (highest)).
- Generally, Alternatives I and II are more risky in the operability and stakeholder risk facet areas. Alternatives I and II preserve the existing ground-based systems (i.e., VOR/DME, ILS) indefinitely as the core aviation navigation infrastructure, and deny to airspace users the safety, capacity, and efficiency benefits that they hope to derive from a widespread transition to GPS-based SatNav. These alternatives will impose significant inefficiency problems in the future for the U.S. air transportation system. Moreover, they will require air carriers to maintain multiple navigation avionics indefinitely. Alternatives I and II have low technical, schedule, and funding risks. Overall, Alternative II (v. 2) is the lowest risk alternative. Alternative I and II do the least for accommodating traffic growth, free flight operations, and for reducing accidents and delays.
- Generally, Alternatives III and IV are more risky in the schedule and funding risk areas. Schedule risks are dominated by the risks associated with WAAS software development and system safety certification, with lesser but significant risk in the LAAS CAT I and CAT III delivery schedules because of the LAAS Other Transaction Authority (OTA) schedule uncertainty contractual approach. Funding risk is very significant because WAAS/LAAS development, deployment, and operations will impose high marginal F&E and operations funding needs in a time of very tight FAA budgets, while offering relatively little offsetting reductions to the FAA through decommissioning of some existing ground-based NAVAIDs. In fact, funding risk is worsened by the strong possibility that the FAA will not be permitted to decommission many of the VOR/DME and ILS systems, as a consequence of probable pressure from user groups (particularly general aviation) for their continued sustainment. Moreover, Congress has been very critical of the WAAS program, and has cut LAAS funding in the FY2000 budget. Technical risk is deemed moderate. Stakeholder support is highest for these alternatives, and these alternatives have the least operability risk.
- The preferred alternative (Alternative IV, BBN), with checkpoints and stretching the WAAS schedule, reduces the schedule and operability risk associated with the baseline Alternative IV, as well as its Benefits Estimate risk. Essentially, stretching the time to go to full robust WAAS and adding checkpoints lower the overall risk significantly, placing the phased alternative as the second best (slightly behind Alternative II (v.2)) in terms of total risk score.

Moreover, LAAS schedule risk is reduced by conversion from an OTA to an FAA-funded development contract. However, funding risk increases because of the desire to accelerate the development and deployment of LAAS. Assuming its funding risk problem (the only high-risk area) can be overcome, this alternative looks attractive from a risk standpoint.

Affordability Assessment

The SatNav programs are a large part of the Agency's Capital Improvement Program (CIP) and operations budgets. Low costs for refurbishment of existing NAVAIDs were predicted on the assumption that SatNav becomes operational by the year 2006. WAAS costs are currently included in the CIP budget and the proposed APB costs are less than the 1998 APB for years 2000-2020. The LAAS APB costs, on the other hand, could exceed the CIP by $7-8M in FY01 and $20M in FY02. The budgets in FY01 and FY02 are extremely tight, and Agency management is meeting as this IAR was prepared to determine overall Agency priorities. If slippage of either program is necessary, it will negatively impact costs, benefits, and risk.

NAS Architecture Capability Assessment

In general, the preferred alternative (Alternative IV, BBN) and the NAS Architecture are consistent in terms of concepts, systems, schedules, and budgets. The preferred alternative is the same as the NAS Architecture in that the NAS will continue to transition to navigation services based on WAAS and LAAS, and significantly reduce the number of ground-based radio NAVAIDs. The capabilities that both WAAS and LAAS will provide are also consistent with those described in the NAS Architecture. The preferred alternative does delay WAAS achieving a "full" capability relative to the NAS Architecture. This delay has been accounted for in estimating the rate of equipage. Additional benefits will then be provided to the user community as soon as they can be made available. The budgets for the WAAS and LAAS also remain generally consistent with the NAS Architecture.

Recommendations

- Approve APBs for WAAS and LAAS (with authority to execute recommended alternative).
- Approve satellite acquisition commencing in FY01.
- Approve use of F&E funds for leased satellite communications.
- Approve transmittal of lease versus buy and cost/benefit analysis to Congress through DOT.

Results of the JRC

On September 2, 1999, the FAA JRC, a board of senior Executives, considered the recommendations of the IAT. Several stakeholders (including the Air Transport Association, the Aircraft Owners and Pilots Association, the Regional Airlines Association, and the Department of Defense) participated in the JRC and made remarks supporting the recommendations.

The JRC approved the aggregate baseline for the WAAS program. The JRC approved the Benefit Cost Analysis, which is embedded in the team's economic analysis. The JRC expressed support for the recommendation to accelerate the LAAS schedule, but could not approve a baseline for an accelerated schedule as an affordability analysis is still required to determine whether the needed funds can be accommodated in the FY 2001 budget.

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1.0 INTRODUCTION

This report documents activities conducted by the Satellite Navigation (SatNav) Investment Analysis Team (IAT) that led to the development of the Investment Analysis Report (IAR) and Acquisition Program Baselines (APBs). As specified in the Acquisition Management System (AMS) and the Investment Analysis Process Guidelines, the report summarizes the mission need, requirements, assumptions, and risks. The report also documents the economic assessment, and the results of the affordability assessment conducted by the System Engineering Operational Analysis Team (SEOAT). Finally, it summarizes the IAT's recommendation to the Federal Aviation Administration (FAA) Joint Resources Council (JRC) for providing a SatNav capability in the National Airspace System (NAS) and it identifies recommended steps.

The FAA's policy to transition from the current ground-based navigation and landing system to a satellite-based system has been stated in several FAA documents. These include the *FAA Strategic Plan*, the FAA's *Plan for Transition to Global Positioning System (GPS)-Based Navigation and Landing Guidance, July 1996*, and the *NAS Architecture (Version 4.0)*. According to these plans, the Wide Area Augmentation System (WAAS) will provide the NAS with satellite-based en route and terminal navigation, as well as a precision approach capability. The Local Area Augmentation System (LAAS) will complete the transition to satellite-based navigation by providing Category (CAT) II/III precision approach and landing service. CAT II is a precision approach with a decision height of less than 200 feet, but not less than 100 feet. CAT III is a precision approach with a decision height of less than 100 feet. LAAS will also provide CAT I service at a number of sites where WAAS does not provide coverage, cannot meet availability requirements, or at major airports where dual ILS or LAAS coverage is desirable to guarantee precision approach services. CAT I is a precision approach with decision height not less than 200 feet.

In the 1980s, the FAA began considering how a satellite-based navigation system could eventually replace the ground-based system. On October 23, 1992, the Transportation Systems Acquisition Review Council (TSARC) approved Mission Need Statement (MNS) # 50, *Application of Satellite Navigation Capability for Civil Aviation.* In 1993, the Secretary of Transportation and the FAA Administrator reported that early utilization of the Global Positioning System (GPS) for civil aviation was a strategic objective of the Department of Transportation (DOT). On April 22, 1994, the FAA accelerated the implementation of satellite-based navigation and approved an acquisition for the WAAS.

With respect to the LAAS program, in February 1996, prior to the initiation of the new AMS, a Key Decision Point (KDP-2) investment decision was proposed. At that time, the FAA Acquisition Executive deferred the investment decision pending further analyses, but approved demonstration and validation activity for developing standards for airborne and ground LAAS equipment.

In January 1998, the FAA's JRC approved the SatNav APBs for the WAAS and LAAS programs. The baseline was prepared for the JRC by an IAT that met from November 1997 through January 1998. The results of its efforts are documented in an IAR dated January 9, 1998. Among its recommendations were that the Agency approve the WAAS and LAAS baselines, and that a government-industry partnership (GIP) be used to develop LAAS. Among the next steps recommended were the following:

- Assess the impact to the FAA of non-DoD Agencies sharing in GPS satellite replenishment costs.
- Perform detailed analyses on the benefits of direct routing to NAS users.
- Complete expanded analyses, using the results of the planned Request for Information (RFI), on the planned and next-generation satellite requirements.
- Conduct an analysis of backup for GPS/WAAS/LAAS. This should begin with the preparation of a mission analysis and MNSs.
- Track the APB “watch items” and the risk mitigation efforts.
- Conduct, preferably by a national panel of scientific and technical experts, an independent assessment of interference risk.
- The airports line of business in the FAA also needs to plan for additional SatNav services, since they expect increased local and regional demand for WAAS/LAAS.
- The GIP needs to aggressively pursue and track the LAAS Full Scale Development (FSD) to ensure it works the way it was envisioned.

The investment analysis conducted in 1997 was limited to one alternative that was identified to the team by FAA senior management at a meeting on November 7, 1997. Key to that analysis were the following assumptions:

- WAAS and LAAS will be certified as the sole means of radionavigation aboard an aircraft (no backup required).
- Additional satellites beyond the two existing Inmarsat3 satellites currently being leased by the FAA will be needed to meet performance requirements.
- GPS selective availabilility will be turned off by the year 2001.
- All ground-based NAVAIDs will be phased out beginning in the year 2005 and ending in the year 2010.
- LAAS development will be funded by industry.

An economic analysis was performed that estimated user costs and costs to decommission the ground-based NAVAIDs. The baseline was developed for WAAS and LAAS using 80/20 cost and benefit estimates; the benefit/cost (B/C) ratio was computed for the estimates of benefits and costs and reported in the IAR. A risk assessment was also performed.

Following the January 1, 1998, investment decision the Agency prepared a report to Congress which was transmitted as a memo from the Secretary of Transportation. The report summarized the FAA's decisions and highlighted areas of risk that the Agency believed were involved in the programs, as well as risk mitigation steps that the DOT and FAA would follow. The letter is referenced in the bibliography.

The General Accounting Office (GAO) completed a report on the FAA's SatNav programs in April 1998 that examined the investment analysis and did some sensitivity studies on the benefits analysis including the Agency's use of passenger value of time savings (PVT). PVT savings are measured for every program in the DOT by DOT policy. The result showed that while benefits would decrease if the Agency discontinued measuring PVT, the B/C ratio would still exceed 2.0. Another analysis showed that the B/C ratio was also positive even if no decommissioning of ground-based NAVAIDs occurred.

The GAO recommended that the Agency revalidate its benefits analysis, especially its claim of large direct routing benefits, and the agency agreed to perform this analysis in FY 1999.

Meanwhile, the WAAS program began to experience some difficulties with both the procurement of leased satellites and its schedule and costs. In response to these difficulties the GPS program manager briefed the Administrator on the problems and issues in September 1998. Present at the meeting were the Inspector General and other members of the DOT's Office of the Secretary, congressional staff, and the Vice President/General Manager of the MITRE Corporation's Center for Advanced Aviation System Development (CAASD). One of the congressional staff asked that the FAA certify that whatever new baseline was adopted, it be the "most cost beneficial" and this request was later coded into congressional language in the FAA's Budget. This precipitated a request by FAA senior managers and the Acquisition Executive that another investment analysis be conducted for the SatNav programs. That effort began in October 1998 and concludes with the JRC of September 2, 1999. The IAT was asked to rebaseline the WAAS and LAAS programs and to respond to later congressional language that asked the FAA to conduct a "Lease versus Buy" analysis of the WAAS satellites.

The approach of this investment analysis focused on the following goals:

- To involve all the stakeholders inside and outside the FAA to the largest possible extent in the conduct of the investment analysis and to keep the process as open to public scrutiny as possible.
- To consider all viable alternatives in the analysis and to make use of all major studies including a major study by Johns Hopkins University/Applied Physics Laboratory (JHU/APL) on the risks of SatNav.
- To revalidate carefully the benefits and costs of the key alternatives.
- To engage the audit agencies (DOT's Office of the Inspector General (OIG) and the GAO) and the MITRE CAASD organization.
- To focus on risk reduction strategies in considering which alternative to recommend.

The IAT consisted of representatives from the sponsoring office (AVR- the Office of Regulation and Certification), the GPS Integrated Product Team (IPT), the Architecture and System Engineering Office, airports, Air Traffic Services, the investment analysis staff, and CAASD. OIG and GAO staff sat in on many of the team meetings and the Department of Defense (DoD) was involved in meetings and briefings.

The investment analysis can best be understood by considering it to occur in three phases. The first phase, Alternatives Development, culminated in the first public meeting on February 25, 1999, where the Agency revealed the four basic alternatives it proposed to consider. Four basic alternatives were identified based on different levels of investment in WAAS. Each had several subvariations depending on the extent of roles for LAAS and ground-based NAVAIDs, including Loran-C. Much feedback was received, most of it favorable, and most of it endorsing the FAA's approach and alternatives chosen. One new alternative was proposed by an industry attendee, and the IAT gave it careful consideration and responded back to the proposer with reasons it was rejected.

Each public meeting had a question and answer period and each was followed by a chance for individuals or organizations to meet individually with the IAT. A list of attendees at the three public meetings, including those who met "one-on-one" with the team, is denoted by the * in Tables 1-1 and 1-2. The minutes, all presentations, and a Fact Sheet for each public meeting was posted on the Agency's Webpage and attendees were notified of future meetings via electronic mail. All meetings were also posted in the Public Register.

Table 1-1. User Groups that Attended the SatNav User Forums

Airbus	DoD*
Air Canada*	Helicopter Association International*
ALPA	ICAO*
AOCI*	National Association of State Aviation Office
American Airlines*	NavCanada*
ANSP*	NBAA*
AOPA*	NW Airlines*
ATA*	Port Authority of NJ/NY*
ATCA	RAA*
Continental Airlines	Satellite Navigation Users Group*
CNS/ATM Focus Team*	United Airlines
Delta Airlines*	United Postal Service
*Denotes those organizations who met one-on-one	

Table 1-2. Industry Groups that Attended the SatNav User Forums

Aerospace Industries*	Litton Industries
Airport Systems International*	Lockheed Martin*
Airspace Global	Megapulse*
Air Systems, ATM	Motorola*
Allied Signal*	MCA Resource Corporation
ARINC	North Star Technologies*
Boeing*	Omnistar*
Booz Allen & Hamilton	Optimus Corporation
Canadian Marconi*	Pegasus

Table 1-2. Industry Groups that Attended the SatNav User Forums, Cont.

COMSAT Mobile Communications	QED*
Crown Communications	Radix Technologies*
DCS Corporation	Radix Technologies*
DORS International*	Raytheon*
Draper Laboratory	Rockwell Collins*
Fernau Avionics	RTCA*
General Aviation Manufacturers Association*	Science Applications Int'l. Corp.
Honeywell*	Scitor Corporation
Horn Engineering*	Seneca Corporation*
Hughes Space & Communications*	SOIT*
Illgen Simulation Technologies*	Space Communications
International Loran Association*	SRC
ITT Aerospace Communications*	Systems Software*
Jeppesen-Sanderson	TRW*
Litton Aero Products	Wilcox
Locus, Inc.*	
*Denotes those organizations who met one-on-one	

During the second phase, the IAT performed a technical evaluation of the alternatives. (See the section on alternatives analysis for more details on the process and results of the study.) The results were briefed at the second public meeting on April 6, 1999. Studies of availability and accuracy were briefed and twelve sub-alternatives were identified as worthy of further economic analysis. At that meeting the economic analysis was also discussed, along with the decision criteria that the team would be using to select among the alternatives. Feedback was again fairly positive and the team met with several user and industry groups who volunteered confidential data on costs of equipment, equipage rates, benefits, and risks of the alternatives.

During the third phase, the IAT conducted an economic analysis, developing estimates of FAA user costs and benefits for each alternative and also conducted a risk assessment. The IAT went offsite to review the data collected and the analysis, and then held a third public meeting on July 7, 1999, to discuss with the users the estimates on cost, benefits, and user equipage received. Considerable feedback was received from both users and industry, as well as from internal FAA sources. The data was also reviewed with the DoD and several user groups, including a satellite users group composed of representatives of the major user groups including the DoD.

The IAT then completed its economic analysis, including its cost/benefit analysis and the "Lease versus Buy" study for the WAAS satellites. Since the alternatives included different quantities of ground-based NAVAIDs, both maintained and decommissioned, the economic analysis included costs for both the maintenance of existing ground-based NAVAIDs and the decommissioning costs of those that would not be kept beyond the life of the study (2000-2020).

The IAT then chose an alternative to recommend to the JRC. The decision criteria that were used to choose the alternative were: (1) Mission Effectiveness: to what extent the alternative improves mission performance for the external and internal customers of the Agency; (2) Return on Investment: value of the alternative in economic terms to the FAA and the users of the airspace we control; (3) Risk: how much risk the alternative has in terms of uncertainty and magnitude; and (4) Strategic Alignment: the extent to which the proposed alternative supports strategic organizational objectives. See the section on the alternatives analysis for more details.

Before going to the investment decision, the IAT took its costs and benefit data before the SEOAT, which performed an affordability assessment of the programs against all other programs in the FAA's Capital Investment Plan (CIP). See the section on affordability for their analysis. Finally, an architectural assessment was performed to assess whether the preferred alternative was consistent with the FAA's published NAS Architecture. This assessment is given in the section below on architecture assessment.

The JRC is being asked to approve the WAAS and LAAS rebaselining that represents the preferred alternative. They are being asked to approve the cost/benefit analysis and the "lease versus buy" analysis prior to them being forwarded through the DOT to Congress.

The IAT is also recommending several next steps to address some concerns raised during the investment analysis and to follow-up on some analyses. See the section below on next steps.

The IAT has shared its data and analyses with both the GAO and the OIG. The GAO is currently conducting an evaluation of the FAA's SatNav programs and this study will be used by them in their work.

Results of the JRC: On September 2, 1999, the FAA JRC, a board of senior Executives, considered the recommendations of the IAT. Several stakeholders (including the Air Transport Association, the Aircraft Owners and Pilots Association, the Regional Airlines Association, and the DoD) participated in the JRC and made remarks supporting the recommendations.

The JRC approved the aggregate baseline for the WAAS program. The JRC approved the Benefit Cost Analysis, which is embedded in the team's economic analysis. The JRC expressed support for the recommendation to accelerate the LAAS schedule, but could not approve a baseline for an accelerated schedule as an affordability analysis is still required to determine whether the needed funds can be accommodated in the FY 2001 budget.

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2.0 MISSION NEED, BENEFITS, AND REQUIREMENTS

2.1 Mission Need

MNS #50, Application of Satellite Navigation Capability for Civil Aviation, describes the current navigation capability shortfalls and their corresponding effect on capacity, safety, and supportability issues. The MNS also addresses the manner in which a differential GPS-based system can improve and extend the FAA's ability to provide en route, terminal, and CAT I/II/III approach and landing services. The MNS states the following deficiencies with respect to precision approach capabilities:

> "Some qualifying airports for which service has been requested do not have an approach aid capable of providing the appropriate level of service. Current systems cannot be sited due to terrain constraints, lack of real estate or, in many cases, financial reasons. There is a backlog of approximately 600 precision approaches due to cost and logistics. More runways would qualify for this capability with lower cost of service."

The primary mission of SatNav is to provide a satellite-based navigation capability for all phases of flight in the NAS from en route through precision approach. GPS, when augmented with WAAS and LAAS, will provide this capability.

The secondary mission of WAAS is time distribution, which is accomplished by providing users with a time offset between the WAAS Network Time (WNT) and Universal Coordinated Time (UTC). This time offset is determined by the United States Naval Observatory (USNO) and passed to the WAAS Master Stations (WMSs) through an interface between the WAAS and the USNO.

2.2 Benefits

SatNav, over a period of time, was intended to replace existing en route navigation and approach aids such as VHF Omni-directional Range/Distance Measuring Equipment (VOR/DME), Instrument Landing System (ILS), and Loran-C. Decommissioning the aging NAVAIDs could save the FAA Operations and Maintenance (O&M) because it could replace about 2/3 of the ground-based systems with 48 WRSs, eight WMSs, and 160 LAAS. This O&M savings was one of the drivers behind the FAA's decision to invest in WAAS and, in general, to transfer to SatNav. However, inasmuch as interference to GPS may cause occasional outages, a Basic Backup Network (BBN) of VOR/ME and ILS must be retained indefinitely so that lesser cost savings will be more achievable than previously hoped.

SatNav will operate continuously, unaffected by interruptions due to corrective and preventive maintenance. WAAS and LAAS will provide the potential for any runway suitable for instrument approaches to become a candidate for implementation of a precision approach capability. Airport approach/runway lighting will have to be installed if lower minimum (less than 3/4 mile) are required.

Given these factors, pilots will have access to many more airports and runways than are currently equipped with ILSs. This will offer benefits in terms of improved schedule reliability, reduced flight cancellations, and fewer diversions. Also, in high-density terminal areas there will be additional runways that may be used in instrument conditions and secondary airports available to absorb the capacity demands, thereby reducing delays.

In terminal areas, SatNav will permit the introduction of short finds (during light to moderate traffic) to save both time and fuel.

WAAS and LAAS will provide a navigation capability that supports precision approach operations to every IFR runway in the country. Under the Administrator's Safer Skies Agenda, one of the key recommendations to reduce the accident rate is to replace all NPAs, which is only possible with a technology such as WAAS. Precision approaches will enhance safety by reducing cockpit crew workload and minimizing the possibility of controlled-flight-into-terrain (CFIT). Increased safety also occurs because all pilots can be trained to program the precision approach operations at all runways all the time.

SatNav will also provide the opportunity to optimize en route operations. En route airways will no longer be dependent on the placement of ground-based NAVAIDs. The present airway system can be restructured to provide users with shorter routes and improved use of altitude and upper winds. By exploiting the inherent flexibility in routing, alternate/parallel routes can be used to meet changing traffic situations and to improve recovery time after the lifting of flow control restrictions such as those caused by severe weather conditions. By increasing system capacity in high-density areas, system delays will be reduced.

Improved navigation accuracy provided by SatNav will offer the opportunity to incrementally reduce separation standards. Potential reductions include non-radar separations in en route airspace, as well as terminal separations due to reduced obstacle clearance requirements and protected airspace. Reduced separation standards directly translate into increased system capacity and reduced delays; however, SatNav will not eliminate delays that result from the variables of severe weather conditions and wake turbulence that can exist in the terminal or airport traffic areas.

2.3 Requirement for GPS Augmentation

GPS alone does not satisfy all requirements for civil air navigation. To meet these requirements, WAAS and LAAS will improve the integrity, accuracy, availability, and continuity of GPS by using special equipment that constantly monitors the GPS and Geostationary Satellite Transponder (GST) broadcast signals. The WAAS determines integrity and corrections for GPS satellites and the ionosphere, then broadcasts this data to the user via the GSTs. This broadcast data enables users to improve their position accuracy and to determine when GPS satellites should not be used. LAAS data does the same, but uses a VHF data broadcast medium.

2.3.1 WAAS

The WAAS is a NAS safety-critical system consisting of the equipment and software that augments the GPS Standard Positioning Service (SPS). SPS is the GPS signal that has been made available to civil users. The GPS Precise Positioning Service (PPS) is encrypted and is available only to military users. The WAAS provides an SPS-like Signal-in-Space (SIS) to WAAS users to support en route through precision approach navigation. The WAAS users include all aircraft with approved WAAS avionics using the WAAS for any approved phase of flight. The SIS provides two services: 1) integrity and differential corrections data on all GPS and geostationary satellites, and 2) an additional GPS/SPS ranging signal that improves system availability and positional accuracy for the user.

2.3.1.1 WAAS Program Description

The concept of a WAAS was proven by means of the FAA Navigation Satellite Test Bed (NSTB). Figure 2-1 depicts an example WAAS architecture. The GPS satellites' data are received and processed at widely dispersed sites referred to as WRSs. These data are forwarded to data processing sites referred to as WMSs, which process the data to determine the integrity, differential corrections, residual errors, and ionospheric information for each monitored satellite, and generate geostationary satellite SatNav parameters. This information is sent to a Ground Earth Station (GES) and uplinked along with the geostationary SatNav message to geostationary satellites. These geostationary satellites downlink this data on the GPS Link 1 (L1) frequency with a modulation similar to that used by GPS.

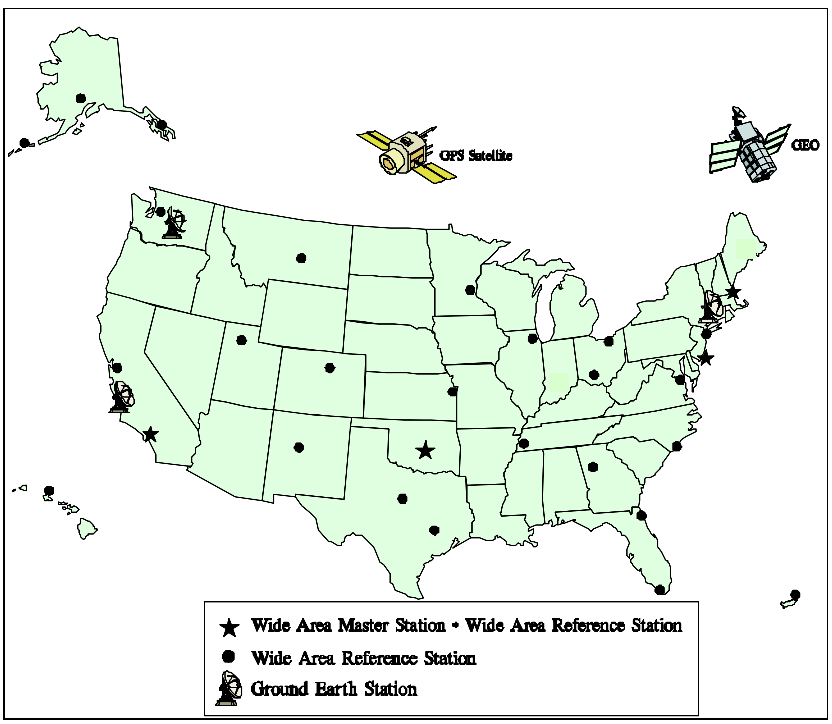

Figure 2-1. WAAS Architecture Concept

In addition to providing GPS integrity, the WAAS verifies its own integrity and takes any necessary action to ensure that the system meets the WAAS performance requirements. The WAAS also has a system O&M function that provides information to FAA Airway Facilities (AF) NAS personnel.

The WAAS user receiver typically processes: 1) the integrity data to ensure that the satellites being used are providing in-tolerance navigation data, 2) the differential correction and ionospheric information data to improve the accuracy of the user's position solution, and 3) the ranging data from one or more of the geostationary satellites for position determination. The WAAS user receivers are not considered part of the WAAS.

2.3.1.2 WAAS Performance Requirements

The Final Requirements Document, Wide Area Augmentation System (WAAS) Application of Satellite Navigation Capability for Civil Aviation, outlines the basic requirements for WAAS. Tables 2-1 and 2-2 summarize WAAS requirements. Meeting the threshold requirement is necessary to enable some aircraft to operate in the NAS using only SatNav, but with some operating limitations. Compliance to the objective requirements will provide a satellite-based service equivalent to the existing ground-based infrastructure and will enable all aircraft to rely on SatNav. Generally, achievement of the threshold requirement is the goal of WAAS Expanded Operational Capability (EXOC); improvement to the objective requirement level is the goal of WAAS Full Operational Capability (FOC). In addition to the performance specified in Tables 2-1 and 2-2, the system will be used to support NPA with vertical guidance when the precision approach capability specified below is unavailable.

Users will be notified via their onboard avionics, and by the notices to airmen (NOTAMS) when the service is inadequate to conduct operations.

Table 2-1. En Route Through NPA Goals and Definitions

Term	Definition	Threshold	Objective
Availability	That portion of time when GPS/WAAS can be used for ENR-NPA operations.	99.9% of the time.	99.999% of the time
Accuracy-ENR-NPA Accuracy 95% Horizontal	Degree of conformance between a 95% estimated horizontal position and its true value.	Within 100 meters, 95% of the time.	Within 100 meters, 95% of the time.
Integrity Probability of Broadcasting Misleading Information	Probability that position error exceeds the Integrity Alarm Limit without annunciation.	99.99999% probability that misleading data is not broadcast.	99.99999% probability that misleading data is not broadcast.
Integrity Time-to-Alarm	Period of time that starts when an out-of-bound condition occurs and ends when the user is notified.	8 seconds.	8 seconds.
Continuity	Probability that an ENR-NPA flight operation can be completed once it has started.	99.99%	99.9999% for ENR. 99.999% for NPA
Service Volume	Volume in which ENR-NPA service is provided.	CONUS, Hawaii, Puerto Rico and oceans in between. Most of Alaska.	CONUS, Hawaii, Puerto Rico and oceans in between. Most of Alaska.

Table 2-2. Precision Approach Goals and Definitions

Term	Definition	Threshold	Objective
Availability	That portion of time when WAAS can be used for precision approach operations.	95% of the time.	99.9% of the time.
Accuracy 95% Horizontal	Degree of conformance between an estimated horizontal position and its true value.	Within 16 meters, 95% of the time in the horizontal axis.	Within 4.4 meters, 95% of the time in the horizontal axis.
Accuracy 95% Vertical	Degree of conformance between an estimated vertical position and its true value.	Within 5.5 meters, 95% of the time in the vertical axis.	Within 4.4 meters, 95% of the time in the vertical axis.
Probability of Broadcasting Misleading Information	Probability that position error exceeds the Integrity Alarm Limit without annunciation.	99.99999% probability that misleading data is not broadcast during a precision approach operation. (150 seconds)	99.99999% probability that misleading data is not broadcast during a precision approach operation. (150 seconds)
Integrity Time-to-Alarm	Period of time that starts when an alarm condition occurs and ends when the user is notified.	6 seconds.	5.2 seconds.
Continuity	Average probability that a precision approach flight operation can be completed once it has started.	99.9945% per approach (150 seconds)	99.9996% per 15 seconds
Service Volume	Volume in which precision approach service.	CONUS	CONUS, Hawaii, and Puerto Rico. Selected airports in Alaska.

2.3.2 LAAS

The LAAS is intended to complement the WAAS by providing additional augmentation to support CAT I/II/III precision approach applications. LAAS will also provide a CAT I capability at selected locations where the WAAS cannot or where dual WAAS/LAAS coverage is desired, as well as provide a signal that can be used for surface navigation in and around the airport area. The LAAS will require the development, test and evaluation, and fielding of a new generation of local area differential GPS facilities.

2.3.2.1 LAAS Program Description

The LAAS project will provide the necessary architecture specification, Minimum Operational Performance Standards (MOPS), and a system specification that will satisfy the requirements for a CAT I/II/III precision approach system. This augmentation will provide precise correction data to airborne and surface receivers that will result in navigation accuracy of less than one meter to distances of 20 miles or more from the airport.

The LAAS specification will describe a ground station to receive GPS signals, make corrections, and transmit them to users. Upon completion and approval of the LAAS specification and MOPS, FSD will begin. The LAAS CAT I FSD is expected to be completed by October 2001, then procurement of LAAS will begin. The LAAS CAT I FSD will be accomplished using the FAA's OTA, a process that uses a cost-sharing partnership between government and industry to develop the system at minimum cost to the government. CAT II and III systems will be developed and acquired under a conventional acquisition program. The LAAS is expected to be fully operational by the end of FY10.

2.3.2.2 LAAS Performance Requirements

LAAS shall provide all-weather approach, landing, and surface navigation capabilities. LAAS ground stations shall be capable of processing GPS civil signals. The airborne equipment shall also be capable of processing ground data transmitted over the LAAS data broadcast. The LAAS equipment shall be capable of estimating system accuracy and generating integrity alarms when the system should not be used for navigation.

The information presented to the air traffic controller describing system status shall be as similar to existing ILS status information as feasible. The LAAS shall provide the following information to Air Traffic Control (ATC):

- Status and configuration of LAAS components and equipment.
- Representation of level of service being provided to the coverage area precision approach (CAT I/II/III), and surface navigation. Tables 2-3 through 2-8 show the LAAS performance requirements.

Table 2-3. Vertical NSE Requirements

Performance Category	Height above Threshold	Vertical NSE (m)
1	200 ft. - 100 ft.	4.4
2	100 ft. - 50 ft.	2.0
3	100 ft. - 0 ft.	2.0

Table 2-4. Lateral NSE Requirements

Performance Category	Height above Threshold	Lateral NSE (m)
1	200 ft. - 100 ft.	9.0
2	100 ft. - 50 ft.	6.9
3	12 ft.	6.1

Table 2-5. Vertical Integrity Requirements and Recommendations

Performance Category	Time-to-Alarm Requirement (Threshold)	Time-to-Alarm Recommendation (Objective)	Integrity Level Requirement
1	6 sec	6 sec	10^{-7}/ approach
2	2 sec	1 sec	10^{-9}/ approach
3	2 sec	1 sec	10^{-9}/ approach

Table 2-6. Lateral Integrity Requirements and Recommendations

Performance Category	Time-to-Alarm Requirement (Threshold)	Time-to-Alarm Recommendation (Objective)	Integrity Level Requirement
1	6 sec	6 sec	10^{-7}/ approach
2	2 sec	1 sec	10^{-9}/ approach
3	2 sec	1 sec	10^{-9}/ approach

Table 2-7. Continuity Requirements

Performance Category	LAAS SIS Continuity Requirement (Threshold)	LAAS SIS Continuity Recommendation (Objective)
1	1 - 4 x 10^{-6} / 15 sec	1 - 4 x 10^{-6} / 15 sec
2	1 - 2 x 10^{-6} / 15 sec	1 - 2 x 10^{-6} / 15 sec
3	lateral: 1 - 2 x 10^{-6} / 30 sec vertical: 1 - 2 x 10^{-6} / 15 sec	lateral: 1 - 2 x 10^{-6} / 30 sec vertical: 1 - 2 x 10^{-6} / 15 sec 1 - 1 x 10^{-7} over last 60 sec

Table 2-8. Availability Requirements

Service Availability Requirement	Location
0.999 - 0.99999	Airport (Single-Multiple) ILS

All LAAS equipment shall be sited at a secure location on airport property and will require no additional security. No cryptographic equipment will be required to process the GPS civil SIS.

2.3.2.3 LAAS Critical System Characteristics (CSCs)

Multiple Runway Service:

The LAAS shall be capable of providing precision approach capabilities simultaneously to multiple runways.

Advanced Flight Procedures:

The LAAS shall be capable of supporting advanced approach and landing procedures (e.g., parallel approaches and curved approaches).

LAAS Avionics Interoperability:

- All LAAS avionics (whether CAT I/II or IIIa/b certified) shall be able to operate using the LAAS SIS broadcast by all LAAS ground systems.
- LAAS CAT I equipped aircraft shall be able to operate at a CAT III ground facility commensurate with its intended function and level of service authorized.

- CAT III equipped aircraft shall be able to operate at a CAT I ground facility commensurate with its intended function and level of service authorized for that specific location and crew complement.

Compatibility with Existing Systems:

- Since the LAAS will be implemented as a replacement for an existing precision approach system, it shall be able to operate concurrently with existing precision approach navigation systems on a non-interfering basis.
- The airborne equipment shall provide the capability to interface with the existing automatic landing flight deck annunciation philosophy.

Data Security:

The LAAS shall provide required civil aviation services without the need for encryption.

2.3.3 Programmatic Interdependencies

WAAS is an enabling technology that provides the capability for all users to conduct reliable area navigation (RNAV) throughout the service volume. Although currently available avionics and flight management systems can accomplish this, the cost per aircraft is still quite high and the benefit is marginal because air traffic requires a large percentage (e.g., 70%) equipage before using RNAV procedures in a given airspace. The high cost associated with purchasing avionics means that universal equipage with this capability, necessary for Free Flight, will not occur in the near to mid term future. By contrast, the anticipated low cost WAAS receiver and increased benefit of universal precision approach will help ensure equipage of all system users. In addition, WAAS ensures that all system users use a common navigation reference. By itself, WAAS will not permit Free Flight; however, it is a critical component of the equipment changes required to transition to this new concept of operations. Additionally, LAAS surface navigation capability can support runway incursion prevention.

2.3.4 DoD and ICAO Interoperability

The WAAS program is in direct coordination with the Department of Defense (DoD) through the GPS Joint Program Office (JPO). The FAA is coordinating with the DoD and the intelligence agencies the issues of intentional and unintentional interference, jamming, and spoofing of the GPS/WAAS signals.

The FAA GPS IPT participates in the DoD Joint Precision Approach and Landing System (JPALS) Integrated Product Team (IPT) meetings, and reviews and comments on key documents pertaining to the acquisition of the JPALS, such as their Analysis of Alternatives and the Operational Requirements Document (ORD).
As upgrades to the WAAS and LAAS programs (technical refresh), both systems will make use of the new GPS civil signal on 1176.45 MHz (L5) when it becomes available. While WAAS and LAAS are not dependent on this new signal, the reliability of SatNav service will improve since the combined system is much less susceptible to unintentional interference and certain rare ionospheric

conditions. This capability will reduce the risk in enabling the FAA to eventually decommission the ground-based NAVAIDs

Both WAAS and LAAS will be compliant with the International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPs) for Satellite-based Augmentation Systems (SBAS) and Ground-based Augmentation Systems (GBAS), respectively.

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3.0 ALTERNATIVES ANALYSIS

This section documents the rationale for the initial selection of particular navigation architecture alternatives, describes each alternative in terms of FAA-provided functionality and operational capability, presents analysis of the performance of each alternative, and recommends a set of cases as input for the IAT's cost, benefits, and risk teams.

3.1 Approach

Four primary architecture alternatives were developed, all meeting a "minimum" set of operational navigational performance requirements but ranging in the degree of user and FAA investments in ground- and satellite-based NAVAID assets. Key minimum requirements for each architecture are as follows:

- The navigation and landing service must meet accuracy, integrity, availability, and continuity of service performance levels of existing systems.
- The navigation service must be global and seamless.
- The navigation service must permit RNAV and Free Flight operations.
- Instrument approaches with vertical guidance in the form of precision approach or NPA with vertical guidance (NPV) service must be extended to each IFR runway.
- The navigation and landing service must be extended to the airport surface.
- The navigation service must support a terrain avoidance warning system for IFR-equipped aircraft.

A set of key guidelines was developed for alternative development in order to confine the analysis to a more manageable set of parameters. These guidelines are:

- The alternatives must accommodate White House policy decisions (e.g., selective availability off).
- Selective availability will be turned off by the year 2006.
- Another "safety of life" GPS L5 will be operational after the year 2015.
- Loran-C will be operated and maintained by DOT at least through the year 2008.
- Surveillance in congested airspace will continue to be provided by a sensor independent of Global Navigation Satellite System (GNSS).
- WAAS Phase I geostationary satellites (single geostationary satellite coverage for 3/4 CONUS) are inadequate for widespread user equipage.
- Growth in precision approach runway qualifiers must be accommodated.

3.2 Development of Alternatives

To develop alternative navigation architectures, it is necessary to consider the operations of each major group of airspace users and applicable navigation technologies for every phase of flight. Combinations of technologies that would not provide service for every phase of flight or that would exclude particular user groups have not been pursued (e.g., a Loran-C-only operation). Some newer technologies that would require development were not included in the alternatives, but may be pursued in later studies after a better understanding of their feasibility and operational concepts are known. It is possible that a small number of U.S. airports will find Microwave Landing Systems (MLS) and other technologies advantageous; we assumed that these "niche" applications will not significantly impact the overall evaluation. Finally, we believe that, subject to further review, all of the candidate architectures can meet FAA requirements.

Our intent is to focus on decisions that must be made in the near term, especially the WAAS architecture. Thus, we defined four major alternatives, which span the investment alternatives for the WAAS structure. Each alternative is a combination of satellite-based and ground-based modules, with each module providing specific levels of service at an associated cost.

3.2.1 Definitions

3.2.1.1 WAAS

- *No WAAS* means GPS is not augmented and the WAAS Phase I assets are decommissioned.
- *Simplified WAAS without precision approach* means en route RNAV through NPA service is provided with sufficient redundancy to preclude single point of failure. Some operational constraints are expected as GPS space vehicles or augmentation assets fail. Differential corrections required for precision approaches are not provided. Retention of another navigation source, such as VOR or DME, would be required for busy airspace and airports. No satellite-based precision approach service will be provided by this system.
- *Simplified WAAS with precision approach* means WAAS provides differential corrections and suitable availability to support en route RNAV through CAT I precision approaches in all CONUS airspace. Some limited operational restrictions are expected. Retention of ILS would be required for many airports, especially outside CONUS (e.g., Alaska, Hawaii).
- *Full WAAS* means adding WAAS resources to provide a level of robustness to support en route RNAV through *precision approach*es with no operational restrictions other than operations during periods of intentional jamming. Many ground NAVAIDs can be decommissioned, with a BBN retained to mitigate possible GPS jamming or interference.

3.2.1.2 LAAS

Four levels of LAAS are defined:

- *No LAAS*

- *Full LAAS* means LAAS supports precision approach operations without precision approach WAAS resources.
- *LAAS to supplement Simplified WAAS with precision approach* means LAAS provides CAT II/III precision approach services and supplements WAAS CAT I availability at the busiest airports.
- *LAAS to supplement Full WAAS* means LAAS provides CAT II/III precision approach services and supplements WAAS CAT I availability only where needed. Most ILSs could be decommissioned.

3.2.1.3 VOR/DME/VORTAC

Three networks of VOR, DME, and VORSs (collocated with) TACAN (VORTACs) are defined:

- Current network means the current system, including projected growth over the study period.
- The MON [1] is defined as a network of 614 VOR/DMEs/VORTACs and enough Tactical Air Navigations (TACANs) to provide coverage along routes between major airports and associated satellite airports.
- The BBN [1] is a network of 222 VOR/DME/VORTACs and enough TACANs to provide roughly single-system coverage across CONUS above 6,000 feet AGL.

3.2.1.4 ILS

Three networks of ILS are defined:

- Current system of CAT I/II/III ILS, including projected growth over the study period.
- ILS MON (which includes approximately 419 CAT I ILSs and 99 CAT II/III ILSs).
- The ILS BBN (which includes approximately 332 CAT I ILSs) is the ILS network at strategic airports to facilitate recovery from an unlikely widespread GPS outage.

3.2.1.5 Inertial Systems/FMSs

In all alternatives, it is assumed that all new jet transports will be produced with inertial systems and Flight Management System (FMS); some implementations of the inertial/FMS/GPS interface will allow continued navigation performance in the case of GPS outages. Potentially low-cost inertial systems are under development, but are not expected before the year 2008.

3.2.2 Description of Alternatives

Table 3-1 summarizes the four alternatives in terms of the navigation systems provided by the U.S. government to support particular operational capabilities. The intended role of each navigation system is denoted by the bracketed letter P, S, I, which represent *primary*, *supplemental, and* *insurance*, respectively. Primary refers to the navigation system providing the highest level of service. Supplemental refers to the navigation system used in addition to the primary system to extend service in particular cases. Insurance refers to an augmentation provided by the FAA to mitigate the effects of a widespread SatNav outage.

The "Expected User Equipage" and "Planned Decommissioning of Ground NAVAIDs" rows in Table 3-1 need to be determined through coordination with the user community. The expected user equipage for each will need to be determined for each class of user (based on the operational capabilities desired and through collaboration with the user community) and consequent decommissioning of ground-based NAVAIDs will be determined accordingly.

Four levels of decommissioning are considered:

- None
- To MON
- To BBN
- All (i.e., to zero)

Table 3-1. Summary of Navigation Alternatives

Operational Capability	Alternative I	Alternative II	Alternative III	Alternative IV
RNAV and to Support Free Flight Objectives	GPS [S], DME/DME [P], VOR/DME [P], (Loran-C) [S]	GPS/WAAS [P], DME/DME [S], VOR/DME [S], (Loran-C) [S]	GPS/WAAS [P], DME/DME [S], VOR/DME [S], (Loran-C) [S]	GPS/WAAS [P], DME/DME? [I] VOR/DME? [I] (Loran-C) [I]
Station Referenced Navigation	VOR [P], DME [S], NDB [P]	VOR [S], DME [S], NDB [S]	VOR [S], DME [I], NDB [S]	VOR [I], DME [I], NDB [I]
NPV (vertical component)	Baro VNAV [P]	Baro VNAV [P]	GPS/WAAS [P]	GPS/WAAS [P]
Precision Approach	(a) ILS [P] (b) ILS [S], LAAS [P]	(a) ILS [P] (b) ILS [S], LAAS [P]	ILS [S], WAAS/LAAS [P]	ILS [I], WAAS/LAAS [P]
Expected User Equipage (Note 1)	- Limited SatNav - Full current	- SatNav on new a/c - Current on existing aircraft	- SatNav on new and 90% existing a/c - Current on existing aircraft	- SatNav on new and 90% existing a/c - Current on 50% existing aircraft
Planned Decommissioning Ground NAVAIDs	(a) none (b) ILS to BBN	(a) MON VOR/DME (b) ILS to BBN	To MON VOR/DME/ILS ---------or-------- To BBN VOR/DME/ILS	To BBN VOR/DME/ILS ---------or-------- All (depends on users equipping with GPS RFI mitigation)

*Note 1: Free Flight operations will have to be able to handle cases where the RNAV capability is lost, particularly in high-traffic airspace. This is a particular limitation for Alternative I, where a large number of aircraft may be using low-availability GPS to conduct Free Flight operations.

The following description of the four alternative navigation architectures are presented from three perspectives:

- Navigation services provided by the FAA,
- Operational capabilities, and
- Associated user equipage.

Figure 3-1 illustrates the navigation and landing operational capabilities of interest in this assessment. These capabilities include the following: precise horizontal positioning to support airport surface navigation and surveillance operations, departure and missed approach guidance, direct routing, horizontal positioning to support terrain alerting, three-dimensional curved approaches, and the entire range of instrument approaches, including NPAs, NPAs with vertical guidance, and precision approaches (CAT I/II/III).

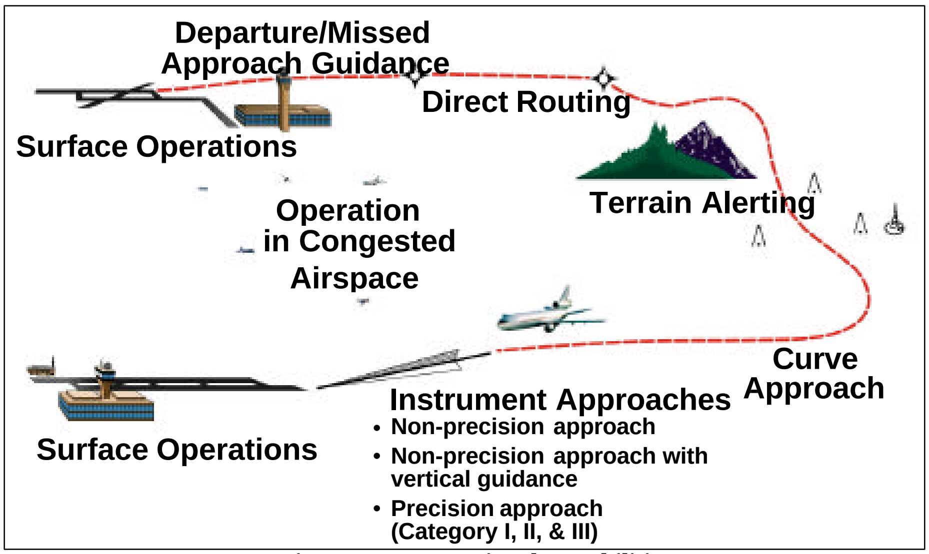

Figure 3-1. Operational Capabilities

Figure 3-2 illustrates the range of alternatives in terms of the government-provided functionality. The increasing amount of SatNav capability (from left to right) is accompanied by a decreasing amount of ground-based NAVAIDs, illustrating an FAA affordability constraint. The FAA January 98 baseline at the extreme right of the figure represents the FAA's JRC-approved plan discussed in Section 3.1; this baseline assumed a robust SatNav capability that might eventually allow the FAA to remove all ground-based NAVAIDs.

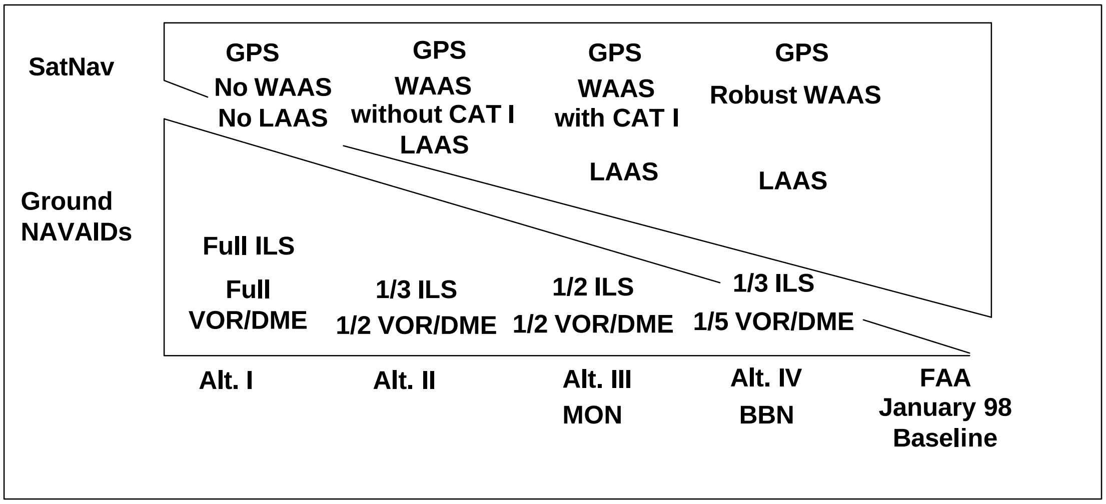

Figure 3-2. Alternatives Selected for Detailed Economic Analysis

Alternative I use the DoD-provided GPS without FAA augmentation, and retains the entire ground-based NAVAID infrastructure including growth to accommodate demand. (Additional ILSs to meet increasing demand for precision approaches may face spectrum constraints at some time.) The WAAS assets currently being fielded would be decommissioned. The other three alternatives assume that once the SatNav capability is fielded, users will equip to achieve operational benefits, thereby allowing the FAA to begin decommissioning parts of the ground-based infrastructure.

Alternatives II and III take advantage of the WAAS assets currently being fielded and provide an operational capability by adding one more geostationary satellites to the existing two Inmarsat3 geostationary satellites to eliminate the single point of failure that exists with the Inmarsat3s alone, which covers about 3/4 of CONUS. Two or more geostationary satellites would be sought for a long-term sustainment of this level of capability to achieve dual geostationary satellite coverage throughout the coverage volume. The achievable performance of Alternatives II and III would allow users to equip with only SatNav avionics for the services provided, and comes close to, but does not meet the most demanding NPA availability requirements (en route and terminal availability requirements would be met). Accordingly, a complement of ground-based NAVAIDs is retained referred to as the MON [1], which is roughly half the current network, for users who wish to equip to achieve high availability by combined GPS/conventional avionics (e.g., for scheduled air carrier service not equipped with inertial), or choose to fly IFR only with conventional VOR/DME and ILS avionics.

The difference between Alternatives II and III is as follows: in Alternative II, WAAS provides en route through NPA service, whereas in Alternative III, WAAS also provides CAT I precision approach service. Alternative II needs fewer WRSs than the 25 currently being fielded, so about 10 of them could be decommissioned. The resulting en route through NPA service would allow the VOR/DME and TACAN NAVAIDs to be eventually decommissioned to the MON level, but current ILSs (plus growth) would be retained.

For both Alternatives I and II, a variation is considered that would use LAAS as a replacement for ILS by placing a LAAS at each ILS airport (currently about 710 ILS airports with at least one ILS, and this would need to grow to accommodate new demand for precision approaches). This would allow ILSs to be eventually decommissioned to a simple backup level known as the BBN [1].

Alternative III WAAS uses all the current WRSs, provides en route through CAT I service, uses LAAS to provide CAT II and III service, supplements CAT I availability at the busiest airports, thereby allowing VOR/DME, TACAN, and ILSs to be eventually decommissioned to the MON level.

Alternative IV is similar to Alternative III, but adds one more geostationary satellite and enough WRSs to achieve a robust WAAS service, and needs fewer LAAS because WAAS achieves higher CAT I availability at more airports. Three or more geostationary satellites would be sought for a long-term sustainment of this level of capability to achieve triple coverage throughout CONUS and dual coverage throughout the remainder of the coverage volume. This robust capability offers the best opportunity to eventually decommission the ground-based NAVAIDs down to the lowest level (BBN). Loran-C is considered as a possible supplement to retaining VOR/DME to the MON or BBN levels.

Figure 3-3 illustrates the operational capabilities associated with each alternative and the user equipage required to achieve those operational capabilities. Figure 3-3 also shows that progressing from Alternative I through Alternative IV generally results in increasing operational capability and potentially decreasing airborne equipage.

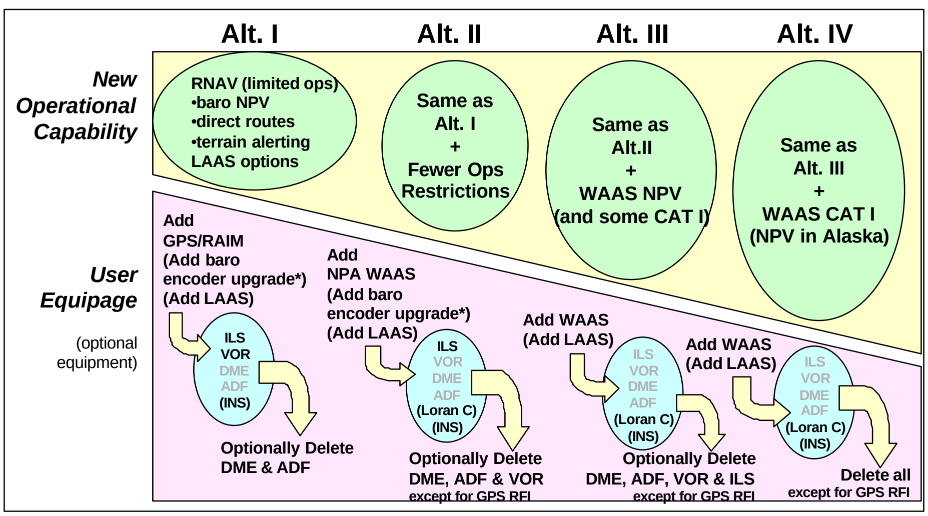

Figure 3-3. Operational Capabilities and User Equipage

For Alternative I, users who equip with GPS/Receiver Autonomous Integrity Monitoring (RAIM) avionics achieve the RNAV capabilities associated with unaugmented GPS. These RNAV capabilities include direct routing, NPA, terrain alerting, and vertical guidance. The vertical guidance capability would use GPS/RAIM for the lateral positioning and barometric altimeter inputs for vertical positioning. To use barometric altimeter inputs, most general aviation aircraft would need to upgrade their barometric altimeter encoder, and the GPS/RAIM avionics would need to provide a means to input local altimeter corrections and perform the vertical guidance function (similar to the vertical guidance function of CAT I WAAS avionics). Equipping with GPS/RAIM allows users to optionally delete DME and Automatic Direction Finder (ADF) avionics. For the LAAS variation of Alternative I, users equipping with LAAS would achieve the operational benefits associated with LAAS at equipped airports, including surface operations, curved approaches, precision approaches (through CAT III). For Alternative II, users who equip with WAAS avionics achieve the same capabilities as described for GPS/RAIM avionics for Alternative I, except that much higher availability results in far fewer operational restrictions (see Section 3.3.1.1). Because of the higher availability of en route through NPA service, users may optionally delete VOR avionics (in addition to deleting the DME and ADF). Vertical guidance is achieved with the same barometric altimeter encoder upgrades as described for Alternative I, and the LAAS capabilities are the same for the LAAS variation as were described for Alternative I. For Alternative III, users who equip with WAAS avionics achieve the same capabilities as described for WAAS avionics in Alternative II with the addition of vertical guidance and CAT I precision approach provided as part of the WAAS, so the barometric altimeter encoder upgrades are not necessary for Alternative III. LAAS equipage in Alternative III is optional to achieve CAT II/III precision approach or to achieve higher availability of CAT I precision approach at LAAS airports. For Alternative IV, the operational capabilities are the same as for Alternative III (in fact, the avionics are identical), except the availability is higher with Alternative IV, thereby providing a SatNav capability with the least amount of dependence on ground-based NAVAIDs.

3.3 Performance Assessments

The performance assessment of the alternatives includes several types of analyses. Performance of the SatNav modules of each alternative is assessed in terms of availability [5], which is the fraction of time a particular service (to complement the SatNav service, e.g., en route navigation service) meets the accuracy, integrity, and continuity of function requirements for that service.

The performance of the ground-based navigation modules of each alternative is assessed in terms of the coverage provided. For Alternative I, the ground-based navigation systems continue to provide the same services provided today; no detailed assessment has been made to show whether it will be able to meet current requirements and any future requirements to accommodate anticipated growth. For the other alternatives in which the ground-based navigation modules complement the SatNav services, the performance is assessed in terms of its effectiveness in filling that particular complementary role. Specifically, coverage is analyzed for the MON and BBN VOR/DME networks at various altitudes.

3.3.1 SatNav Availability Analysis Results

3.3.1.1 En Route Through NPA Results

En route through NPA navigation service is a two-dimensional (horizontal) positioning capability with specified accuracy and integrity requirements, and when this capability is used for primary means navigation, continuity-of-function and availability requirements are also specified. In Alternative I, the accuracy and integrity requirements are achieved using GPS receivers with RAIM, as specified in Technical Standard Order (TSO) C-129. In the other alternatives, the accuracy and integrity requirements are met with a minimum-capability WAAS receiver, as specified in the WAAS Minimum Operational Performance Standard (MOPS), RTCA/DO-229A [2].

Figure 3-4 compares the NPA (most stringent case) availability for the four main alternatives for three different assumptions for the GPS satellite constellation size/replenishment strategy. Results assume a three-year restoration time for the geostationary satellites. Each column in the figure is composed of average daily unavailability (1–availability) for 25 locations throughout the WAAS service volume. The bold horizontal line at 10^{-5} unavailability represents the 0.99999 availability requirement; results below the line meet the requirement.

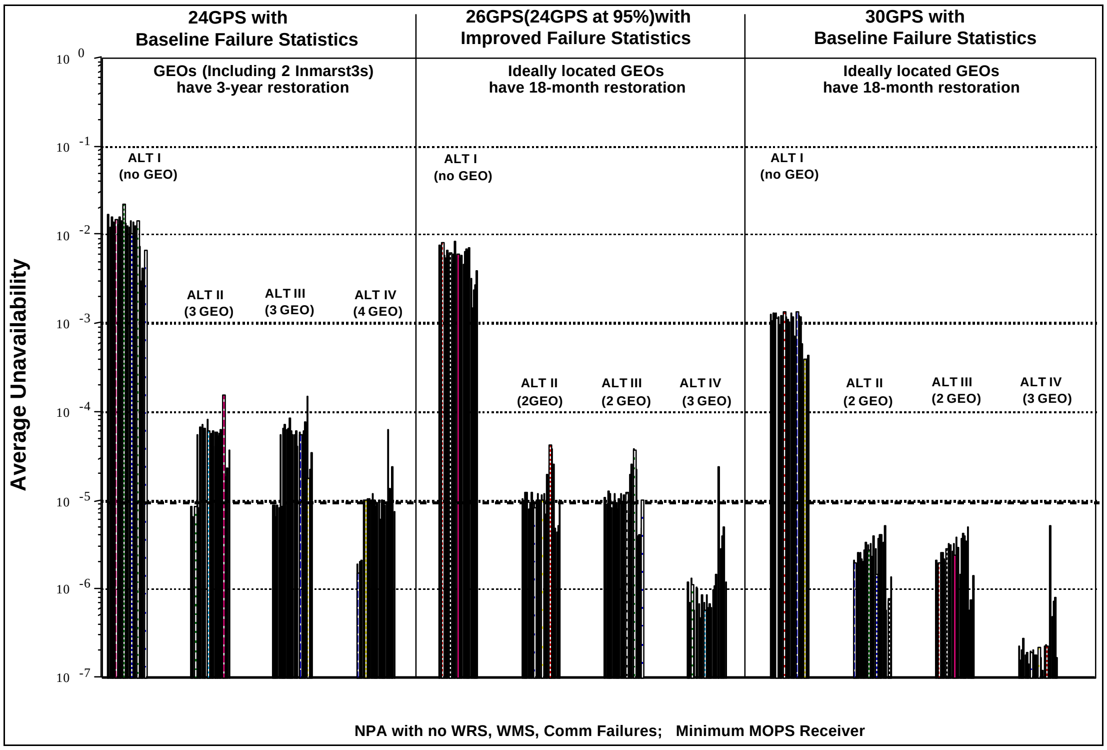

Figure 3-4. NPA Availability Results

For any of the three GPS constellation assumptions, the results in Figure 3-4 show that Alternative I can rely on SatNav only as a supplement to ground-based navigation because it is several orders of magnitude away from the 0.99999 availability requirement. Alternatives II and III do not meet the requirement for the conservative GPS assumptions (based on the current GPS signal specification), but can nearly meet the requirement for either of the *improved GPS* assumption (conservatively based on the DoD's draft ORD) at most CONUS locations. Alternative IV is shown to meet the availability requirement at most CONUS locations (nearly meet it at all locations) even for the conservative GPS assumption (and with significant margin with the *improved GPS* assumption).

Although, Alternatives II and III can meet the availability requirement with the *improved GPS* assumptions approximately 3/4 of CONUS is shown to have only dual-geostationary satellite coverage, which raises two issues. First, this would not meet a current requirement for *average catastrophic-loss probability*, which effectively requires three geostationary satellites in view (triple coverage). Second, even if this requirement were relaxed, a single, catastrophic loss of a geostationary satellite would result in a single-point failure that would remain for a long time period (three years assumed in the availability analysis for replacing a failed geostationary satellite). Requiring users to carry a backup (complementary) navigation capability would provide protection against operational restrictions (e.g., for operations in congested airspace). This is the basis for retaining VOR/DME to the MON level in Alternatives I and III. Adding a geostationary satellite (triple coverage) would greatly reduce the likelihood of dropping to a single-point failure.

3.3.1.2 NPV Results

NPA with vertical guidance (NPV) can be achieved by different methods. One method is to use the two-dimensional positioning capability of SatNav (or other RNAV source with adequate accuracy and integrity) for lateral guidance, while using vertical position information (with adequate precision) from a barometric altimeter system. For most general aviation aircraft, an upgrade to existing equipment would be required to achieve the necessary precision, and a means to input local altimeter corrections would be needed.

Another method of achieving vertical guidance capability is to use WAAS with vertical guidance. This capability would be included in the WAAS avionics for Alternatives III and IV, so the additional costs associated with altimeter upgrades would not be necessary. (An assumption is that the vertical guidance algorithms and waypoint database needed for vertical guidance would be common to both vertical guidance methods described and would likely be embedded in the GPS or WAAS avionics.)

The performance of the first vertical guidance method is assessed assuming the lateral guidance is based on SatNav with lateral guidance requirements equivalent to NPA requirements. Therefore, neglecting failures of the barometric altimeter system, the vertical guidance service based on this method would be equivalent to the NPA availability results shown above in Figure 3-4 above.

The performance of the second vertical guidance method for Alternative III is illustrated in Figure 3-5, which uses a color code to depict the different availability levels achieved over the geographic area. The figure shows that an availability of 0.995 or better is achievable throughout CONUS, Mexico, and Canada (below approximately 60 degrees latitude). Areas along the West Coast (where there is triple-geostationary satellite coverage) achieve availability of 0.9995 or better.
This result assumes:

- Improved GPS outage parameters, consistent with DoD's current position to maintain 24 operational GPS satellites
- A three-year geostationary satellite restoration
- A new WAAS algorithm being developed for monitoring ionospheric data [4]
- Nominal ionospheric activity (i.e., no severe ionospheric storms)

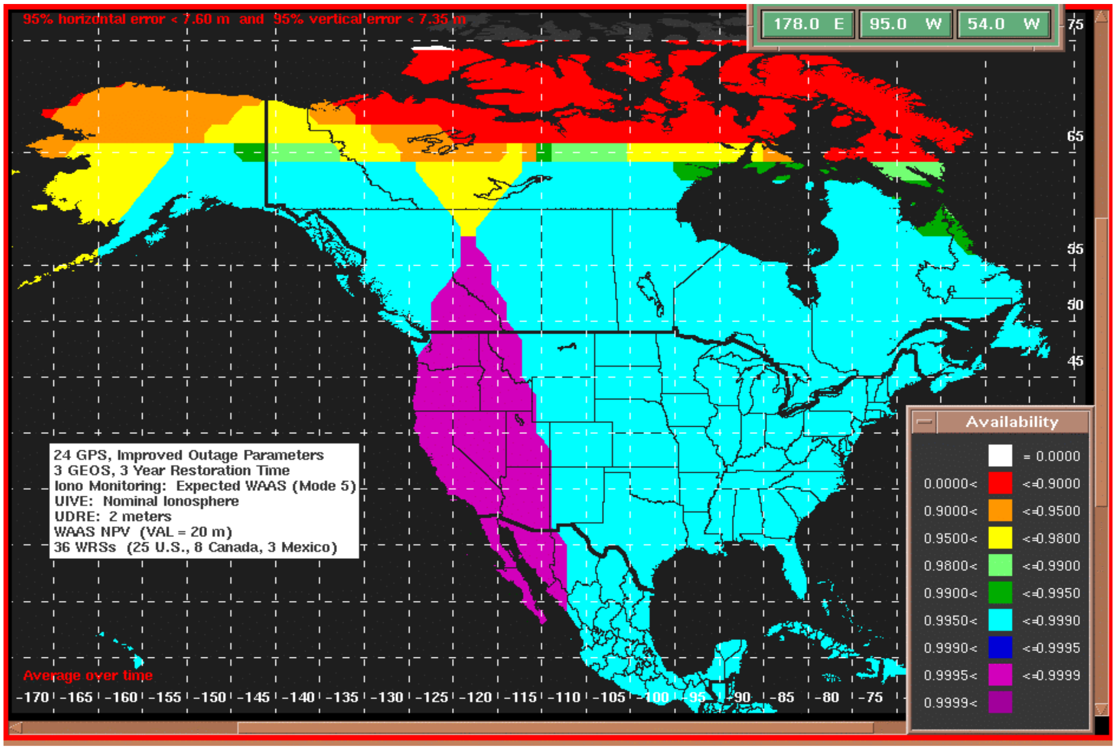

Figure 3-5. WAAS NPV Results for Alternative III (3 GEOs providing mostly dual coverage)

3.3.1.3 CAT I Results

The CAT I precision approach service, which is provided by ILS today (MLS in a few locations), is provided by LAAS in variations of Alternatives I and II, and by a combination of WAAS and LAAS in Alternatives II and IV (with ILS as a backup). Figure 3-6 compares the availability results of LAAS for the four basic alternatives for the conservative and *improved* GPS assumption. The results show LAAS can achieve the 0.999 to 0.99999 requirement even for the conservative GPS assumption and (nearly meets 0.999) without any geostationary satellites (Alternative I). However, for high traffic density airports, it may be necessary to achieve better than 0.999 to satisfy user demand (this is achieved today at many airports with more than one ILS). For Alternative I, this higher availability would be achieved either by taking credit for the *improved* GPS assumption or by using LAAS at high-traffic density airports with the addition of an APL, as illustrated below in Figure 3-7.

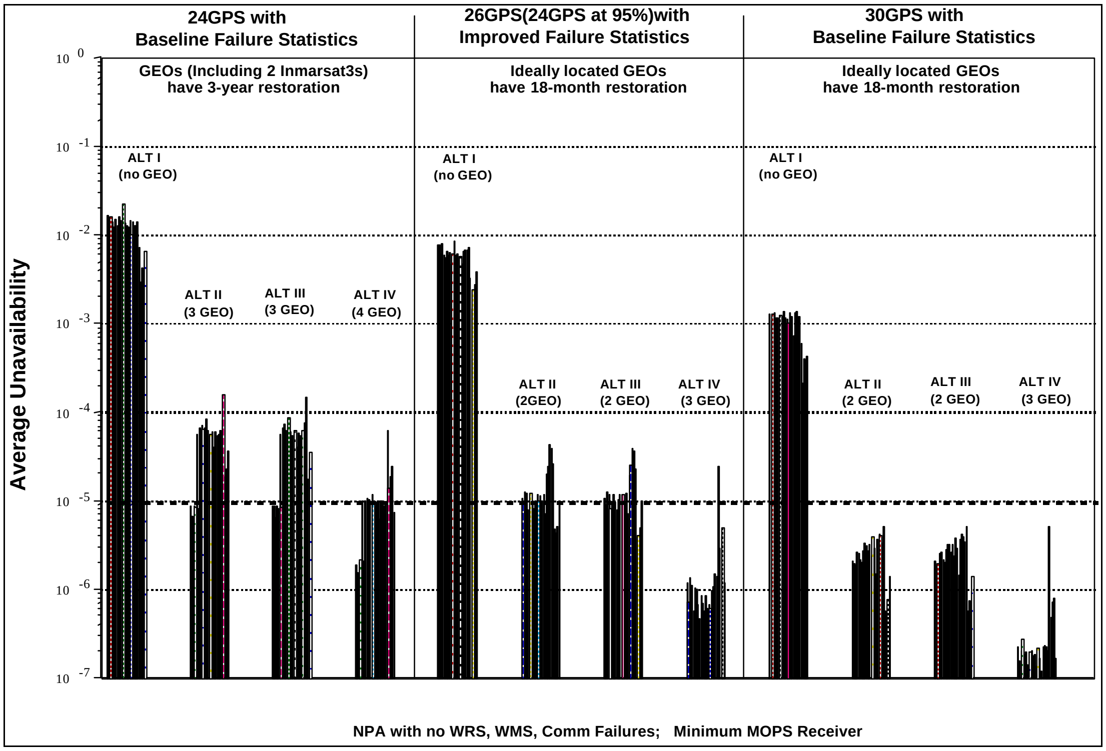

Figure 3-6. CAT I LAAS Results

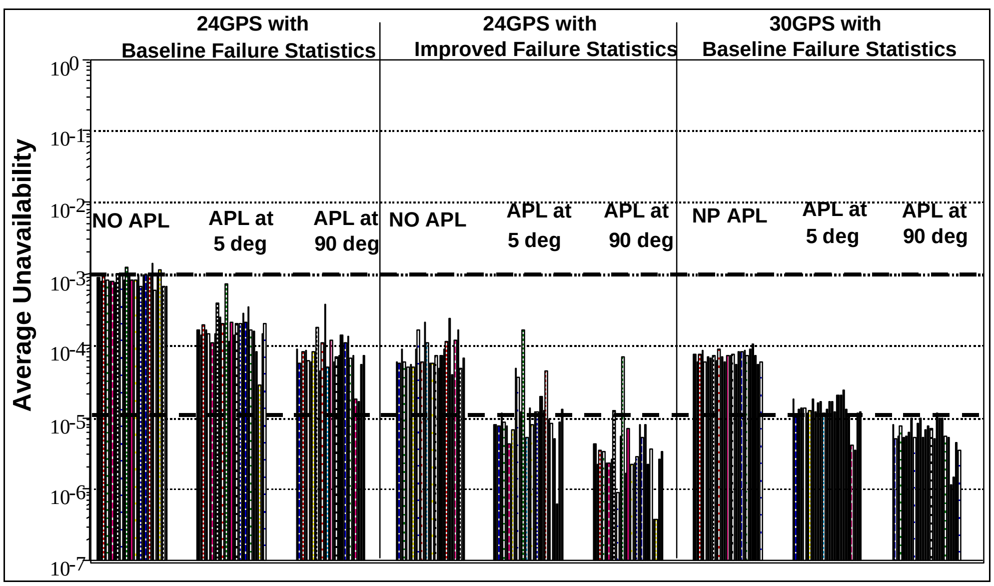

Figure 3-7. Effect of APLs on LAAS Availability without Geostationary Satellites

The performance of WAAS CAT I service for Alternative III is illustrated in Figure 3-8, which shows about 0.995 availability can be achieved nearly throughout CONUS, Mexico, Canada (below about 60 degree latitude), and southeastern Alaska with the *improved* GPS assumption. (This result is quite similar to the result in Figure 3-5 for WAAS vertical guidance, so there may not be an availability benefit in using WAAS NPA over simply using WAAS CAT I.) Although this availability is quite good (considering the limited geostationary satellite and WRS assets), it does not meet the 0.999 requirement. This result is the basis for the increased number of LAAS assumed in Alternative III (compared with Alternative IV). Sixty additional LAAS are used to ensure that the top 200 airports are provided with high availability for users who want it and are willing to equip with LAAS avionics. The number 200, although somewhat arbitrary, is based on those airports accommodating 98% of air carrier and 86% of air taxi instrument operations (1992 data). Alternative III retains ILSs to the MON level.

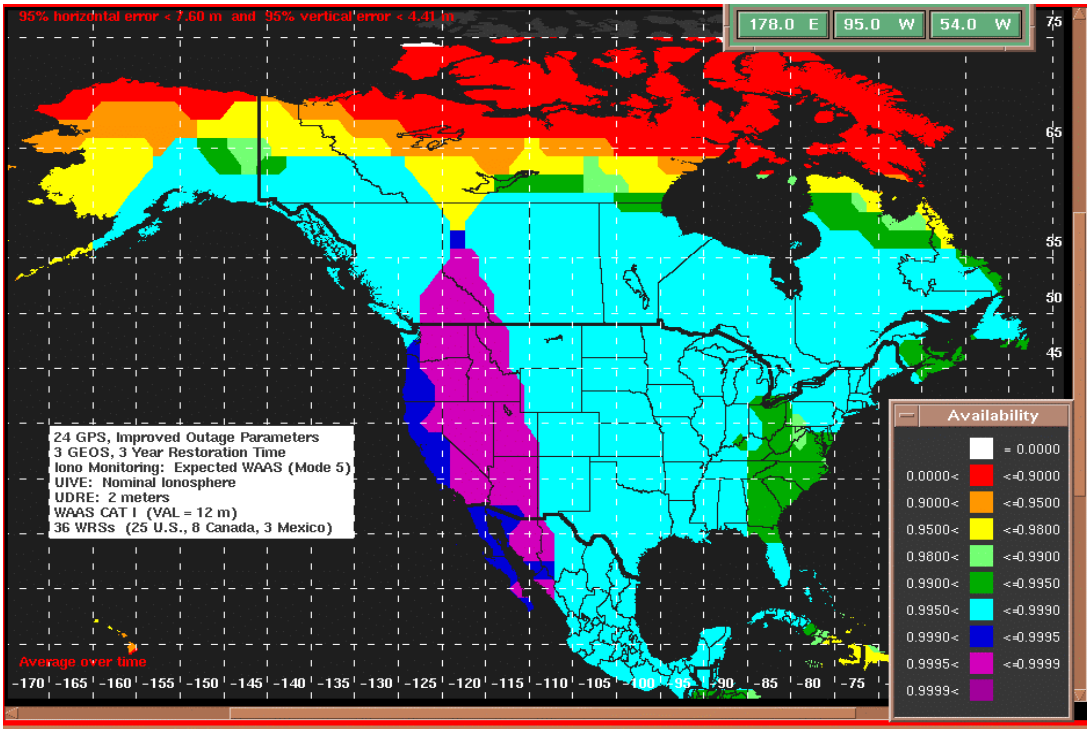

Figure 3-8. WAAS CAT I Results for Alternative III (3 GEOs providing mostly dual coverage)

Alternative IV adds another geostationary satellite (relative to Alternative III) to permit continued, unrestricted operations after a single geostationary satellite failure, and supplements the number of WRSs to provide complete CAT I coverage throughout the service volume. Figure 3-9 shows the WAAS CAT I availability for Alternative IV. To meet the 0.999 requirement, this result assumes:

- Improved GPS outage parameters
- The new WAAS algorithm being developed for monitoring ionospheric data
- Nominal ionospheric activity (i.e., no severe ionospheric storms)
- Improved User Differential Range Error (UDRE) value of 1.5 meters, projected by the WAAS contractor to be achievable in the final WAAS configuration.

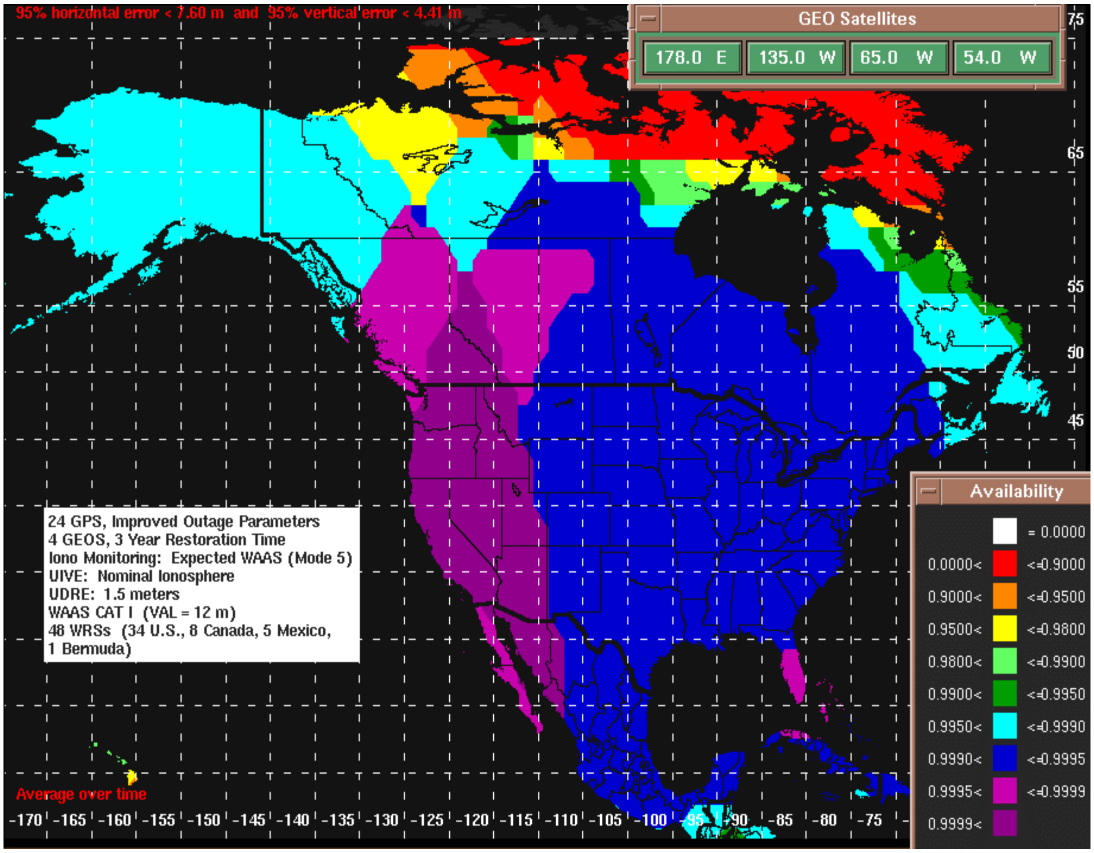

Figure 3-9. WAAS CAT I Results for Alternative IV (4 GEOs providing mostly triple coverage)

3.3.2 Ground-based Navigation System Analysis Results

3.3.2.1 VOR/DME/TACAN Coverage Results

Coverage analysis of the MON and BBN VOR/DME and TACAN networks were conducted. FAA Standard Service Volume limitations and blockage by terrain are reflected in the coverage result plots. Results for VOR/DME were very similar to the results for TACAN, so only the VOR/DME results are shown in this paper. Figure 3-10 shows the coverage for the BBN at 24,000 feet Mean Sea Level (MSL) altitude; Figure 3-11 shows the coverage for the BBN at 6,000 feet MSL; and Figure 3-12 shows the coverage of the MON at 6,000 feet MSL.

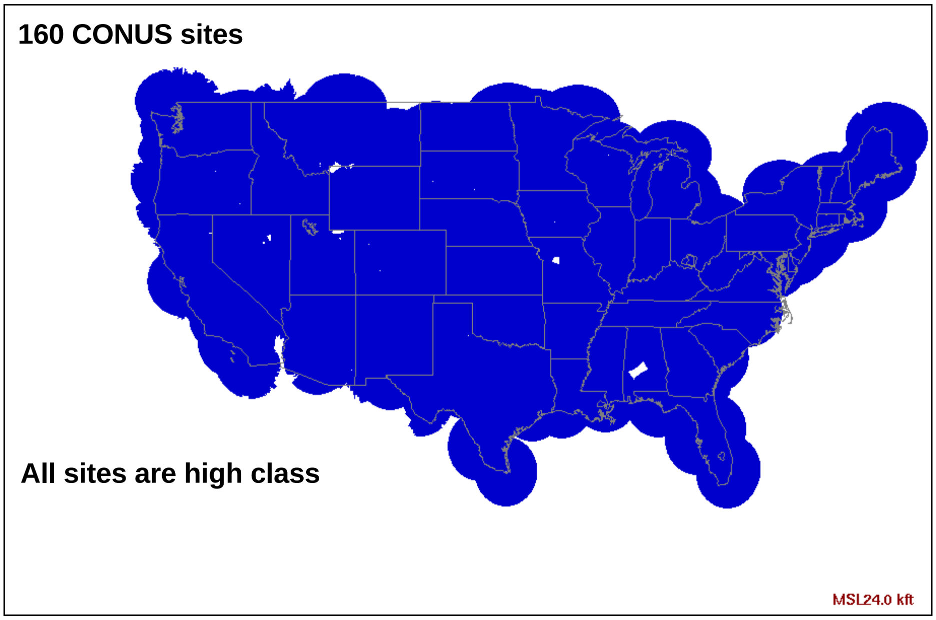

Figure 3-10. BBN VOR/DME Coverage at 24,000 Feet MSL

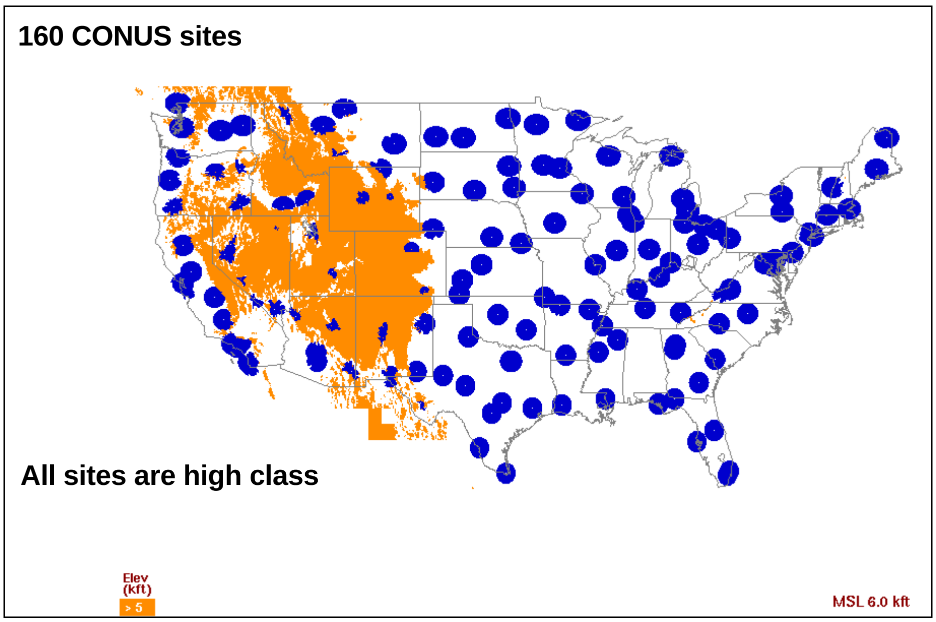

Figure 3-11. BBN VOR/DME Coverage at 6,000 Feet MSL

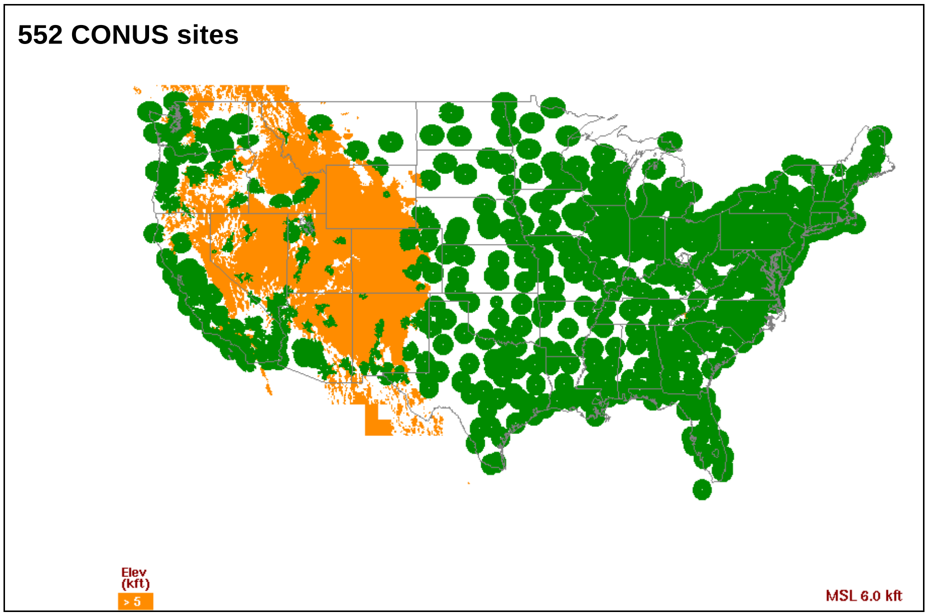

Figure 3-12. MON VOR/DME Coverage at 6,000 Feet MSL

The operational implications for air carriers are that the BBN or MON provides adequate high-altitude coverage to overfly a GPS outage area and to conduct terminal navigation operations and instrument approaches to equipped airports. For general aviation, the operational implications are as follows:

- The BBN might support emergency operations to deal with a GPS outage, but provides poor low-altitude en route coverage.
- The MON supports operations between the busiest airports, but many smaller airports are not served with instrument approach capability.
- A possible role for Loran-C is to supplement the BBN low-altitude en route coverage or to supplement the number of instrument approach airports for both MON and BBN for users who wish to equip with instrument-capable Loran-C avionics.

3.3.2.2 Loran-C Results

The potential role of Loran-C to complement the SatNav services involves its use as an IFR NAVAID during possible SatNav service outages. Loran-C is currently used as an IFR supplemental navigation system for en route and terminal operations, but there are currently no NPAs approved for Loran-C. The primary role for Loran-C explored in this analysis is to supplement the backup capability of a MON or BBN infrastructure of VOR/DMEs.

3.4 Recommended Cases for Detailed Analysis

Four primary navigation architecture alternatives were developed that meet the key minimum requirements discussed in Section 3-1. Twelve cases including a baseline case for each of the four primary alternatives, plus variations on these four are recommended for detailed analysis by the

SatNav investment analysis cost analysis team, benefits analysis team, and risk analysis team. These twelve cases are illustrated in Figure 3-13.

	Alt. I	Alt. II	Alt. III	Alt. IV
Baseline Cases	**No WAAS, No LAAS Full VOR/DME/ILS**	**NPA WAAS, No LAAS MON VOR/DME, Full ILS**	**WAAS w/vertical, LAAS MON VOR/DME/ILS**	**Robust WAAS, LAAS BBN VOR/DME/ILS**
Variations on the Baseline Cases	• Full LAAS, BBN ILS	• Full LAAS, BBN ILS • Baseline plus Loran-C	• BBN VOR/DME/ILS • Baseline plus Loran-C	• Baseline plus Loran-C • Airborne GPS RFI mitigation, no BBN • No BBN, no airborne GPS RFI mitigation

Figure 3-13. Alternatives Recommended for Detailed Economic Analysis

3.4.1 Alternative I

Alternative I baseline case has no WAAS (costing analysis should include costs to decommission WAAS Phase 1 assets currently being fielded), no LAAS, and a full VOR/DME and ILS ground system infrastructure (including additional ILSs to meet anticipated demand for precision approach services). The benefits analysis can claim an RNAV capability benefit, but should address the operational limitations associated with the poor availability that limits GPS/RAIM navigation to a supplemental-means capability. The benefits analysis should address the lack of benefits for the following: widespread RNAV equipage (impeding progress toward achieving direct routing benefits for users who are equipped), surface navigation and surveillance operations, curved/segmented approach/departure procedures, and precision approach minimums to all instrument runways. The cost and benefits analyses should illustrate the notion that the only means of achieving the FAA’s safety goal of vertical guidance for all instrument approaches is for users to equip for Baro VNAV for runways without an ILS approach. This can be done either by assuming all users equip and estimate the user cost impact, or by assuming many do not equip and estimate the lost safety benefit. The risk analysis should address the possible Very High Frequency (VHF)-spectrum and FM-broadcast-interference issues associated with an expanded ILS infrastructure (and any other issues related to pre-1995 worldwide plans for transitioning from ILS to MLS [6]). There are currently about 1,062 ILSs at about 710 airports. The FAA reports a backlog demand of 600 precision approaches. Some estimates of growth throughout the analysis period are as high as over 30 new ILS installations per year, leading to 678 new installations for a total of 1,740 ILSs.

Alternative I (v. 1) uses LAAS as an ILS replacement, allowing reductions of ILS to the BBN level. The number of LAASs assumed in the cost and benefits analyses should be consistent with the assumed number of ILS equipped airports in the Alternative I baseline case. Assuming one LAAS for each precision approach airport, 710 LAASs are needed for current ILS airports. One additional LAAS for each new ILS airport in the baseline would be needed for this variation. To estimate the total number of LAASs needed for this variation, the number of new airports receiving the 678 new ILSs in the baseline case should be determined (some of these new ILSs will be on runways at airports that already have at least one ILS). The large number of LAASs for this alternative could justify a quantity discount relative to current LAAS cost estimates. Relative to the baseline case, the benefits analysis should address the additional benefits of surface navigation and surveillance operations, curved/segmented approach/departure procedures for LAAS equipped users at LAAS equipped airports. Also relative to the baseline case, the risk analysis should show an improvement for the end-state VHF-spectrum and FM-broadcast-interference issues, but a possible higher risk during the transition because of the larger number of LAAS VHF channels needed while existing ILSs remain.

3.4.2 Alternative II

Alternative II baseline case has a simplified WAAS with no precision approach capability (costing analysis should include costs to decommission all but 15 of the WAAS Phase 1 WRSs), no LAAS, a full ILS ground system infrastructure (including additional ILSs to meet anticipated demand for precision approach services), and a reduced VOR/DME ground infrastructure (MON level). Alternative II (v. 1) uses LAAS as an ILS replacement, similar to Alternative I (v. 1), and the risk analysis will need to capture the same risks about being able to accommodate this level of growth. Relative to GPS/RAIM capability in Alternative I, the benefits analysis should show that the RNAV service from WAAS in Alternative II has significantly fewer operational restrictions due to the better availability shown in Section 3.2.2. The cost analysis should reflect the cost of dual geostationary satellite coverage according to plans being developed by FAA's AND-730 (e.g., addition of one geostationary satellite to the existing Inmarsat3 geostationary satellites in the near term, and sustainment of two well-placed geostationary satellites in the long-term).

Alternative II (v. 2) is the same as the baseline except it retains Loran-C as an optional backup capability. The cost analysis should include the costs of retaining Loran-C beyond the year 2008 (all alternatives assume retaining Loran-C through the year 2008) and some portion of the user community equipping for Loran-C (Aircraft Owners and Pilots Association (AOPA) currently estimates about 1/3 of their general aviation membership would equip with Loran-C as a backup). The benefits analysis could perhaps characterize a small benefit of Loran-C over a VOR/DME backup because more airports would be accessible during a GPS outage. The risk analysis should identify some risk about developing an NPA capable Loran-C, gaining international standardization as a GPS backup, and availability of affordable avionics, but can show a reduced risk in the FAA being able to reduce the VOR/DME infrastructure to the MON level.

3.4.3 Alternative III

Alternative III baseline case has a simplified WAAS with precision approach (same geostationary satellite configuration as for Alternative II), LAAS for CAT II/III and to supplement WAAS CAT I, and a reduced VOR/DME and ILS ground system infrastructure (MON level). The cost, benefits, and risk analyses should characterize the significant advantage over Alternative II of providing the vertical guidance element of WAAS. The relatively small incremental increase in FAA cost (e.g., additional WRSs and associated terrestrial communications) results in significant benefits and reduced risks. The main benefit is the provision of vertical guidance for all instrument approaches without the need for users to equip with Baro VNAV capability. The main reduced risk is that users are more likely to equip (particularly the general aviation community has expressed a strong support for precision approach capability to be included with WAAS).

Alternative III (v. 1) reduces the VOR/DME and ILS infrastructure to the smaller BBN level. Although a less likely outcome to assume, this variation reflects the cost savings that could occur if GPS satellite and geostationary satellite reliability and restoration is much better than expected and user equipage followed (e.g., general aviation opt to not include a VOR/DME backup, and air carriers rely more on inertial for backup).

Alternative III (v. 2) is the same as the baseline except it retains Loran-C as an optional backup capability, with similar economic analysis implications as for Alternative II (v. 2).

3.4.4 Alternative IV

Alternative IV baseline case has a robust WAAS and LAAS for CAT II/III to supplement WAAS CAT I, and a reduced VOR/DME and ILS ground system infrastructure (BBN level). This alternative provides for triple geostationary satellite coverage (e.g., addition of two geostationary satellites to the existing Inmarsat3 geostationary satellites in the near term, and sustainment of three well-placed geostationary satellites in the long-term.) It should be noted that the existing two Inmarsats effectively only provide the coverage associated with one well-placed satellite. As stated, the long-term sustainment is for three well-placed GEO satellites. However, the unavailability of GEOs in well-located positions and/or longer replenishment times, will likely drive the number of satellites required to four GEOs. Thus, the cost analysis and associated lease versus buy analysis includes the costs associated with four GEOs. The cost and benefits analyses should capture the notion that fewer users would retain VOR/DME and ILS with the more robust WAAS and LAAS performance. The risk analysis should show that this alternative has the lowest risk of poor user acceptance, and therefore provides more confidence of being able to reduce the VOR/DME and ILS infrastructure to the smallest possible configuration.

Alternative IV (v. 1) is the same as the baseline except it retains Loran-C as an optional backup capability, with similar economic analysis implications as for Alternative III (v. 2), particularly in terms of user acceptance of reducing the VOR/DME infrastructure to the BBN level.

Alternative IV (v. 2) deletes the entire VOR/DME and ILS infrastructure by assuming users equip with airborne GPS Radio Frequency Interference (RFI) mitigation capabilities, such as identified in the JHU/APL [7] study. The cost analysis should show the cost savings to the FAA due to decommissioning all ground-based NAVAIDs, and the corresponding increase in user cost to equip with the airborne capability. The risk analysis should show the increased risk of relying on the particular set of assumptions in the JHU/APL risk assessment in being able to deal with possible future interference threats.

Alternative IV (v. 3) also deletes the entire VOR/DME and ILS infrastructure, but also assumes no airborne GPS RFI mitigation capability is required. This variation is included only to gain insight into the costs (to FAA and users) of GPS RFI mitigation, and is not intended to be a viable end-state architecture.

3.5 Decision Criteria

The four major areas of decision criteria are Mission Effectiveness, Return on Investment, Risk, and Strategic Alignment. Key criteria are items that are likely to be significant discriminators among alternatives, such as those related to safety, affordability, user acceptance, and risk.

- **Mission Effectiveness**: Impact of the project in improving mission performance for external or internal customers.

Key criteria:

- Safety enhancements provided by an alternative such as vertical approach guidance, contributions to reduced risk of collisions, and recovery from jamming and satellite outages.
- Ability to provide services with minimal operational constraints. Operational constraints include any restriction that keeps an aircraft from flying the most time- and fuel-efficient route, including fixed airways, long approach paths, and higher than necessary approach visibility and ceiling minimums. Operational constraints also include traffic and weather delay, lack of access, unpredictability, and lack of responsiveness to requested flight changes.

Other criteria:

- Supportability: the ability to keep a system operationally available and environmental effects such as noise mitigation.

Return on Investment: Value of the project in economic terms to the FAA and users.

Key criterion:

- The Net Present Value (NPV) is the present value of the benefits to both the users and the FAA less the present value of the costs to both the users and the FAA. The result is positive when the benefits are greater than the costs.

Other criteria:

- Life cycle costs (LCCs) during the period of the analysis (2000-2020).
- Benefit/cost (B/C) ratio is the present value of the benefits to both the users and the FAA divided by the present value of the costs to both the users and the FAA. This includes FAA and user LCCs and benefits. Other items closely related to the B/C ratio are internal rate of return (a discount rate) and the investment payback period.
- Near term investment requirements or the up-front costs to the FAA and users.

- Far term recurring costs beyond the period of the analysis (2020).
- Non-quantified benefits in two areas. Strategic benefits are dependent on other new technology, such as automatic dependent surveillance-broadcast (ADS-B). Non-quantified incremental benefits are those that the investment analysis team was unable to quantify at the high-confidence level because of insufficient data or resources.

Risk: The risk is defined as risks resulting from uncertainty.

Key criteria:

- Operability risk is the risk that the delivered product will not meet the clientele's important mission needs or, worse, may have inherent safety, human factors, or other major flaws that severely compromise its mission performance.
- Stakeholder risk is the probability and consequences of an alternative's failure to receive continued support (from users, providers, or other stakeholders) for the development and operation of the system mix.
- Technical risk is the probability and consequences of an alternative's failure to achieve its intended technical and performance objectives, including safety and security objectives.

Other criteria:

- Schedule risk is the probability and consequences of failing to achieve the states in the system evolution by the planned dates; this includes installation and transition schedules.
- Funding risk is the probability and consequences of an alternative's failure to achieve stable availability of enough funding to develop, field, and maintain required systems.
- Management risk is the risk associated with managing a complex acquisition program.

Strategic Alignment: Extent to which the proposed investment supports strategic organizational objectives.

Key criteria:

- Compatibility with U.S. leadership role in definition of future global navigation systems, which includes compatibility with approved international standards.
- Compatibility with other FAA and DoD programs.

3.6 Ranking and Scoring

Elements were ranked on a scale corresponding to colors. For each ranked element, the best alternative was given a green rating. Alternatives virtually equal to the best alternative were also given a green rating. Alternatives slightly worse than the best alternative were given a yellow-green rating, those moderately worse were rated yellow, and those significantly worse were rated red-yellow. Alternatives considered unacceptable with regard to a given element were rated red for that element.

Ratings were converted to numerical scores on a five-point scale, with green corresponding to four and red corresponding to zero. Scores were weighted and compiled as shown below in Table 3-2.

Table 3-2. Weighted Scores

Overall Weighting	
Mission Effectiveness	35%
Return on Investment	35%
Risk	15%
Strategic Alignment	15%
Mission Effectiveness Weighting	
Reduce Operational Restraints	60%
Safety	25%
Other	15%
Return On Investment Weighting	
NPV	60%
LCC	20%
B/C ratio	10%
Other	10%
Risk Weighting	
Operability	20%
Stakeholder	16%
Technical	16%
Schedule	12%
Funding	12%
Management	8%
Other	16%

Strategic alignment was ranked and scored without sub-elements. Table 3-3 shows the results of the weighted scoring, with each element scoring between zero and four.

Table 3-3. Weighted Scores Results

	Alt I v.0	Alt. I v.1	Alt. II v.0	Alt. II v.1	Alt. II v.2	Alt. III v.0	Alt. III v.1	Alt. III v.2	Alt. IV v.0	Alt. IV v.1	Alt. IV v.2	Alt. IV v.3	Alt. IV MON
Total	**1.68**	**2.13**	**1.75**	**2.12**	**1.78**	**3.31**	**3.25**	**3.25**	**3.59**	**3.55**	**3.63**	**3.63**	**3.31**
Mission Effectiveness 35%	**Y**	**YG**	**Y**	**YG**	**Y**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**
Safety 25%	**Y**	**YG**	**Y**	**YG**	**Y**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**
Reduce Operational Restraints 60%	**Y**	**YG**	**Y**	**YG**	**Y**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**
Other Areas 15%	**RY**	**YG**	**Y**	**G**	**YG**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**
Return on Investment 35%	**RY**	**Y**	**RY**	**RY**	**RY**	**YG**	**YG**	**YG**	**G**	**G**	**G**	**G**	**YG**
NPV 60%	**R**	**R**	**R**	**R**	**R**	**YG**	**YG**	**YG**	**G**	**G**	**G**	**G**	**YG**
LCC 20%	**G**	**G**	**YG**	**YG**	**YG**	**YG**	**YG**	**YG**	**YG**	**YG**	**YG**	**YG**	**YG**
B/C Ratio 10%	**Y**	**Y**	**RY**	**RY**	**RY**	**YG**	**YG**	**YG**	**G**	**YG**	**G**	**G**	**YG**
Other 10%	**Y**	**YG**	**Y**	**YG**	**Y**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**
Risk 15%	**Y**	**Y**	**YG**	**Y**	**YG**	**Y**	**RY**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Strategic Alignment 15%	**RY**	**Y**	**Y**	**YG**	**Y**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**

Weighted average scores fell within four ranges. In general, a difference in overall score of less than 0.2 can be considered insignificant. Alternatives I and II without LAAS averaged about 1.7, while Alternatives I and II with LAAS averaged about 2.1. Alternative III and Alternative IV with

MON of ground-based NAVAIDs averaged about 3.3, while the remaining variations of Alternative IV averaged about 3.6.

The recommended path to the Alternative IV baseline is consistent with the above figures. If equipage rates and operational risks change, Alternative III and Alternative IV with MON are still available options along the same path. Although not explicitly included in the recommended path, other variations of Alternative IV also remain available along the recommended path.

3.7 Selection of Alternatives for Economic Analysis

In order to more efficiently utilize the available resources, the cost team requested that the IAT narrow the list of 12 alternatives to a more manageable number that represented the most viable solutions from an operations perspective. Based on the three decision criteria of Mission Effectiveness, Risk, and Strategic Alignment, the IAT chose one alternative from each of the main alternative types. These are shown in bold in Figure 3-14.

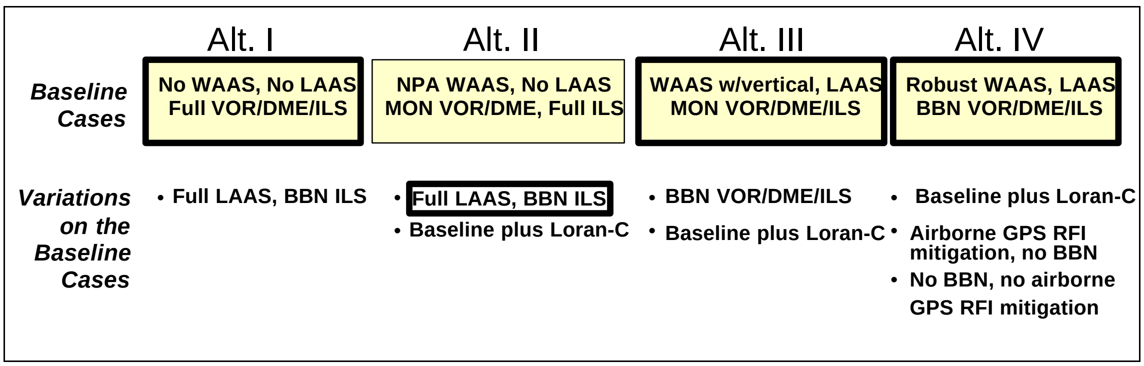

Figure 3-14. Alternatives Selected for Detailed Economic Analysis

For Alternative I, the baseline case was selected (v. 0). The variation that included full LAAS was not evaluated further as the cost of procuring the necessary LAAS ground systems was estimated and was comparable to the cost of Alternatives III and IV, which are known to provide additional benefit.

For Alternative II, the case that includes LAAS was selected (v. 1). Under this alternative, SatNav provides all of the precision approach services using LAAS, and WAAS provides the other services. The option where ILS provides precision approach was not considered, as it is not significantly different from the Alternative I (v. 0) case. The extension of Loran-C beyond the year 2008 was not considered as it would not significantly affect costs or benefits.

For Alternative III, the baseline case was selected (v. 0). The variation that included a reduced ground-based navigation network (the BBN) was rejected because the risk was determined to be unacceptable. The extension of Loran-C beyond the year 2008 was not considered, as it would not significantly affect costs or benefits.

For Alternative IV, the baseline case was selected (v. 0). The options where all ground-based NAVAIDs would be decommissioned were rejected because the risks were determined to be unacceptable. The extension of Loran-C beyond the year 2008 was not considered, as it would not significantly affect costs or benefits. A variation whereby ground-based NAVAIDs were only decommissioned to the MON level was also evaluated to determine the sensitivity of this alternative.

3.8 Downselect to a Preferred Alternative

The following paragraphs provide a description of the factors that were considered in downselecting to a single recommendation. Section 4 provides the results of the detailed economic analysis, which indicate that the recommended alternative is the most cost effective.

The Requirements Document defines a requirement for vertical guidance capability to every IFR runway in the NAS. This requirement stems from the FAA Safer Skies Agenda, which has concluded in several of its safety analysis teams that precision approaches should replace NPAs to help fulfill the Agency's objective of a five-fold reduction in the accident rate. Each of the alternatives considered fulfills that requirement. In Alternatives I and II, at runways not covered by ILS or LAAS, the vertical guidance capability is provided by Baro VNAV, which uses radionavigation for lateral guidance and the aircraft barometer for vertical guidance. In Alternatives III and IV, augmented SatNav (WAAS/LAAS) provides vertical guidance that is independent of the aircraft barometer. The standards and procedures that support Baro VNAV operations are based on the NPA standards and do not provide an equivalent level of safety to a true precision approach, although the addition of vertical guidance is a substantial safety improvement.

In addition, the Baro VNAV capability does not provide the same efficiency benefit since the obstacle clearance surfaces for Baro VNAV operations are much larger than the precision approach obstacle clearance surfaces. This means that the approach minimums for Baro VNAV are not as low as the precision approach minimums, and similar to the NPA minimums. For the general aviation community, Baro VNAV is also more expensive to implement due to the need for an accurate altitude encoder to interpret the analog barometric reading and feed that to the navigation equipment.

Two other factors that distinguish Alternative I and II are compatibility with the overall NAS modernization and international compatibility. Alternative I does not support the future NAS Architecture as it is defined, since it does not provide a reliable and ubiquitous positioning service. Alternative II provides a basic navigation capability reliably, but do not offer the precision needed to support many other applications such as ADS-B. From an international perspective, U.S. operators benefit from a common global RNAV capability that allows users to operate everywhere in the world. To achieve worldwide acceptance, the U.S. has been encouraging other States to adopt SatNav. Alternatives I and II would be a dramatic FAA policy change that would affect worldwide acceptance of SatNav.

Also, the avionics would have to be upgraded (forcing another transition in the aircraft) should a later decision be made to implement WAAS.
Lastly, Alternatives III and IV provide a better growth capability with the planned improvements in GPS services. With the advent of GPS L5, the WAAS capabilities defined in Alternatives III and

IV will provide a precision approach service throughout the footprint of the geostationary satellite. This has the potential to improve the safety of U.S. carriers operating into South and Central America.

Based on all of these issues, Alternatives I and II were eliminated by the team. The primary factors were the combination of reduced safety benefit, reduced efficiency benefit, and increased general aviation costs.

It was more challenging to differentiate between Alternatives III and IV. The primary difference in service between these two alternatives is the reliability of the services that are provided, Alternative IV being the more reliable. Because of this additional reliability the IAT assumed a slightly faster rate of equipage for Alternative IV. As more users rely on SatNav, it will become more important that the service be reliable, since the effect of an outage of SatNav would be more dramatic as it would affect a larger percentage of the operating aircraft. Therefore, more users can safely rely on SatNav under Alternative IV than can under Alternative III.

There is also a relationship between the user equipage rates and the services that the FAA provides. By providing a more reliable service, users are more confident in transitioning from conventional ground-based NAVAIDs to SatNav. Before they invest in the receiving equipment, they want to see an FAA commitment to make the new services reliable. Therefore, there is a difference in the projected rate of user equipage between Alternatives III and IV; Alternative IV resulting in greater equipage.

The increased equipage has a secondary effect of increasing the size of the efficiency benefit. There are limitations of what can be accomplished with RNAV capability in a mixed-equipage environment based on resource limitations, human factors, and controller workload. The controller's task is complicated by the need to keep track of which aircraft have which capability, and the fact that some aircraft cannot be easily redirected using RNAV capabilities. This means that the increased equipage under Alternative IV (primarily increased equipage of general aviation aircraft) also increases the benefit that can be delivered to air carrier aircraft. To ease this transition, the FAA plans to provide these benefits based on RNAV capability, independent of the navigation sensors that support that capability wherever it is possible.

Based upon these considerations and supported by the economic analysis, the team selected Alternative IV and attempted to refine the alternative to mitigate risks. These risks include:

- **User equipage**: The entire aviation community needs to move together towards the transition of navigation. If it does not, the NAS will be composed of different user needs and an unaffordable system. The FAA cannot afford to provide comprehensive satellite-based service, while at the same time provide a full ground-based navigation service. Currently, the new services benefit from widespread support within the aviation community. The proposed implementation strategy allows the FAA to revise their plans if users fail to accept the new services.
- **Ground-based NAVAID transition**: A related issue is the definition of the FAA policy for the sustainment of conventional ground-based NAVAIDs. Users have demanded that sufficient time be provided to gain confidence in the new satellite-based services and allow them addi-

tional time to equip. The implementation strategy provides sufficient overlap to be acceptable to the aviation community, but must be as short as practical to manage costs.

- **Interference**: The GPS Risk Assessment Study, performance by the JHU/APL, highlighted the risk of interference. The FAA has concluded an initial investigation into the threat of such an event, and will coordinate that threat definition with other government agencies. The FAA needs some time to develop mitigation strategies as appropriate and evaluate their effectiveness. Therefore, the implementation strategy defers that portion of the investment associated with relying entirely on SatNav. All alternatives retain a portion of GBNA so interference should not be a safety issue. Also, Alternative II, III, and IV assume a rapid response to locate interfering sources.
- **Ionospheric activity**: As identified in the January 1998 Report to Congress on the status of the WAAS program, one of the principle technical risks is the effects of the ionosphere on GPS signals. This risk exists due to a lack of sufficient data on what the ionosphere can do during period when solar activity is maximized. Based on previous observation experts believe the effects will be minimal throughout CONUS but may be a problem in Alaska and Hawaii. Fortunately, over the next two years the FAA will be able to collect a substantial amount of ionospheric data during the maximum, worst-case conditions. The implementation strategy allows the FAA to collect this data and incorporate any new concepts or strategies into the WAAS services.
- **GPS sustainment**: The JHU/APL GPS Risk Assessment Study stated that there may be a more cost effective combination of assets to provide equivalent satellite-based services. For example, an increase in the size of the GPS constellation could reduce the number of geostationary satellites required by the FAA. These national policy issues have to be coordinated through the Interagency GPS Executive Board (IGEB), established earlier this year. The IGEB has already agreed to develop the National GPS Plan called for by the JHU/APL study and is scheduled to be completed within a year. Similarly, Europe has proposed their own set of satellites (Galileo) that could be used to reduce the FAA requirements for augmentation. The implementation strategy provides time to work with the IGEB to resolve GPS policy issues and possibly incorporate Galileo, by deferring that portion of the investment associated with relying entirely on SatNav. Analyses to date have shown that even with 30 GPS satellites and SA off, geostationary satellites wold be required to meet a 5 “nines” availability and 3 “nines” precision approach requirement.

Under the restructured Alternative IV (shown in Figure 3-15), the FAA and users have time to gain experience and confidence in SatNav during the implementation of a full SatNav capability. The basic idea is to focus near term investment on expanding precision approach capability and making the service reliable enough so that some operators can use SatNav exclusively. For WAAS, this means developing new algorithms to model ionospheric activity and adding additional reference stations. It also includes the addition of another geostationary satellite. With WAAS Phase 1, most of the U.S. has the single point of failure because there is only one geostationary satellite visible. If that geostationary satellite fails, WAAS service is gone for several years while a replacement satellite is procured. It is essential that another satellite be obtained to provide some redundancy and reduce the risk that WAAS service is lost.

For LAAS, the near term investment involves accelerating the initial FAA purchase of LAAS to align it with WAAS capability. This is important, as the air carrier community does not want to invest twice: they want to be able to install one piece of equipment that provides both LAAS and WAAS capabilities. Otherwise, the WAAS SIS may be available but no operators will be equipped to use it.

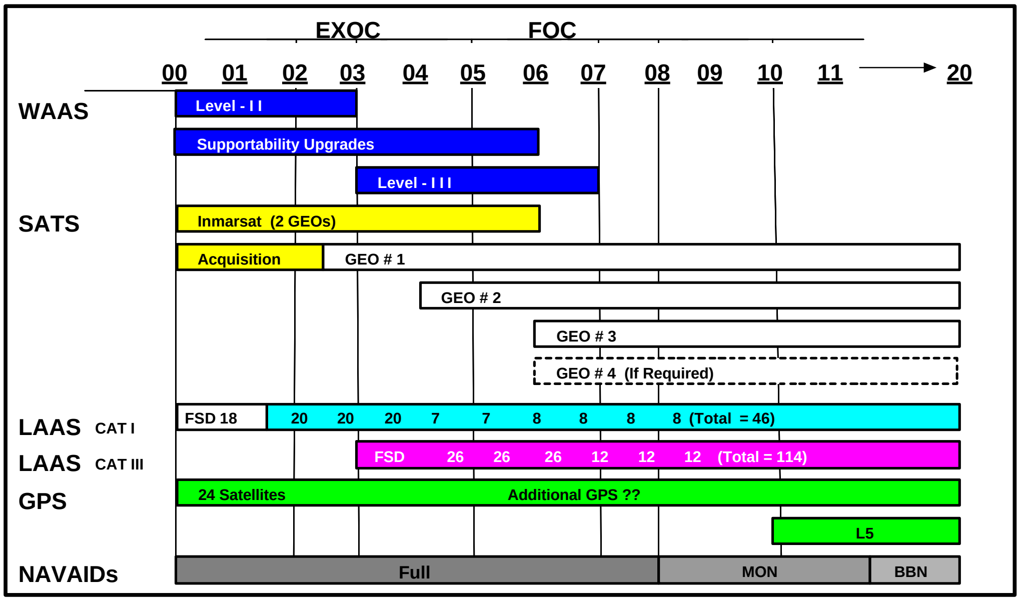

Figure 3-15. Restructured Alternative IV (BBN) Timeline

In the long-term, the restructured Alternative IV enhances the reliability of all of its services, to a point where it provides a service that is just as reliable as the complete set of existing ground-based NAVAIDs. This level of reliability will be required if the majority of operators rely on satellite-based services for navigation. For WAAS, this involves adding additional hardware to make the system more robust to failures. It also involves obtaining additional geostationary satellite services, so that there are three geostationary satellites visible (triple coverage) from everywhere in the contiguous U.S. and at least dual coverage elsewhere in the coverage volume. When the Inmarsat3 satellites currently under lease are replaced, this redundancy can be obtained by access to three or more satellites (depending on their location). Four are assumed for the restructured Alternative IV to address the risk of not getting optimal orbit locations.

Under the proposed alternative, there is a deployment of CAT I systems in support of EXOC. There are a total of 160 LAASs built into Alternative IV, and the investment is spread across six years to promote affordability.

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4.0 ECONOMIC ANALYSIS

4.1 Economic Comparison of Alternatives

The economic analysis considered the following criteria: FAA LCC, user LCC, user benefits, NPV, and the B/C ratio in analyzing all of the candidate alternatives; Alternatives I, II, III, and IV. The analysis was based on conservative point estimates or most likely values. In comparison to the other alternatives researched during the SatNav investment analysis, Table 4-1 clearly indicates that Alternative IV (BBN) is the most economically viable alternative and is referred to as the preferred alternative.

Table 4-1. Economic Summary of Alternatives

Most Likely	Net Present Value ($M)*	Benefit/Cost Ratio
Alternative I	280	1.5**
Alternative II	94	1.0**
Alternative III (MON)	1,857	2.1**
Alternative IV (BBN)	2,493	2.4

Range Estimates for the Alternative IV (BBN) (with and without PVT)

	NPV Range	NPV Conservative Estimate	B/C Range	B/C Conservative Estimate***
With PVT	1,995 - 4,245	2,469	2.1 - 3.3	2.4****
Without PVT	0 - 840	72	1.0- 1.5	1.1****

* NPV is the difference between benefits and costs, (discounted to present value)
** These alternatives have B/C ratio <1 if PVT is not counted.
*** The conservative estimate is the high-confidence 80/20 estimate.
**** See updated B/C ratio and NPV in Appendix C of this report.

Table 4-2 summarizes the ranges on the LCC and life cycle benefit (LCB) estimates for the preferred alternative (Alternative IV, BBN) both at high-confidence and most likely estimates.

Table 4-2. Economic Summary of the Preferred Alternative (Alternative IV, BBN)

	Reference Case		Alternative IV (BBN) with PVT		Alternative IV (BBN) without PVT	
OPTIONS	Range	High-Confidence	Range	High-Confidence	Range	High-Confidence
LCC (Present Value $M)	$5,420-$5,690	$5,590	$6,920-$7,630	$7,393	$6,920-$7,630	$7,393
Relative LCB (Present Value $M)	0	0	$3,790-$6,120	$4,349	$1,700-$2,680	$1,937
NPV ($M)	N/A	N/A	$1,995-$4,245	$2,469	$0-$840	$72
B/C Ratio	N/A	N/A	2.1-3.3	2.4	1.0-1.5	1.1
		Most Likely		**Most Likely**		**Most Likely**
LCC ($M)		$5,512		$7,335		$7,335
LCB ($M)		N/A		$4,316		$1,902
NPV ($M)		N/A		$2,493		$79
B/C		N/A		2.4		1.1

The formula used to calculate the B/C ratio is described below using discounted most likely costs and benefits:

$$LCB_{\text{Alternative}} \div (LCC_{\text{Alternative}} - LCC_{\text{Reference Case}})$$

*Alternative IV (BBN) with PVT: $4,316 / ($7,335-$5,512) = 2.4
*Alternative IV (BBN) without PVT: $1,902 / ($7,335-$5,512) = 1.1
*Essentially, the B/C ratio calculates the benefits of the alternative divided by the incremental costs of the alternative, measured against the Reference Case. By definition, the Reference Case benefits are zero.

The formula used to calculate NPV is described below, again using discounted most likely costs and benefits:

$$LCB_{\text{Alternative}} - (LCC_{\text{Alternative}} - LCC_{\text{Reference Case}})$$

*Alternative IV (BBN) with PVT: $4,316 – ($7,335 - $5,512) = $2,493
*Alternative IV (BBN) without PVT: $1,902 – ($7,335 - $5,512) = $79
*Refer to Table 4-2 above for summary of quantitative results.

4.2 Risk Adjustment

Crystal Ball, a risk analysis software tool, was used to develop high-confidence estimates on costs and benefits using a Monte Carlo simulation. Risk was embedded within the cost and benefit estimates through the use of ranges due to statistical distribution on specific parameters. Statistical forecasts were placed on total life cycle O&M costs, F&E costs, and LCBs for the preferred alternative (Alternative IV, BBN) and the reference case to generate high-confidence estimates. The resulting confidence intervals generated from the forecasts were additionally used, in a separate spreadsheet, in the form of uncertainty ranges to generate high-confidence estimates for the B/C ratio and NPV.

Numerical ranges were used in the estimate of LCCs and LCBs to adjust certain variable for risk. Crystal Ball uses a sensitivity analysis utility to produce tornado charts.

Due to the relative uncertainty about how users will equip for WAAS and LAAS, the IAT applied the following ranges per year around the assumed user avionics equipage rate (Table 4-3).

Table 4-3. WAAS and LAAS Equipage Rates (%)

Range\Year	2000	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15-20
Low	11	13	15	19	23	28	32	36	40	44	54	67	81	94	100	100
Most Likely	11	13	15	30	45	50	54	59	63	66	76	84	92	100	100	100
High	11	13	19	40	62	66	70	75	79	82	92	96	100	100	100	100

The user avionics equipage rate has the largest impact on the range of statistical confidence intervals for the LCC of Alternative IV (BBN). See Figures 4-1, 4-2, and 4-3 below.

On the cost estimate side, several variables in addition to user avionics equipage rate had high degrees of risk. Of these risk adjusted variables, the ones with the most significant effect on the forecast value for the total LCC of Alternative IV (BBN) were as follows:

- Annual satellite service acquisition costs associated with four geostationary satellites,
- GPS WAAS unit equipage cost for general aviation low-end,
- Approach Lighting System with Sequenced Flashing Lights (ALSF) technical refresh cost,
- New ALSF cost,
- Multi-mode Receiver (MMR) unit equipage cost for air carriers,
- Localizer cost, and
- VOR cost.

Figure 4-1 shows a graph of the main cost drivers of the model.

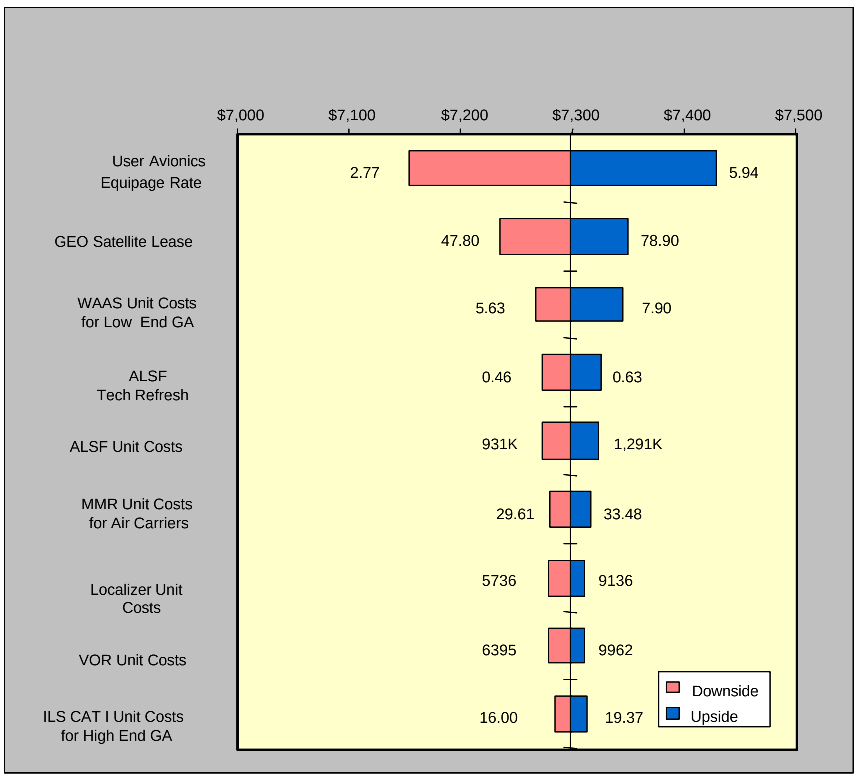

Figure 4-1. Alternative IV (BBN) Cost Drivers for Total Costs – PV

The cost team developed user costs by the categories of general aviation, air carriers, and regionals. User costs were estimated using an approach that applied an assumed avionics cost, by user class, to an estimated user avionics equipage rate by user class. As noted above, equipage rates for WAAS and LAAS was one of the main cost drivers.

Unit costs were developed from internal FAA knowledge, and vendor and user inputs for each class of users evaluated. Due to uncertainty on the actual costs for low-end general aviation to equip with WAAS, a range was applied to the unit equipage cost of a low of $5,000, a most likely of $6,000, and a high $9,000. This range was based on informal discussion with three manufacturers of the WAAS equipment for general aviation use.

Due to uncertainty on the unit equipage cost to air carriers for the MMR, a range was applied to the unit equipage cost of a low of $28,000, a most likely of $31,700, and a high of $35,000. This range was based on informal discussion with equipment manufacturers and air carriers.

In developing the costs for acquiring GEO satellite services, it was determined to use the value of $12M per year for the low cost, a most likely of $17M per year, and a high value of $25M per year. For the case of four geostationary satellites, it was assumed that a low of $42M, a most likely of $68M, and a high of $90M per year. This range represents that there would be some economies of scale in acquiring the services of four geostationary satellites and uncertainty over what the exact cost will be in the year 2008. Figure 4-1 shows that the satellite service acquisition cost of four geostationary satellites has the second largest impact on the range of statistical confidence intervals for the LCC of Alternative IV (BBN).

For the cost of technical refresh of the ALSF, a point estimate or most likely value of $540,000 was used with a range of $460,000-$700,000. These values were based on expert judgement from ARX-200, ILS Integrated Requirements Team (IRT).

The analysis of the benefits estimates showed several key drivers as well. Figures 4-2 and 4-3 below show the risk-adjusted variables with the most significant effect on total LCBs.

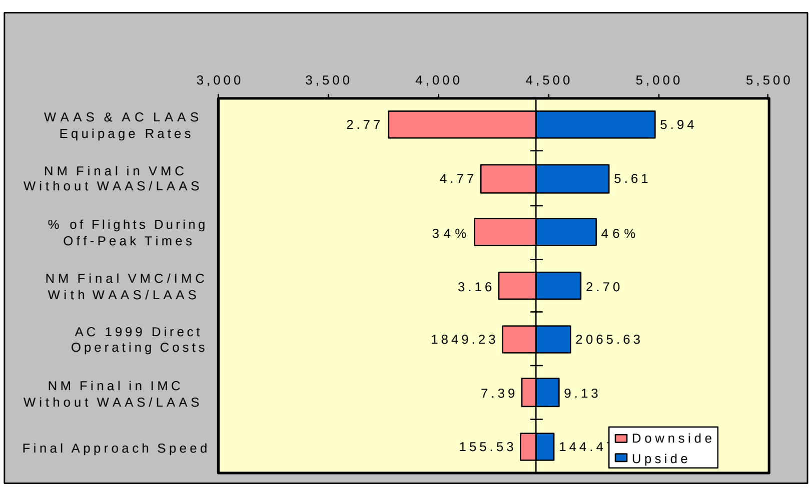

Figure 4-2. Alternative IV Benefits with PVT Tornado Chart

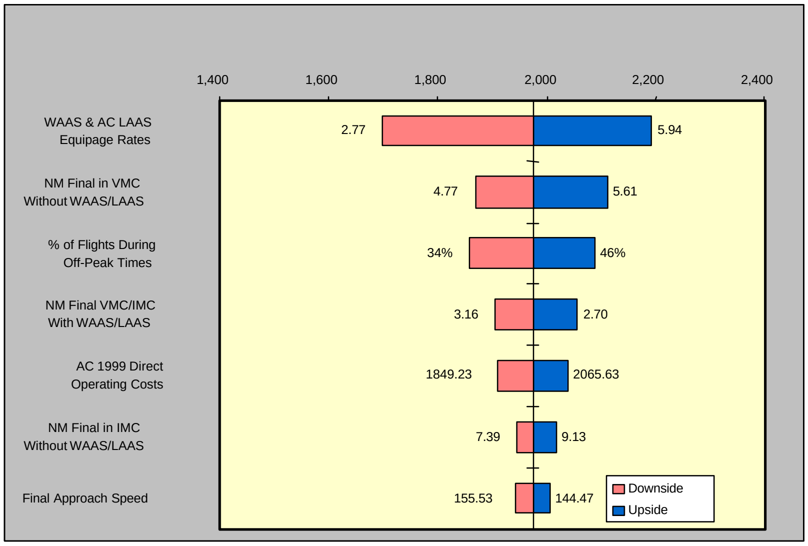

Figure 4-3. Alternative IV Benefits without PVT Tornado Chart

The variable having the second most significant effect on LCBs, after user avionics equipage rate for LAAS and WAAS, for Alternative IV (BBN) is the nautical miles (NM) in visual meteorological conditions (VMC) without WAAS or LAAS. A most likely value of 5 NM was used with a range of 4 NM to 6 NM to adjust for risk. This most likely value and range were also developed based on expert judgement from Air Traffic, Flight Standards, and Aircraft Certification.

4.3 Life Cycle Costs

LCC estimates for the alternatives represent the most likely costs for acquisition, transition, operation and maintenance, technical refresh, and disposition in then-year dollars. Alternative IV (BBN) is the preferred alternative. For comparison, the costs for an additional "variant", Alternative III (MON) is shown in Table 4-4 below. Attachment 1, BOE contains the specific details of the scope of the cost estimate, assumptions, and the basis of these estimates. The most likely costs shown below for the preferred alternative (Alternative IV, BBN) were risk adjusted later for inclusion in the Acquisition Program Baselines (APBs) for WAAS and LAAS.

Table 4-4 also shows F&E and O&M costs for WAAS, LAAS, lights, airport, ground-based NAVAIDs, and Loran-C. In addition, the table shows projected user costs under each alternative. Detail of how these costs, including user costs, were derived are shown in Attachment 1, BOE.

Table 4-4. Most Likely LCCs for the Alternatives (Then-Year $M)

	Ref. Case	Alt. I (v.0)	Alt. II (v.1)	Alt. III (MON)	Alt. IV (BBN)	Alt. IV (MON)
Total Costs	**$ 11,359**	**$ 12,795**	**$ 17,453**	**$ 15,716**	**$ 15,803**	**$ 15,912**
F&E	**$1,506**	**$2,223**	**$4,988**	**$4,216**	**$4,768**	**$4,793**
WAAs	$1	$1	$1,640	$1,766	$2,462	$2,462
LAAS	$0	$0	$1,649	$804	$690	$690
Lights	$282	$615	$598	$598	$598	$598
Airport			$272	$272	$272	$272
GBNA	$1,103	$1,488	$711	$657	$628	$654
Loran-C	$119	$119	$119	$119	$119	$119
O&M	**$3,994**	**$4,714**	**$4,290**	**$4,020**	**$3,776**	**$3,860**
WAAs	$0	$0	$590	$675	$700	$700
LAAS	$0	$0	$754	$284	$221	$220
Lights	$225	$332	$296	$296	$296	$296
GBNA	$3,521	$4,134	$2,403	$2,518	$2,311	$2,396
Loran-C	$248	$248	$248	$248	$248	$248
User Costs	**$5,859**	**$5,859**	**$8,174**	**$7,479**	**$7,259**	**$7,259**

The WAAS and LAAS F&E costs show the costs for establishing the systems and performing regular technical refresh, or service life extensions of the WAAS and LAAS programs. In addition, F&E covers the maintenance for the first two years of installation of the WAAS and LAAS hardware. The WAAS F&E also include satellite service acquisition costs. The O&M costs capture the annual recurring costs for site-level maintenance, depot logistics support, training, second-level engineering, and flight inspections.

The lights under F&E include the cost of acquiring additional CAT III lights (ALSF-2 and Runway Visual Range (RVR)) for the locations that will be upgraded to CAT III through LAAS or in the case of Alternative I (v.0), through ILS. The F&E costs also include the technical refresh cost of the existing and new ALSF-2 lights. The ongoing maintenance of lights is captured under O&M. Also, due to the addition of LAAS, are associated airport costs for touch down zone lighting (TDZL) and center line lighting (CLL). These airport costs are shown as part of F&E, but are not included as part of the total LAAS program costs.

Ground-based NAVAID (GBNA) costs are included to capture the F&E and O&M costs of the ground-based NAVAID system under each alternative. Under F&E, the ground-based NAVAID costs include the cost of technical refresh of the existing system and additional systems for Alternative I (v.0). Decommissioning costs are included where appropriate. Loran-C costs include the cost of continuing to operate Loran-C through the year 2008.

User costs include the costs to the general aviation, air carriers, and regionals for equipping new and retrofitting existing aircraft with avionics and annual maintenance to support each alternative.

Tables 4-5 and 4-6 summarize the LCC the preferred alternative (Alternative IV, BBN) by F&E and O&M in then-year dollars.

Table 4-5. SatNav Alternative IV (BBN) F&E LCCs

	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY10-FY20	Total
WAAS	111	114	135	136	165	155	157	90	110	106	1205	2484
LAAS	5	21	31	55	68	51	41	41	38	38	307	696
Lights	11	11	11	12	12	12	12	13	59	60	389	602
Airport	0	0	0	0	0	0	0	0	67	69	138	274
GBNAs	7	8	8	51	52	54	25	11	51	52	317	635
Loran C	12	13	13	13	13	14	14	14	15	0	0	120

Note: 1) SatNav Alternative IV (v.0), "High-Confidence" F&E Cost Estimates (Then-Year $M)

Table 4-6. SatNav Alternative IV (BBN) O&M LCCs

	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY10-FY20	Total
WAAS	1	2	10	19	23	25	32	33	37	39	484	705
LAAS	0	0	0	2	4	5	7	8	10	10	176	222
Lights	9	9	9	9	9	10	10	10	12	13	198	298
GBNAs	137	139	142	145	148	151	154	157	115	117	923	2327
Loran C	26	26	27	27	28	28	29	29	30	0	0	250

Note: 1) SatNav Alternative IV (v.0), "High-Confidence" O&M Cost Estimates (Then-Year $M)

Figures 4-4, 4-5, and 4-6 illustrate the F&E and O&M costs for each alternative. As the figures indicate, Alternative IV (BBN) offers cost savings in comparison to Alternative I and II.

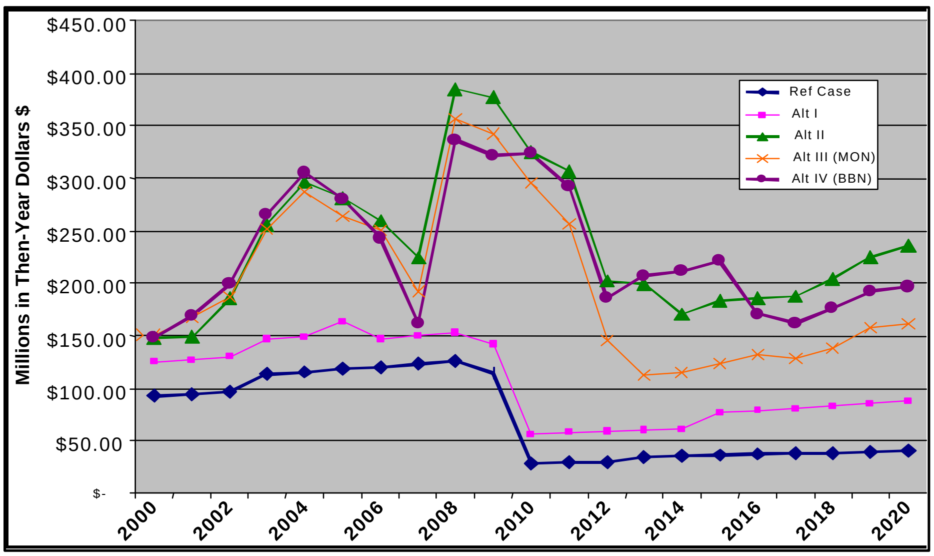

Figure 4-4. Comparison of F&E Most Likely Costs by Year

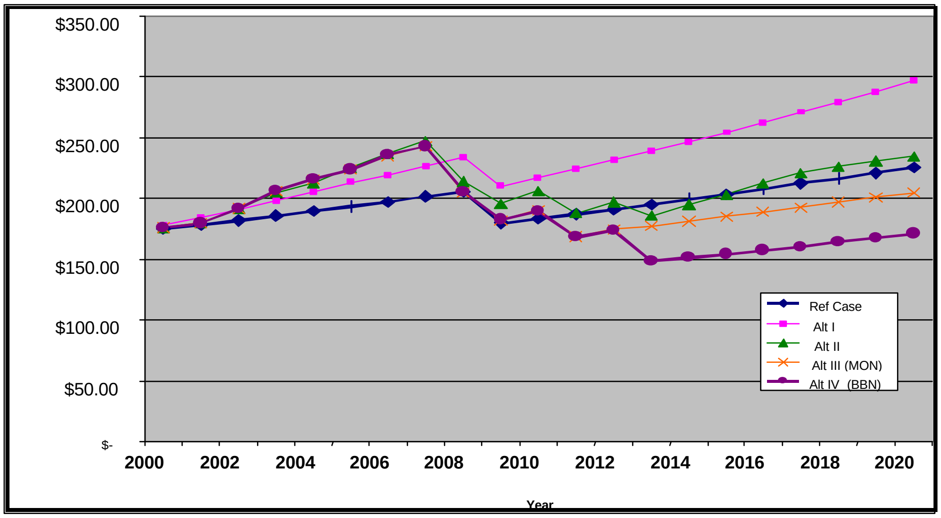

Figure 4-5. Comparison of O&M Most Likely Costs by Year

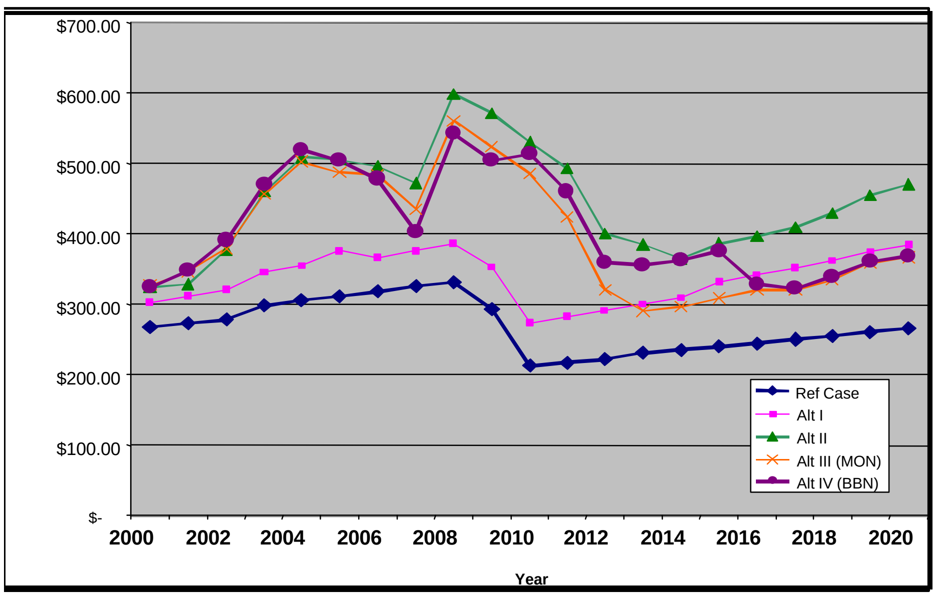

Figure 4-6. Comparison of F&E and O&M Most Likely Costs by Year

4.4 Life Cycle Benefits

4.4.1 Benefits

The benefits assessment was performed as part of the SatNav investment analysis conducted by the FAA. The purpose of the overall investment analysis is to identify the optimum navigation system configuration for the NAS. The FAA and the ICAO acknowledge that the aeronautical navigation system of the future will be based on the GNSS. The SatNav infrastructure in the NAS will rely on the GPS and its two augmentation systems - the WAAS and the LAAS. Aviation industry leaders recognize the potential of augmented SatNav for enhanced safety and operational capabilities, and are committed to a transition to space-based navigation. The NAS has begun incorporating SatNav capabilities to meet emerging user needs for increased system coverage and accuracy. As defined by the investment analysis, the 'optimum' navigation system is one that meets the FAA's intentions to:

- Provide enhanced safety through the provision of near-universal vertical approach guidance,
- Demonstrate continued world leadership by the U.S. for aeronautical development,
- Promote user acceptance,
- Provide user benefit as early as possible,
- Provide NAS Architecture compatibility,
- Spread FAA investment to promote affordability, and
- Provide the best NPV.

Tables 4-7 and 4-8 show the value of LCBs for the preferred alternative (Alternative IV, BBN) with and without PVT in then-year dollars. By DOT policy, all benefits are calculated assuming that time savings to passengers can be given a dollar benefit, i.e., PVT. The GAO requested, and the Agency agreed to show the sensitivity of our economic analysis if PVT was not counted as a benefit.

Table 4-7. SatNav Alternative IV (BBN) (with PVT) Life Cycle Benefits

	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10-20	Total
Total Program	$0	$0	$0	$70	$227	$299	$382	$427	$510	$577	$12,696	$15,188
Note: 1) SatNav Alternative IV (BBN) High-Confidence Benefits Estimate (Then-Year $M)												

Table 4-8. SatNav Alternative IV (BBN) (without PVT) Life Cycle Benefits

	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10-20	Total
Total Program	$0	$0	$0	$60	$123	$150	$182	$199	$231	$255	$5,324	$6,523
Note: 1) SatNav Alternative IV (BBN) High-Confidence Benefits Estimate (Then-Year $M)												

Figures 4-7 and 4-8 below illustrate the total benefits by alternative in present value terms on an annual basis.

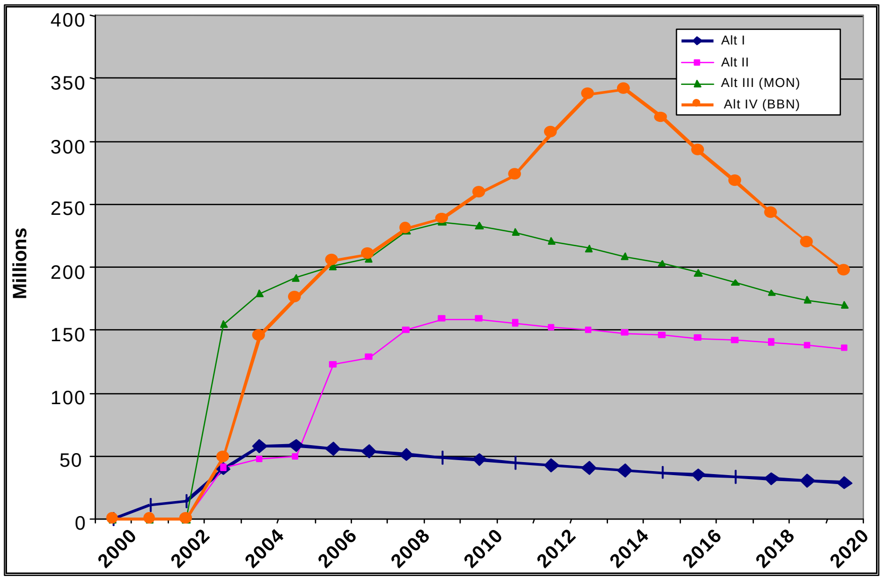

Figure 4-7. Annual Benefits by Alternative with PVT

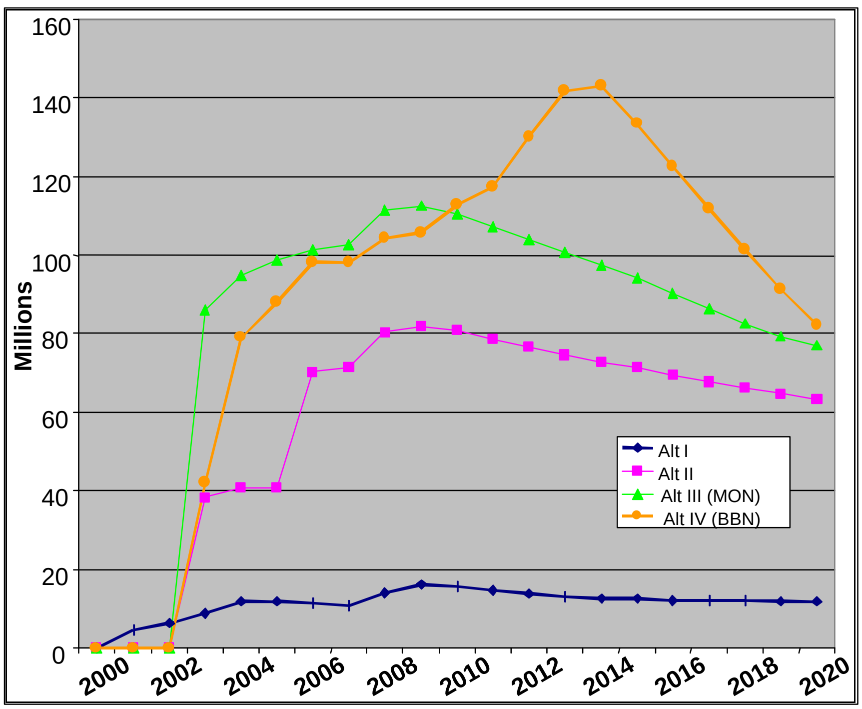

Figure 4-8. Annual Benefits by Alternative without PVT

The annual benefits of the preferred alternative, in present value, decline significantly after the year 2014. This is partially because the rise in constant dollar benefits due to traffic growth is more than offset by the decline due to the discount rate. A more significant factor is the in the treatment of en route area navigation (RNAV) benefits. RNAV benefits are greatly influenced by air carrier equipage rates with a suitable RNAV system. In the preferred alternative, air carriers are assumed to be fully equipped with WAAS by the time ground-based NAVAIDs are reduced to the BBN. In the reference case, RNAV equipage grows more slowly as aging aircraft are replaced, but continues to grow throughout the period of the analysis. In the later years, the difference in RNAV equipage between the alternative and the reference case decreases. Since benefits are always expressed as changes from a reference condition, the en route benefits of the preferred alternative decrease.

4.4.2 Benefits Assessment Approach

The objective of the benefits assessment is to determine the impacts of the WAAS and LAAS augmentation systems. To accomplish this, the assessment first identifies relevant characteristics of an augmented space-based system, then determines the operational effects that result from those system characteristics. The major effects that result from augmented SatNav operations are illustrated by the following general examples:

- An increased number of instrument approaches extends all-weather service to a greater number of cities and reduces traffic complexity resulting from back-course approaches, circle-to-land operations, etc.
- Lower landing minimum improves on-time performance by reducing the frequency of flight disruptions (e.g., missed approaches, diversions, delays, and cancellations).
- More approaches with vertical guidance improve safety by reducing the risk of CFIT.
- Improved surveillance using SatNav-based ADS-B and cockpit display of traffic information (CDTI) improves traffic efficiency and reduces the risk of collision.
- Increased navigation accuracy and flexibility improve traffic efficiency by facilitating more effective NAS configurations and optimized fuel/time navigation solutions.
- Reduced infrastructure cost occurs as many surface NAVAIDs are decommissioned in favor of space-based systems.

As illustrated by these examples, SatNav generates a wide range of aviation benefits in the general categories of: 1) increased operational effectiveness, 2) increased safety, and 3) reduced cost. In addition, the assessment addresses a fourth category consisting of non-aviation benefits. All benefits within these four categories were assessed qualitatively. Many of the benefits were also assessed quantitatively to determine their economic impact. To accurately assess the impact of SatNav augmentation systems, benefits are classified as either ‘incremental,’ or ‘strategic.’ Incremental benefits can be implemented by GPS augmentation without need for major enabling technologies. Strategic benefits require enabling technologies. Figure 4-9 below depicts the categorization of benefits. Those that are denoted with a ‘$’ symbol are incremental benefits that were evaluated quantitatively. Benefits that are not so denoted are either non-quantifiable incremental benefits or strategic benefits, which are discussed qualitatively. Figure 4-9 also indicates the various technical dependencies of specific benefits.

■ = Non-Quantified Benefit
$ = Quantified Benefit

	Incremental	Strategic	Incremental Requirements				Strategic Dependencies		
			WAAS /LAAS	Moving Map	Terrain DB	Mass Equipage	ADS-B	CDTI	NAS DSSs
INCREASED OPERATIONAL EFFECTIVENESS									
Increased number of IFR landing facilities.	■		●						
Expanded air services.	■		●						
Reduced number of flight disruptions.	$		●						
More effective airport configurations.	■		●			●			
Improved surface surveillance.		■	●			●	●		●
Improved surface navigation.	■		●	●					
Improved terminal procedures.	$		●			●			
Improved low-altitude surveillance.		■	●			●	●		
Increased availability of RNAV routings.	$		●			●			
Increased usage of airborne self-separation.		■	●			●	●	●	
Optimized controller tasking.		■	●			●	●		●
INCREASED SAFETY									
Improved surface surveillance.		■	●			●	●		●
Improved surface navigation.	$		●	●					
Improved airborne collision avoidance.		■	●			●	●	●	
Reduced risk of CFIT on approach.	$		●		●				
Reduced risk of CFIT en route.	■		●		●				
REDUCED COSTS									
Reduced GBNA costs.	$		●			●			
NON-AVIATION BENEFITS	■$		●						

Figure 4-9. Incremental Benefits, Strategic Benefits, and Technical Dependencies

Reduced Delays due to Reduced Minimums: Many airports suffer delay because of the need to discontinue visual approaches to secondary runways when weather drops below minimums caused by local obstructions. At many highly delayed airports these minimums are well above basic IFR, typically a 2,500-5,000-foot ceiling and five miles or greater visibility. If the greater navigation precision of WAAS/LAAS can be used to reduce the radar-based obstacle clearance requirements, then the higher capacity visual approaches can be continued longer. At some airports the percentage of time between these minimums and basic IFR is 15% or more of the time. Alaskan Airways is using required navigation performance (RNP) procedures at several Alaskan airports to reduce minimums caused by obstructions dramatically. This is the kind of benefit that should be achievable at airports with obstruction-limited visual approaches.

Establishment of Approaches to Closely Spaced Parallels: The RTCA Minimum Aviation System Performance Standard (MASPS) for ADS-B indicated that approaches to runways spaced as closely as 1,500 feet could be supported with blunder rates comparable to today's 3,400-foot spacing, using Precision Runway Monitor (PRM). The benefit of reduced delays at a number of highly congested airports from this technology could be significant.

Establishment of Temporary Approaches: Airports often need temporary approaches to replace approaches lost to construction projects. A good current example is Memphis, which is contemplating using a taxiway as a runway during a major runway rehabilitation program. The FAA has no ILSs available for temporary use, yet WAAS/LAAS could provide the capability with no ground NAVAID required. In the case of Memphis, because of FedEx's strong interest, an ILS may be found. However, often times the airport simply loses the approach capability, or suffers with higher minimums and delays during the construction period.

Multiple Glide Slopes: Lufthansa, at Frankfurt airport, is developing a system of dual thresholds to reduce final approach spacing caused by wake vortex separation requirements. The basic technique involves creating a second glide slope, either on the same runway or on a closely spaced parallel, with a displaced threshold and higher glide path to allow lighter aircraft to stay above the vortices generated by heavies. Wake Vortex separations have reduced capacity and increased delay at many U.S. airports. WAAS/LAAS would allow the establishment of such secondary glide slopes and permit safe reduction in final approach spacing.

Surface Surveillance/Runway Incursions: Improved surface navigation may minimize the need to widen taxiway fillets for long-wheelbase aircraft like the 777-300, A340-500, and A3-XXX. Under current airport design standards, substantial sums will need to be spent to widen pavements, when a precisely navigated oversteer maneuver would assure adequate clearance.

4.4.3 Quantification of Benefits

Six areas of benefits were quantified for this analysis: avoided approach disruptions, terminal shortened paths, en route, precision approach safety, surface safety, and non-aviation cost savings. Two other areas, O&M cost savings and avionics cost savings, were examined and found to be less than their respective incremental costs; the net cost differences were included in total costs rather than benefits. Basis of estimates are described below.

Avoided approach disruptions: These were divided into two areas, avoided disruptions due to CAT II/III (LAAS) capabilities and avoided disruptions due to CAT I (WAAS or LAAS) capabilities.

In the first area, traffic projections and climatology data were obtained for each airport projected to receive CAT III LAAS. Differences in minimums between current and projected approaches were compared to climatology data to determine the percent of time that disruptions would be avoided. That figure was multiplied by projected traffic. The result was the approximate number of approaches per year that would be flown in weather below current minimums but at or above future minimums. Installation schedule by airport and projected equipage rates were factored in to calculate number of approaches per year that would benefit from LAAS (avoided disruptions). The Office of Aviation Policy and Plans (APO) establishment criteria for precision approaches, along with updated critical values were used to determine the average benefit per avoided disruption.

The second area (CAT I) was calculated in much the same way as the first. National average climatology figures were used, with an estimated decrease in minimums from a 600-foot ceiling and 1 1/4 mile visibility (based on average non-precision minimums in the NAS) to a 200-foot ceiling and 3/4 mile visibility. The number of non-ILS airports with certified WAAS approaches was assumed to grow from 18 in the year 2003 to 1,295 in the year 2009.

Terminal shortened paths: Equipage with WAAS or LAAS will enable aircraft to turn to final approach course with three-dimensional course guidance, thereby needing a shorter distance on final approach course.

This benefit will be realized by those aircraft not approaching the runway on extended final, and will be available only when there is not an arrival queue delaying final approach.

Terminal shortened path benefit assumptions are:

- (flights per year) * (direct operating costs per hour) * (NM saved per trip) / (NM per hour) * (percent of aircraft equipped with WAAS or LAAS) * (percent of flights potentially affected)
- Flights per year based on FAA forecast
- Direct operating costs based on APO critical values (reduced 10% for late-flight fuel flow)
- NM saved per trip: Assume 7.5 NM final approach distance in instrument meteorological conditions (IMC) (12%) and 5 NM final approach distance in visual meteorological conditions (VMC) (88%) without WAAS/LAAS; 3 NM final approach distance (IMC/VMC) with WAAS or LAAS; save twice the difference for flights entering terminal area from opposite direction of runway heading
- NM per hour: 150
- Average distance saved with WAAS/LAAS is 4.7 miles.
- Percent of aircraft equipped with WAAS: see Attachment 1, BOE

En Route: Based on an FAA multi-center study, an estimated 0.74% flight time savings can be achieved by aircraft flying GPS-based point-to-point routes rather than VOR-based airways.

En route RNAV route benefit assumptions are:

- (Percent benefit) * (flights per year) * (direct operating costs per hour) * (NM per trip) / (NM per hour) * (percent availability of RNAV routes) * (percent of aircraft equipped for RNAV) * (availability of RNAV equipment)
- Benefit of GPS augmentation is the difference between benefit for a given alternative and benefit for the reference case
- Percent benefits = 0.74%, based on multi-center study
- Flights per year based on FAA forecast
- Direct operating costs based on APO critical values
- NM per trip based on FAA forecast
- NM per hour based on FAA forecast
- RNAV route availability = based on two-year-prior equipage rate (see Attachment 1, BOE)
- RNAV equipage rate = 50% (for inertial navigation system (INS) RNAV) plus 50% of GPS/WAAS equipage rate (see Attachment 1, BOE)
- Availability = 99.9% for INS RNAV and GPS/RAIM, 99.999% for WAAS

Precision Approach Safety: One of the FAA's goals is to enhance system safety through the increased availability of continuous vertical guidance during instrument approaches. Augmented GPS makes achievement of that goal feasible. Of today's 2,500 IFR airports, only about 1/4 are equipped with precision approaches. But with access to a ground-based augmentation station, precision approaches to at least CAT I minimums become feasible at virtually any U.S. location.

A study of CFIT accidents conducted by Allied Signal Corporation revealed that over 75% of these accidents between 1975 and 1995 occurred during NPAs. Other studies of National Transportation Safety Board accident reports have reached less certain conclusions. Because of the small number of accidents involving CFIT during the approach phase of flight, accurate quantification of these safety benefits is difficult.

Benefits were calculated using the basic methodology described in APO establishment criteria for precision approaches. Safety benefits of precision approached are estimated by comparing the incidence and resulting costs of NPA accidents with the same for precision approach accidents to estimate a differential cost per approach. This differential is then multiplied by the number of annual precision approaches enabled by GPS augmentation to complete the safety benefit for a given year. This is done for the different aircraft classes: general aviation, air carrier, and regionals. Accident costs are measured by the frequency and resulting costs of fatalities, injuries (serious and minor) and aircraft damage or destruction.

Aircraft accidents were evaluated by three different groups over a similar time period, and results were significantly different. Probability distributions were used to incorporate all three studies into the analysis.

Surface Safety: Surface accidents over a 14-year period (1985-1998) were evaluated for cause to determine which may have been prevented by augmented GPS without such additional improvements as ADS-B. Only two accidents fit the criteria of being caused by lack of situational awareness on the airport surface by the pilot. The cost of those accidents was estimated (as above) and amortized into an annual accident cost based on traffic figures during the period evaluated. WAAS/LAAS equipage rates and traffic projections were used to estimate the benefits of avoided surface accidents.

Non-Aviation Cost Savings: Benefits in this area were based on projected use of augmented GPS for precision agriculture. The benefits were based only on avoided costs of other GPS augmentation systems, and not on direct benefits such as added productivity or reduced runoff of pollutants. Other areas, such as maritime or land transportation, were not estimated.

4.4.4 Comparison of Benefits

Comparisons of benefits from the January 1998 IAR to the September 1999 IAR are shown in Table 4-9 below.

Table 4-9. Comparison of 1998 and 1999 Benefits

January 1998 *	September 1999 *	Explanation of Benefits
Reduced Flight Disruptions $648M + $806M	$2,938M	1998 assumed a 400-foot ceiling and a one-mile visibility for non-precision minimums; 1999 used a calculated average of non-precision minimums: 600-foot ceiling and 1-1/4 mile visibility.
Reduced Accidents $1,367M	$79M	1998 used older accident statistics; newer statistics showed little evidence for quantified safety benefits on approach. 1999 added benefits of improved surface navigation.
Fewer Avionics Required $612M	0	Lengthened transition period and retention of BBN caused users to retain ground-based avionics longer; total avionics costs are not reduced.
Reduced Fuel Usage Due to Lighter Avionics $30M	0	As above. Total avionics weight is not reduced.
Reduced En Route Flight Times $4,886M	$2,269M	1998 assumed en route benefits could be achieved only with WAAS, while 1999 assumed any suitable RNAV system could reduce en route times. Benefits achieved by more rapid equipage with WAAS.
FAA Benefits $1,414M	0	Lengthened transition period and retention of BBN increase FAA costs; total O&M costs are not reduced.
	Terminal Short Paths $4,357M	Significant terminal benefits achievable with WAAS or LAAS; 1998 assumed they could be achieved with just GPS, but availability and integrity are too low.
	Non-Aviation Cost Savings $803M	Conservative estimate of savings (reduced equipment costs) to the precision agriculture community; this benefit was not considered in the 1998 analysis.
Total Benefits $9.8B (constant 97$)	Total Benefits $10.4B (constant 99$)	$9.8B in constant 1997 dollars is equal to about $10.2B in constant 1999 dollars.
Note: The benefits in this investment analysis combine WAAS and LAAS benefits. * The 1998 investment analysis calculated benefits separately.		

4.5 Return on Investment

Figure 4-10 depicts the cumulative return on the FAA's investment offered by Alternative IV (BBN) in comparison to Alternatives I, II, and III (MON), all of which were researched in the investment analysis process. As the figure indicates, Alternative IV (BBN) starts to slope upward in the year 2006 with a positive cumulative return on investment reached in the year 2008. From the year 2008 to the end of the life cycle, the slope of the curve increases dramatically indicating cumulative quantifiable benefits far exceeding cumulative costs. In comparison, Alternative I achieves a positive return on investment in the 2005 timeframe, but does not offer the same degree of quantifiable benefits in relation to its cost over the life cycle of the alternative which is shown by the comparatively flat slope of its curve.

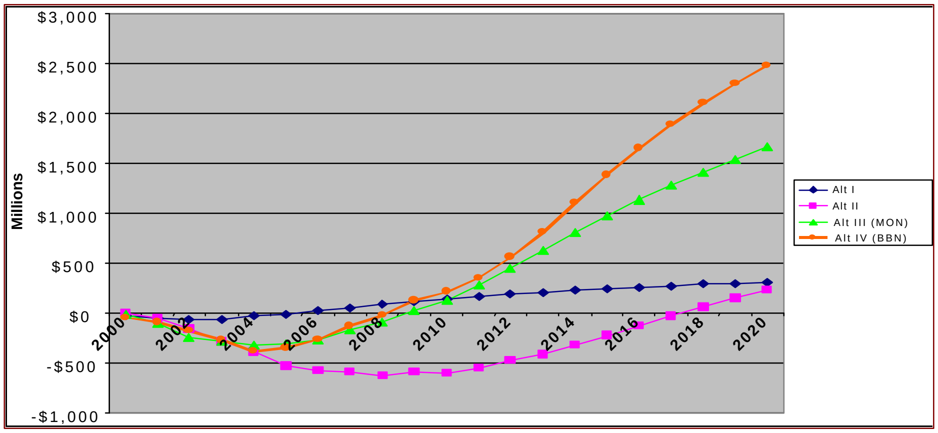

Figure 4-10. Return on Investment with PVT

Figure 4-11 below indicates that without the additional variable, PVT, affecting the analysis, Alternative IV (BBN) is the only candidate alternative to achieve a positive return on investment. Alternative IV (BBN) begins to realize an increasing return on the FAA's investment in the 2011 timeframe, sloping upward rapidly and finally realizing a positive return on investment in the 2018 timeframe. In comparison, Alternative I never realizes an increasing return on investment, actually sloping downward indicating that without PVT, the LCC required to implement the alternative is greater than the potential benefits. Alternatives II and III do slope upward beginning the 2011 timeframe, but do not realize a positive return on investment because the cumulative LCBs do not exceed the cumulative LCCs.

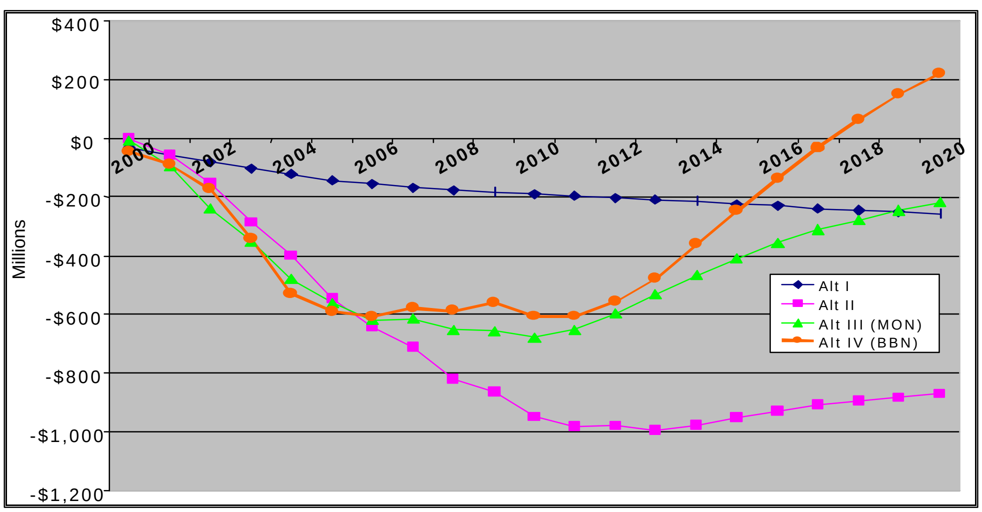

Figure 4-11. Return on Investment without PVT

4.6 Cost Estimates for the Recommended Alternative

Tables 4-10 and 4-11 are the identical cost baselines shown in the respective WAAS and LAAS Program Office APBs. These tables do not reflect the estimated cost of acquiring, installing, and maintaining lights nor do they reflect the costs of maintaining and decommissioning ground-based

NAVAIDs. These costs were, however, included in the overall economic analysis (Tables 4-1 and 4-2) and are shown in Table 4-4, which reflects all program costs, including user costs. Attachment 1, Basis of Estimates contains specific details of these costs.

The IAT, in coordination with AND-700, agreed to calculate benefits and costs for the SatNav investment analysis based on no new MALSRs. A MALSR is used in conjunction with a Category I precision approach for which minimum visibility is one-half mile. Without MALSR, minimum Category I visibility is increased by one-quarter mile. Economic justification for installation of new MALSRs was outside the scope of the SatNav IA.

An ALSF-2 is used in conjunction with a Category II or III precision approach. Costs of ALSF-2 lights for all new Category II/III runways were included in the SatNav economic analysis, but they were not included in the LAAS acquisition program baseline because these costs are not part of the LAAS program budget.

4.6.1 WAAS APB Costs

Table 4-10 shows the cost estimates by major categories for the recommended alternative. The WAAS APB document defines the major categories in more detail. These categories are consistent with the January 1998 WAAS APB.

Table 4-10. WAAS Costs

(Then-year $M)														
Cost Element	PRIOR	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010-20*	TOTAL 2000-20
WAAS Facilities and Equipment (F&E)														
Total F&E Costs	$ 406.4	$ 87.7	$111.0	$113.9	$135.4	$136.0	$165.1	$155.3	$157.4	$89.6	$109.6	$106.0	$1,204.6	$2,483.9
WAAS Operations & Maintenance (O&M)	0.0	0.0	0.9	0.9	10.4	18.6	22.5	25.5	32.2	33.3	36.5	38.7	484.5	$ 703.8
WAAS Life Cycle Costs	$ 406.4	$ 87.7	$111.9	$114.8	$145.8	$154.5	$187.6	$180.8	$189.5	$122.9	$146.1	$144.7	$1,689.0	$3,187.6
Note: The LCC is from FY00-20 compared to previous APB LCC FY98-16.														

*Sunk costs (FY99 and prior) are not included in this cost baseline compared to the 1/98 APB that did include the sunk costs in the total.

4.6.2 LAAS APB Costs

The cost estimates reflected in Table 4-11 shows the costs by major categories for the recommended alternative. The LAAS APB document defines the major categories in more detail. These categories are consistent with the January 1998 LAAS APB.

Table 4-11. LAAS Costs

(Then-year $M)															
Cost Element		Prior Years	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10-20*	Cost FY00-20
Research	R&D	2.7												0.0	**0.0**
Facilities & Engineering	F&E	12.5	11.2	4.8	20.8	31.4	55.4	68.0	50.6	41.5	40.9	38.1	38.0	306.6	**696.1**
Ops & Maintenance	O&M			0.0	0.0	0.0	2.2	3.7	5.3	6.9	8.2	9.6	10.0	176.2	**222.0**
Total Program Cost		15.2	11.2	4.8	20.8	31.4	57.6	71.7	55.9	48.4	49.1	47.6	48.0	482.8	**918.1**
***Note: The LCC is from FY00-20 compared to previous LCC FY98-21**															

Table 4-12 shows that from 1999-2016, there has been very little cost growth between the September 1998 study and this analysis. The overall cost growth in the new APB is primarily due to an increased IA life cycle through year 2020. In addition, LAAS CAT I capability is accelerated by two years to integrate better with WAAS CAT I deployment.

Table 4-12. Comparison with January 1998 SatNav Investment Analysis

WAAS	Prior	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total 1999-16	Total Prior-16	Total Prior-20
1999 IA																										
F&E	406	88	111	114	135	136	165	155	157	90	110	106	108	107	96	115	105	110	111	103	113	118	119	2,119	2,525	2,978
O&M	-	-	1	1	10	19	23	25	32	33	37	39	40	40	41	42	43	44	45	46	47	48	49	515	515	704
Total	406	88	112	115	146	155	188	181	190	123	146	145	148	148	137	157	148	154	156	148	159	166	168	2,634	3,040	3,682
1998 IA																										
F&E	406	138	136	124	39	10	10	10	35	31	-	-	-	34	35	-	-	-	-	-	-	-	-	600	1,007	1,007
O&M	-	33	36	41	121	122	125	126	129	127	121	122	124	128	130	134	137	140	147	-	-	-	-	2,043	2,043	2,043
Total	406	170	173	164	160	132	135	136	164	158	121	122	124	162	165	134	137	140	147	-	-	-	-	2,643	3,049	3,049
Difference																										
F&E	0	(50)	(25)	(10)	97	126	155	145	123	59	110	106	108	73	61	115	105	110	111	103	113	118	119	1,519	1,519	1,971
O&M	0	(33)	(35)	(40)	(111)	(103)	(102)	(101)	(97)	(94)	(85)	(83)	(84)	(87)	(89)	(92)	(94)	(96)	(102)	46	47	48	49	(1,528)	(1,528)	(1,339)
Total	0	(83)	(61)	(49)	(14)	22	53	45	26	(35)	25	23	24	(14)	(28)	23	12	14	9	148	159	166	168	(9)	(9)	633

LAAS	Prior	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total 1999-16	Total Prior-16	Total Prior-20
1999 IA																										
F&E	13	11	5	21	31	55	68	51	41	41	38	38	37	19	20	20	22	24	30	31	33	35	37	572	585	720
O&M	-	-	-	-	-	2	4	5	7	8	10	10	12	14	16	16	16	16	17	17	17	18	18	153	153	224
Total	13	11	5	21	31	58	72	56	48	49	48	48	49	33	36	36	38	40	47	48	50	52	55	726	738	943
1998 IA																										
F&E	7	7	4	7	7	82	85	91	88	1	1	10	10	10	11	11	11	12	12	12	13	13	13	459	466	516
O&M	-	-	-	-	0	0	3	7	10	14	16	16	17	17	18	18	18	19	19	20	20	21	21	192	192	274
Total	7	7	4	7	7	82	89	97	99	14	16	26	27	28	28	29	30	30	31	32	33	34	34	651	658	791
Difference																										
F&E	6	5	1	14	24	(27)	(17)	(40)	(47)	40	38	28	27	8	9	9	11	12	18	19	20	22	23	113	119	203
O&M	0	0	0	0	(0)	2	0	(1)	(3)	(6)	(6)	(6)	(5)	(3)	(1)	(2)	(2)	(3)	(3)	(3)	(3)	(3)	(3)	(39)	(39)	(51)
Total	6	5	1	14	24	(25)	(17)	(41)	(50)	35	31	22	22	5	8	7	8	10	16	16	17	18	21	74	80	153

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5.0 RISK ANALYSIS

A risk assessment of all 12 alternatives was conducted in support of this SatNav investment analysis. Additionally, the new "phased alternative" combining Alternatives III and IV was added and assessed after it was developed. This assessment was accomplished primarily to provide a quantitative, numerical risk rating to be used in evaluating the overall attractiveness of the alternatives, since risk is one of the four criteria to be evaluated. Additionally, the risk assessment identified the greatest risk areas, which in turn were used to adjust the most likely cost and benefit estimates to an 80% confidence level. Finally, the risk assessment provided an initial basis for developing a Risk Management Plan for the preferred alternative (contained in the final part of this section), which includes an identification of the major risks flowing from implementing the preferred alternative, together with mitigation strategies that can eliminate or reduce the impact associated with those risks.

5.1 Methodology

A risk analysis team was formed from members of the IAT who were independent of the sponsor, the IPT, and the alternatives analysis team. This independent approach was intended to ensure objectivity and to create a fresh perspective on risk. However, the team relied on the sponsor, IPT, and the alternatives analysis team for most of the input documents and for their expert opinions on risk.

The group used the basic six-step methodology developed by the Volpe National Transportation System Center (VNTSC) and documented in its report, *Risk Assessment Guidelines for the Investment Analysis Process, July 1997: Report No. WP-59-FA7N1-97-2.*

These steps first involve the identification of potential risks that may occur throughout the entire life cycle of each alternative in 10 different facets (e.g., technical risk, operability risk). Each risk is then assessed as to its probability of an adverse occurrence, and the severity of the impact if the adverse event actually does occur. Next, the overall risk rating of the alternative is calculated through a weighting and summing process. Lastly, the risks are compared among the alternatives. The basic purposes are to identify any alternatives that appear too risky to be implemented; to develop risk scores that can be incorporated into an overall scoring algorithm for evaluating the alternatives; and to signal the places where risk mitigation should be applied (i.e., those facets of the alternatives where risk probability and impact are relatively substantial).

In doing the risk assessment, the risk team initially developed risk assessments for all individual navigation systems (e.g., WAAS, VOR/DME) before examining the risks of the alternatives, which are composed of different mixes of systems. Using these individual system assessments as their basic input, the risk team next developed risk assessments of the two polar opposite Alternatives I and IV. Alternative I is essentially the "business as usual" alternative, with no transition to augmented GPS satellite-based navigation (i.e., no WAAS or LAAS). Alternative IV is the "robust WAAS" option, with phase-down of all existing ground-based systems to a BBN as soon as practicable. The new phased alternative essentially is an adaptation of Alternative IV, which builds in checkpoints to assess the degree to which risk has been mitigated before proceeding beyond Alternative III and going fully to completion. Within Alternatives I and IV, the team then developed the sub-alternatives' scores as sensitivity departures from the basic alternative (e.g., what happens to risk scores within Alternative I if LAAS is substituted for ILS?). Similarly, Alternative II scores were derived as sensitivity departures from Alternative I, and Alternative III scores as sensitivity departures from Alternative IV. This approach enabled the risk team to make credible, realistic comparisons of relative risk between alternatives quickly and easily.

5.2 Risk Facet Weighting

The risk team developed its weighting of the risk facets through a three-step process: 1) rank-order the facets in accordance with their perceived importance to the SatNav investment decision; 2) weight each facet through a pair-wise comparison to capture relative importance more precisely, and 3) normalize the weights so that each risk facet has an appropriate relative percentage of the total weighted risk score.

The risk team concluded that operability risk, technical risk, and stakeholder risks were the most important facets, cumulating to about half of the total risk score. In particular, operability risk captures the risks that the delivered product will not meet the clientele's important mission needs or, worse, may have inherent safety, human factors or other major flaws that severely compromise its mission performance. Operability was judged the most important risk facet. Supportability risk, producibility risk, cost estimate risk, and benefits estimate risks were considered to be relatively less important facets. Supportability and producibility were deemed relatively less important mostly because all alternatives envision use of Commercial-Off-the-Shelf (COTS)-based components, which should have inherently minimal supportability and producibility risks. Cost and benefits estimates risks were weighted low for a different reason. Although important, a high cost and/or benefits estimate risk rating would tend to "double count" these risks and unfairly penalize certain alternatives in the investment analysis selection. That is, since 80% confidence level cost and benefits baselines already were being used to compensate for risk and uncertainty in the computation of NPV for the return on investment decision criterion, it would be unfair also to penalize riskier cost and benefit estimates again in the risk scores. Funding risk, schedule risk, and management risk were deemed of medium importance. All are more important than the risks just discussed, but they are still a notch below the top-ranked facets of operability, technical, and stakeholder risk.

Table 5-1 below summarizes the risk facet weights that were developed and used by the risk team.

Table 5-1. Risk Facet Weightings

Risk Facet	Rank	Weight	Cumulative Weight	Normalized Weight
Operability	1	10	10	0.20
Technical	2	8	18	0.16
Stakeholder	3	8	26	0.16
Funding	4	6	32	0.12
Schedule	5	6	38	0.12
Management	6	4	42	0.10
Supportability	7	2	44	0.04
Producibility	8	2	46	0.04
Cost Estimate	9	2	48	0.04
Benefits Estimate	10	2	50	0.04
				1.00

5.3 Summary of Risk Assessment

Table 5-2 on the following page shows the results of the risk assessment for all 12 alternatives and the phased alternative under consideration by the investment analysis team. Both total numerical risk scores and stoplight assessments of individual risk facets are shown. A detailed discussion of the table follows in the next section. However, the table may be summarized as follows:

- Risk is not a significant discriminator in choosing among alternatives, i.e., there is no compelling case for selection or elimination of alternatives solely on the basis of their risk scores. The alternatives are all "moderate risk" with middle-of-the-road scores ranging from 3.3 (lowest) to 5.7 (highest).
- Generally, Alternatives I and II are riskiest in the operability and stakeholder risk facet areas. Simply stated, these status-quo alternatives will tend to preserve the existing ground-based systems (i.e., VOR-DME, ILS) indefinitely as the core aviation navigation infrastructure, and deny to airspace users the safety, capacity, and efficiency benefits that they hope to derive from a widespread transition to GPS-based SatNav. These alternatives will impose significant inefficiency problems in the future for the U.S. air transportation system. Moreover, they will require air carriers to maintain multiple navigation avionics indefinitely. On the other hand, Alternatives I and II have low technical, schedule, and funding risks. Overall, Alternative II (v. 2) is the lowest risk alternative.
- Generally, Alternatives III and IV are riskiest in the schedule and funding risk facet areas. These alternatives have comparable total risk scores to those of Alternatives I and II. Schedule risks are dominated by the risks associated with WAAS software development and system safety certification, with lesser but significant risk in the LAAS CAT I and CAT III delivery schedules because of the LAAS OTA schedule uncertainty contractual approach. Funding risk is very significant because WAAS/LAAS development, deployment, and operations will impose high marginal F&E and operations funding needs in a time of very tight FAA budgets, while offering relatively little offsetting reductions to the FAA through decommissioning of some existing ground-based NAVAIDs. In fact, funding risk is worsened by the strong possibility that the FAA will not be permitted to decommission many of the VOR/DME and ILS systems, as a consequence of probable pressure from user groups (particularly general aviation) for their continued sustainment. Moreover, Congress has been

very critical of the WAAS program, and has cut LAAS funding in the FY2000 budget. Technical risk is deemed moderate. On the other hand, Stakeholder support is highest for these alternatives, and these alternatives have the least operability risk. Generally, the airspace users say they are very anxious for a transition to SatNav.

- The phased alternative reduces the schedule and operability risk associated with the baseline Alternative IV, as well as its benefits estimate risk. Essentially, stretching the time to go to full robust WAAS and adding checkpoints lower the overall risk significantly, placing the phased alternative as the second best (slightly behind Alternative II (v.2)) in terms of total risk score. Moreover, LAAS schedule risk is reduced by conversion from a GIP to an FAA-funded development contract. However, funding risk increases because of the accelerated development and deployment of LAAS. Assuming its funding risk problem can be overcome (the only high-risk area), this alternative looks attractive from a risk standpoint.

Table 5-2. Risk Summary for 12 Alternatives and New Phased Alternative

	No WAAS or LAAS		NPA WAAS, no LAAS, MO			WAAS w/Vertical			Full Capability WAAS				Phased
	Cx Satr	750 LAA	No LAAS	+750 LA	+Loran	MON	BBN	&Loran	BBN	Loran	RFI	No Bkup	Alternative
Risk Facet (Wt)	**I v. 0**	**I v. 1**	**II v. 0**	**II v. 1**	**II v. 2**	**III v.0**	**III v. 1**	**III v. 2**	**IV v. 0**	**IV v. 1**	**IV v. 2**	**IV v.3**	**III-IV**
Operability (10)	10	10	8	8	8	2	5	2	2	2	2	5	0
Stakeholder (8)	10	10	8	8	5	5	10	5	2	0	2	2	2
Technical (8)	2	5	2	5	2	5	5	5	5	5	5	5	5
Schedule (6)	0	5	0	5	0	5	5	5	8	8	8	8	5
Funding (6)	0	2	2	5	5	8	5	10	8	10	5	5	10
Management (4)	0	5	0	5	0	5	5	5	5	5	5	5	5
Produceability (2)	0	0	0	0	0	0	0	0	0	0	0	0	0
Supportability (2)	2	0	2	0	0	0	0	0	0	0	0	0	0
Benefits Estimate (	0	0	2	2	0	2	5	0	5	2	5	5	2
Cost Estimate (2)	0	2	0	2	0	2	2	2	2	2	2	2	2
Risk Score	**4.0**	**5.7**	**3.6**	**5.4**	**3.3**	**4.1**	**5.3**	**4.3**	**4.1**	**3.9**	**3.8**	**4.4**	**3.5**

Produceability and supportability risks are deemed to be essentially insignificant for all alternatives. Cost estimate risk is considered low for all alternatives.

- Notwithstanding the general truth of the first bullet above, two alternatives may be deemed unacceptable solely from a risk perspective, depending upon one's view of future potential risk and the actual performance that WAAS achieves. Alternative III (v.1) may be considered operationally unacceptable to both the FAA and user groups, particularly from a safety and NAS efficiency viewpoint. This is because the BBN may be deemed insufficient as a backup to GPS/WAAS, given the lack of WAAS robustness under this particular alternative (i.e., WAAS availability may be less than 0.999 in some CONUS locations). In this case, pilots would be left without a sufficiently good backup navigation system during any potential GPS/WAAS outage. Similarly, Alternative IV (v.3) (robust WAAS with no BBN and no jamming protection) may also be unacceptable if one concludes that the actual jamming threat to the air carrier fleet is real and severe. In this case, it would be imprudent to phase out all existing NAVAIDs, while also making no provision for anti-jam protection to airborne GPS/WAAS receivers. Before proceeding with this alternative, the FAA would need to be certain that the jamming threat is insignificant.

Detailed Discussion of Alternatives' Risks: Below, each alternative is discussed in turn to provide the basis of its risk facet scores.

Alternative I (v.0): Basically, this is the status quo alternative; it provides no augmentation to the GPS; no WAAS or LAAS would be operational; "business as usual" with permanent dependence on ground-based NAVAIDs, especially VOR/DME and ILS, albeit with growing use of GPS without augmentation for navigation needs. Risk scores were based on these factors:

- Technical: ILS frequency congestion, siting constraints.
- Operability: Poor end-state functionality. No improvement in safety/CFIT avoidance, since vertical guidance in approaches would be unavailable at most airports, except through barometric aiding to GPS at additional costs to users and with lesser performance than otherwise would be available from WAAS. Since the FAA will not impose a regulatory requirement for barometric aiding, few aircraft would choose to do so voluntarily, so safety/CFIT avoidance would not improve. There would be no significant improvements in Free Flight/capacity improvements for most aircraft either, since RNAV would be generally unavailable, and there would be no added precision or even NPAs at most U.S. airports/runways.
- Supportability: Minor issues with ILS support.
- Stakeholder: Poor support, since all stakeholders want a SatNav transition and, if possible, a sole-means service eliminating the need for multiple avionics. Airlines particularly will dislike this alternative; it provides no opportunity to improve efficiency or safety that is otherwise available with widespread SatNav use. The FAA dislikes this alternative because no safety improvement would accrue to reduce CFIT. General aviation would be unhappy due to no SatNav transition, high cost of barometric aiding, and no Loran-C retention.

Alternative I (v.1): Same as (v.0), but replaces ILS with LAAS; no WAAS; retains VOR/DME. Risk scores (compared for relative risk to v.0):

- Technical: Greater risk due to LAAS CAT III integrity uncertainty ("most evil waveform", etc.).
- Operability: Still has the same basic problems as Alternative I (v.0).
- Supportability: Less risk since only ILS BBN is retained; fewer assets to maintain and lesser operational importance of ILS given LAAS installations.
- Benefits Estimate: Economic benefits of the BBN are uncertain.
- Cost Estimate: LAAS CAT III costs; ILS decommissioning costs are uncertain.
- Schedule: LAAS CAT I, III (particularly) Initial Operational Capability (IOC) uncertain, likely to be late.

- Management: Complexity of managing LAAS under OTA instead of normal contract approach.
- Funding: Higher than (v.0); ILS BBN competes with full LAAS.
- Stakeholder: Same problems as Alternative I; no WAAS/Loran-C; no CFIT reduction.

Alternative II, (v.0): Provides NPA WAAS (insufficient vertical guidance/improved accuracy); no LAAS; only MON VOR/DME; full ILS. Risk scores (compared to Alternative I or, in some cases, Alternative III).

- Technical: Low risk. ILS frequency congestion avoided by installing new ILS only where frequencies are available and where there are no siting constraints.
- Operability: Better than Alternative I because RNAV is available to all users, plus GPS/WAAS could be a sole-means system for those general aviation users having no need for precision approach. However, this alternative is still generally unsatisfactory for the same reasons as Alternative I, i.e., no CFIT safety improvement or any major help to the airlines' needs for greater flexibility/capacity growth.
- Benefits Estimate: Questionable GPS/WAAS fitting rate and ability to decommission NAVAIDs if only modest improvements are available through WAAS.
- Funding: Funding more systems than Alternative I (WAAS with three geostationary satellites) with only modest reduction of support costs for smaller MON VOR/DME network.
- Stakeholder: Better than Alternative I, but it still does not help air carriers much and does not give vertical guidance to reduce CFIT/improve safety.

Alternative II (v.1): Same as Alternative II (v.0), except that there is a full migration to LAAS instead of ILS, but the ILS BBN is retained. Risk scores (mostly compared relatively to Alternative II (v.0) baseline).

- Technical: Increased risk due to LAAS CAT III integrity concerns.
- Operability: Still bad, basically same as Alternative II baseline.
- Supportability: ILS BBN only; less support risk due to fewer assets.
- Benefits Estimate: Same concerns; resistance to decommissioning, slow GPS/WAAS equipage seem likely.
- Cost Estimate: LAAS CAT III and ILS decommissioning cost uncertainty.
- Schedule: LAAS CAT I, III (particularly) IOC uncertainty.
- Management: LAAS OTA schedule uncertainty difficulties in management.
- Funding: Similar to Alternative II baseline; retains more systems with little reduction in O&M costs.
- Stakeholder: Poor; same as Alternative II baseline.

Alternative II (v.2): Same as Alternative II (NPA WAAS, no LAAS), except Loran-C is retained in addition to MON VOR/DME and full ILS. Risk scores (mostly compared relatively to Alternative II baseline).

- Technical: Same as baseline v.0; also some Loran-C issues for IFR operations.
- Operability: Loran-C helps general aviation acceptance, but does not solve basic problems of no CFIT reduction and lack of WAAS efficiency/capacity benefits.
- Benefits Estimate: Lesser general aviation resistance to NAVAID decommissioning due to Loran-C retention.
- Cost Estimate: Less slippage in planned decommissioning dates reduces estimate uncertainty.
- Funding: No airline support for Loran-C; increased overall NAVAIDs cost for FAA.
- Stakeholder: Loran-C retention improves general aviation support.

Alternative III (v.0): "Simple WAAS" (NPA and precision approach throughout CONUS); 200 LAAS; MON VOR/DME/ILS. Risk Scores (compared relative to Alternative IV, mostly).

- Technical: WAAS risks for ionospheric correction algorithms to meet 3 "nines" of CAT I availaility; LAAS risks for CAT III integrity concerns.
- Operability: Better than Alternative II. Provides both precision approach and NPA, but requires MON for backup and need dual GPS/WAAS and conventional avionics. WAAS availability less than 0.999 in some CONUS locations.
- Benefits Estimate: Questionable decommissioning time due to resistance; questionable GPS/WAAS equipage rate.
- Cost Estimate: Prolonged operation of VOR/DME, ILS likely; higher decommissioning costs.
- Schedule: WAAS slippage likely due to software development, certification problems;
- Management: LAAS OTA schedule uncertainty management is difficult.
- Funding: Same as Alternative II; multiple navigation systems needed with little reduction in FAA O&M costs.
- Stakeholder: Better than Alternative II, given vertical guidance (NPA) and more precision approaches. Still, multi-avionics required for precision approach, and no Loran-C retention.

Alternative III (v.1): Same as Alternative III baseline, but only BBN VOR/DME/ILS retained instead of MON VOR/DME/ILS. Risks scores (mostly compared relative to Alternative III baseline):

- Technical: Same (WAAS, LAAS risks as v.0).
- Operability: High risk. May be an unacceptable system from safety and NAS efficiency views. Level of backup is very questionable, given relative lack of WAAS robustness/availability under this particular alternative. May be acceptable if sufficient numbers of users equip with inertial technology.

- Benefits Estimate: Greater resistance to NAVAID decommissioning to BBN level from the general aviation community.
- Funding: Somewhat less risk than Alternative II baseline given that BBN, instead of MON network, reduces FAA funding needs.
- Stakeholders: High risk. If system is unacceptable to the FAA, other stakeholders likely will not accept it either.

Alternative III (v.2): Same as Alternative III baseline, but adds Loran-C to MON VOR/DME/ILS. Risk scores (mostly compared relative to Alternative III baseline).

- Technical: Same (WAAS, LAAS risks as v.0).
- Operability: Same as Alternative III baseline.
- Benefits Estimate: Loran-C retention permits easier decommissioning to MON level.
- Funding: Loran-C funding not supported by airlines; retaining an additional system at FAA expense will be resisted.
- Stakeholder: Same as Alternative III baseline; Loran-C helps general aviation support, but does not improve airlines or FAA support.

Alternative IV (v.0): Robust WAAS (CAT I precision approach in CONUS, NPA in AK, HI); 160 LAAS (mostly CAT II/III); BBN VOR/DME/ILS. Risk scores are based on these factors:

- Technical: Moderate WAAS, LAAS performance risks.
- Operability: Very good, but affordability of GPS/WAAS avionics to the general aviation community may be an issue.
- Benefits Estimate: Probable resistance to decommissioning to BBN levels; probable short-fall in GSP/WAAS equipage rate.
- Costs Estimate: Uncertainty in LAAS CAT III, WAAS out-year costs; avionics costs to us-ers.
- Schedule: High risk. WAAS software development and certification may take longer; LAAS CAT IIII IOC is likely to be late.
- Management: LAAS OTA schedule uncertainty management complexity.
- Funding: High risk. High WAAS costs in a tightly constrained FAA funding, competitive budgetary environment, plus congressional skepticism.
- Stakeholder: Low risk. All stakeholders want full, robust WAAS as soon as possible.

Alternative IV (v.1): Same as Alternative IV baseline, but adds Loran-C to VOR/DME/ILS BBN.

- Technical: Same as Alternative IV baseline.
- Operability: Same as baseline; no real improvement from Loran-C addition.
- Benefits Estimate: Loran-C addition weakens general aviation resistance to decommissioning to BBN level.
- Funding: High risk. No airline support for Loran-C retention; FAA already strapped to pay for robust WAAS.
- Stakeholder: Addition of Loran-C cements general aviation support.

Alternative IV (v.2): Same as Alternative IV baseline, but no ground-based NAVAIDs retained whatsoever. Instead, airborne anti-jam/RFI mitigation for avionics will be required, at least on major air carriers. Risk scores (mostly compared relative to baseline Alternative IV).

- Technical: Same as baseline (WAAS, LAAS performance risks).
- Operability: Same as Alternative IV baseline. However, airlines will be willing to pay for avionics RFI protection if it eliminates need for retaining VOR/DME/ILS avionics.
- Benefits Estimate: Same as Alternative IV baseline. Probable strong resistance to decommissioning, slower GPS/WAAS equipage.
- Schedule: Same as Alternative IV baseline. WAAS software development and certification risks.
- Funding: Lower risk than baseline Alternative IV. Elimination of BBN costs and possibility of GPS/WAAS as only-means navigation source creates more favorable FAA willingness to fund and improves airlines' eagerness to move ahead with WAAS/LAAS avionics.
- Stakeholder: Low risk. General aviation users also will benefit from airlines anti-jam protection, which will reduce the jamming threat to general aviation as a collateral benefit.

Alternative IV (v.3): Same as Alternative IV baseline, but NO BBN and NO RFI mitigation. Risk scores: (mostly compared relative to Alternative IV baseline).

- Technical: Same (WAAS, LAAS performance risks).
- Operability: Moderate risk. Must know actual jamming threat. This alternative is only acceptable if the jamming threat is determined to be very low.
- Benefits Estimate: Same as Alternative IV baseline. Likely resistance to decommissioning schedules, likely slower GPS/WAAS equipage.
- Funding Risk: Lower than Alternative IV baseline, given that the elimination of BBN greatly helps the FAA's funding crunch.

Phased Alternative, III-IV: Begins with Alternative III WAAS system; accelerates LAAS CAT I schedule by converting from GIP to an FAA-funded development program. Adds additional investment to get to full Alternative IV robust WAAS level after performance during solar maximum is proven, users begin to equip with GPS/WAAS, long-term GPS sustainment policy stabilizes, and the GPS jamming threat subsides.

- Technical: Same as Alternative IV baseline.
- Operability: Lower than Alternative IV baseline, since LAAS is delivered sooner.
- Schedule: Deliberate stretching reduces schedule risk.
- Benefits Estimate: Less, due to lesser resistance to the phase-out to BBN level.
- Funding: Higher risk; stretch-out likely makes WAAS program more vulnerable in the budget process, plus earlier funding of LAAS in FY01 (particularly) and FY02 may be very difficult to achieve.
- Stakeholder: Better, due to earlier delivery of LAAS CAT I capability. Congress will like the checkpoints addition to provide an “escape hatch” if problems arise during WAAS/LAAS development/deployment.

5.4 Risk Management Plan for the Preferred Alternative

This plan is being included in the risk assessment for two major reasons: 1) to assist the JRC in its decision by summarizing the risks of the preferred alternative in a more detailed way; and 2) to assist the IPT in developing an Integrated Program Plan by identifying needed risk mitigation actions.

Methodology: Inasmuch as the preferred alternative is an adaptation combining Alternatives III and IV, its risk profile closely corresponds to the risks identified previously for those alternatives. Below, these risks have been summarized, and potentially appropriate risk mitigation strategies have been listed for the risks with the greatest potential impact. Moreover, instead of being depicted precisely along the 10 facets used previously, the risks are arrayed under four broader categories of process risk, product risk, stakeholder risk, and funding risk. Process risk is the set of risks associated with the IPT and its contractor team producing the system, and includes technical risk, producibility risk, management risk, cost risk, and most schedule risks. Product risk is the set of risks associated with achieving the operational purposes for which the system is being built, i.e., the risks of users’ acceptance after it has been produced, as well as those risks concerned with operating and maintaining the system over its intended economic service life. This category includes operability risk, benefits risk, some schedule risk, and supportability risk. Funding risk and stakeholder risk has basically the same content and definitions as their respective risk facets. They are singled out and separated mostly because of their great importance to program success.

5.5 Risk Summary

The risks of the preferred alternative are as follows:

5.5.1 Process Risks

LAAS Program:

- **CAT III Integrity**: The capability of the algorithms to bound errors with confidence for CAT IIIa and IIIb precision approaches remains inconclusive. If not resolved, the system will be unusable for its intended purpose. Ensuring that potentially dangerous signals broadcasted by the GPS itself (e.g., "most evil waveform") are properly detected remains a concern.

  –**Risk Mitigation**: Analysis is continuing in this area and these concerns are expected to be resolvable. Inasmuch as the "most evil waveform" issue relates to the entire GPS program success, and not just to LAAS, DoD and others are all actively looking for solutions. These anomalies could be defined through a formal Failure Modes and Effects Analysis (FMEA) of the GPS space vehicles and/or the GPS SIS. If a FMEA is unavailable or cannot be performed, stringent ground monitoring of all SIS parameters could also protect against the possibility of these rare events.

- **CAT III Availability**: LAAS CAT III availability and other performance requirements have been analytically proven and tested in a laboratory environment. However, the validation work is still ongoing, and proving a system can meet safety-critical certification requirements is always challenging.

  –**Risk Mitigation**: Providing additional APLs can solve the availability concern, if any remains after validation and testing are complete. This will increase somewhat the unit cost of a LAAS installation at any given airport. Other risk mitigation could include the use of WAAS geostationary satellites by LAAS, assuming the geostationary satellites are properly located.

- **LAAS Delivery Schedules for CAT III Systems**: At this time, neither industry partner shows a schedule that achieves the desired IOC in the year 2003, set by the FAA. Moreover, the FAA has very little leverage to push for schedule achievement, given the "Government-Industry Partnership" (GIP) agreement being pursued under the FAA's OTA. While it may be argued that potential overseas commercial sales of CAT I systems may provide a sufficient incentive to get early CAT I delivery, no such incentive exists for CAT III delivery to FAA. There is high risk for CAT III delivery on time. The FAA will provide no more than $8M (it could be less) over two years in milestone payments to each GIP. This is significantly less than the anticipated actual development cost; MOPS/TSO development has not begun; there is a relatively small U.S. market, and perhaps no market at all outside the U.S. (the perceived offshore market is only for CAT I systems).

  –**Risk Mitigation**: The LAAS product team is examining several possible options to ensure on time LAAS CAT III delivery. These include possible new or additional financial incentives, including earlier FAA funding to the GIPs for LAAS CAT III development.

However, late CAT III delivery is not a great problem for FAA, since CAT I capability is more valued by the users and CAT III ILS should provide satisfactory service at least until the year 2015.

- **LAAS Product Team Management/Staffing**: There are only three FAA employees on the LAAS product team, and the team itself has a fairly small contractor support staff. Still, this should be sufficient staffing if the procurement is limited to the 160 LAAS units currently planned.

  –Risk Mitigation: Consider additional staffing needs if unanticipated program growth occurs.

- **Limited FAA Knowledge/Control with OTA Approach**: Based upon the novelty of the OTA method within the FAA, risk concerns arise. The LAAS product team feels they may lack sufficient control over the GIPs, and there may be insufficient market incentive to guarantee that the partners will complete a CAT III system.

  –Risk Mitigation: Same as LAAS delivery schedules for CAT III systems above.

WAAS Program:

- **Requirements Uncertainty**: There are a few areas of requirements uncertainty which may impede timely delivery of an operational capability if not resolved soon. The first is the required Vertical Alarm Limit (VAL) for precision approach. The final WAAS VAL has not yet been selected, and will be a subject of discussion at the ICAO Obstacle Clearance Panel. To be conservative, a 12-meter VAL is being considered for a 200-foot decision height, though some believe 15 meters can be supported from ILS equivalence arguments. An alternative approach is to permit varying levels of performance and to relax the availability requirement. Other requirements uncertainties are the specific requirements for information security, especially those requirements needed to safeguard system integrity against intrusion or tampering; the requirements for remote maintenance monitoring; and any human factors requirements of the navigation system (especially cockpit displays for pilots).

  –Risk Mitigation: The product team and the sponsor (AVR) have developed incremental threshold and Full Operational Capacity (FOC) values for accuracy and availability to provide a range of performance for FOC development. The threshold values are consistent with the 5.5-meter vertical accuracy and 15-meter VAL and are the target level of performance for the WAAS Level II performance upgrade scheduled for completion by EXOC in the 2002-03 timeframe. After achieving the threshold value, the need for a more stringent requirement can be revalidated prior to committing additional resources. If the 4.4-meter vertical accuracy and 12-meter VAL is required for FOC, additional resources are included in the Level III upgrade task to achieve that requirement. The GPS product team also plans to increase participation at RTCA/GNSSP meetings to closely monitor the evolution of operational requirements for precision approach for all SBAS.

- **Performance During Solar Storms**: Scintillation effects during severe ionospheric storms are being studied and may cause problems. Potential problems include loss of signal lock and integrity bounds. The risk is greatest in low and high latitudes (i.e., near the Equator and the North and South Pole, not inside CONUS).

At solar maximums (approximately once every 11 years), ionospheric storms are more frequent and intense. Two different indices are used to characterize ionospheric activity, the Ap index and the Kp index. According to studies by Dr. Bakry El-Arini of CAASD, severe ionospheric storms as defined by the Ap index occur approximately 1.0% of the time and occurred 3.4% of the time during 1991. When measured by the Kp index, severe storms occur 0.17% of the time on average and occurred 0.82% of the time during 1991 ("WAAS Performance During Ionospheric Extremes", B. El-Arini et al, 20 August 1997, briefing to Delaney Panel). According to studies by M. Mendillo of Boston University, about 30% of storms have a major impact on ionospheric Total Electron Count (TEC). A severe storm can last a few days. The main effect is during the first few hours of an ionospheric storm. The results of high ionospheric activity are as follows:

- Larger spatial gradients and rates of change of ionospheric delay over time.
- Scintillation, which is the arrival of a GPS signal via two different paths through the earth's atmosphere, resulting in interference between the signals travelling the different paths.
- Scintillation occurs mostly at equatorial and polar latitudes. One effect can be reductions of signal strength of up to 20 dB or more on one or more GPS satellite signals. The duration of the signal loss can be momentary or up to one or two minutes. The other effect is phase jitter. Either of these effects can cause the loss of lock of one or more GPS signals by a GPS receiver.

The performance of WAAS Phase 1 algorithms has been analyzed using previous ionospheric storm data. During the first hour or two of some (about 1/3 of) ionospheric storms, the ionospheric error bounds become larger, which can decrease WAAS precision approach availability. It is expected that large spatial gradients and rates of change will reduce the probability that precision approach can be conducted down to a 200-foot decision height during a small fraction of time, on the order of 1%. The expected precision approach availability during that time is expected to drop from 0.999 to 0.99. During that same time, WAAS will continue to support NPA-1 approaches (NPAs with vertical guidance, type I), as well as conventional NPA, terminal, and en route phases of flight. Only small geographic regions are affected by severe ionospheric storms at any given time.

Large spatial gradients or rates of change in ionospheric delays could cause unavailability of WAAS precision approach during some fraction of ionospheric storms. Large spatial gradients or rates of change in ionospheric delay should not have an observable effect on LAAS-based operations.

A second risk is that in equatorial and polar regions, including Alaska, Hawaii, and Puerto Rico, GPS/WAAS/LAAS receivers could occasionally lose lock on one or more GPS or WAAS signals, which could result in loss of positioning for periods of time on the order of a minute. Such effects in mid-latitudes (i.e., in CONUS) should be very rare, if they occur at all.

–**Risk Mitigation**: Solar peak storms will be occurring in the 2000-2001 timeframe, providing the best opportunity to observe worst-case ionospheric storm/scintillation effects and make any system design changes that may be needed to compensate.

The GPS product team has initiated testing to investigate and characterize the effects of ionospheric scintillation of GPS/WAAS receivers. This test activity will identify specific signal processing technology needed to mitigate scintillation effects and identify proposed changes to WRS receivers, as well as WAAS avionics, if required. Knowledge gained from this activity will be provided to equipment manufacturers as well. In addition, any specific changes required for the WRS receivers will be included as part of the preplanned product improvements (P^3I) to WAAS for the Level II performance upgrade.

- **CAT I Availability/200-Foot Decision Height**: Ionospheric correction algorithms being implemented in the WAAS Phase I program will provide a 200-foot decision height, but only with low availability and only at certain CONUS locations, even with a full complement of satellites and ground stations. These algorithms do not provide adequate WAAS precision approach along the coasts of the U.S. nor along the northern or southern borders unless additional reference stations are installed in Canada and Mexico. Improved algorithms are being developed, and one research facility believes their proposed new algorithms will meet the requirements. However, the performance of these algorithms remains unvalidated throughout the CONUS airspace. The risk is that if the algorithms do not perform as well as expected, then either the precision approach capability will be lower than the desired 0.999 throughout the U.S., or ILS and/or LAAS will have to be installed at many more airports than currently planned.

–**Risk Mitigation**: The GPS product team has initiated an ionospheric working group, consisting of a panel of GPS, WAAS, and ionospheric experts to oversee the development, prototyping, and validation of an improved ionospheric monitoring algorithm. The expert panel includes representation from the FAA, Stanford University, Mitre, National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL), and Raytheon. The objective of the panel is to develop the validation criteria and specific test case scenarios required to demonstrate successful performance of the candidate improved algorithm developed by JPL. The FAA included additional resources in the Phase 1 contract to protect critical algorithm expertise on the Raytheon team to ensure continuity of personnel for this task. Initially, the ionospheric working group will conduct validation testing in the prototype software environment where changes can be accomplished in an efficient manner. The candidate algorithm will then be validated in the operational software environment at Raytheon. The objective of the ionospheric working group is to complete algorithm validation prior to commencing formal software development activities, thus avoiding potentially costly rework.

- **Sole-means Navigation Capability**: Purely from a technical performance viewpoint, WAAS/LAAS should be able to satisfy the required navigation performance as the only navigation system installed in the aircraft and the only navigation service provided by the FAA. This is a long-term goal that presumes a sufficient number of geostationary satellites, GPS satellites, and ground reference stations. However, interference to GPS/WAAS/LAAS (intentional and unintentional) and other sole-means issues may inhibit users' desires to abandon legacy avionics.

  –**Risk Mitigation**: Continue working towards WAAS/LAAS as the sole-means/only- means system, but retain BBN until assured that the interference threat is minimal and/or anti-jam protection is built into air carrier avionics. In the interim, retention of a BBN of VOR/DME and ILS is needed through at least the year 2015. Additionally, encourage the development of low-cost avionics that may overcome WAAS/LAAS limitations, especially low-cost INS integrated with GPS/WAAS/LAAS that can both compensate for possible GPS/WAAS/LAAS occasional outages and provide autonomous navigation for aircraft.

  The GPS product team has initiated an research & development (R&D) task to develop a prototype directional antenna for GPS/WAAS user equipment that is expected to meet the interference rejection requirements stated in the JHU/APL study. The prototype antenna will be tested in a laboratory environment, and installed and flight-tested at the FAA William J. Hughes Technical Center. Upon successful development of the prototype, a follow-on task will upgrade the antenna to demonstrate a certified installation compliant with FAA-TSO-C144. Results from the study will be provided to users and equipment manufacturers. Use of the improved interference rejection antennas at WRS locations susceptible to interference may also be considered.

- **Location, Cost of Geostationary Satellites**: There is very little uncertainty that the FAA will be able to lease sufficient satellites on schedule, given the robust nature and efficiency of the civil satellite communications market. However, there is greater uncertainty in the number of geostationary WAAS satellites required, due in part to uncertainties in the DoD GPS replenishment strategy and in the specific parameters of the WAAS lease. In any case, the FAA needs at least three satellites in preferred orbit locations to provide adequate redundant coverage within CONUS. Gaining those orbit locations and negotiating acceptable replenishment cycles (18 months) in the event of satellite failure may be difficult and expensive. If more than three satellites are needed because of an inability to get optimal orbit locations or because of the previously described uncertainties, the extra cost per satellite is an estimated $17M per year.

  –**Risk Mitigation**: The number of required geostationary satellites will be better known when the revised DoD policy on GPS constellation maintenance and replenishment is published later this year, and when agreements are reached with potential satellite providers on orbit locations. The FAA will work closely with DoD to establish a favorable GPS maintenance policy. The FAA will also seek maximum competition in satellite capacity arrangements and leasing provisions; ensure the contract guarantees adequate continuity of service through rapid restoration of any failed satellites; and strive for optimal orbit placements.

Decommissioning Timing and Costs: A key cost driver is the schedule for decommissioning unneeded ground-based NAVAIDs (VOR/DME, ILS, etc.) and reducing down to a BBN. Unfortunately, strong political opposition may be expected from user groups that have no strong economic incentive to move to satellite-based navigation, perhaps especially low-end general aviation pilots. Assuming that decommissioning is permitted, costs will be very substantial. If all ground-based NAVAIDs were decommissioned and the sites restored to pristine condition, the costs could be as high as $492M.

–**Risk Mitigation**: Ensure aviation community buy-in of the decommissioning strategy and timetable as a "quid pro quo" at the same time that the WAAS/LAAS investment decision is approved. Conduct frequent user forums to remind everyone of the upcoming transition and to ease the way to satellite-based navigation. Budget for decommissioning costs through the investment decision.

The acquisition strategy for WAAS provides precision approach capability for the entire CONUS during the Level II performance upgrade provided in the 2002-03 timeframe. It is expected that improving CONUS coverage and accuracy earlier in the life cycle will facilitate a more rapid transition to GPS/WAAS avionics by general aviation users. Providing the improved service requires an update to the WAAS ionospheric monitoring algorithm, additional WRSs, and a third geostationary satellite.

- **Lifting of the Congressional Freeze**: The program remains under review, with Congress being skeptical of FAA performance and credibility in delivering the system. Congress reduced FY99 Phase 1 funding and froze Phase 2/3 funding. Draft FY00 congressional language does not include restrictive language for WAAS Phase 2/3. However, the FAA must demonstrate that GPS/WAAS can meet sole-means navigation, conduct a lease versus buy analysis for the geostationary satellites, and revalidate the cost/benefits of SatNav.

  –**Risk Mitigation**: The FAA needs to make a compelling case to Congress that WAAS problems have been resolved and that a credible, low-risk strategy is now in place to deliver the system on time and within budget.

  The FAA supported an independent GPS risk assessment study prepared by the JHU/APL to investigate the feasibility of GPS and its augmentation systems (WAAS, LAAS) to provide a sole-means navigation capability. The study was completed and stated that GPS could provide sole-means navigation. The present investment analysis study addresses the cost/benefit and lease versus buy topics. The results of these activities will be presented to Congress during the FY00 budget process.

- **Software Development**: There is major schedule risk in FOC software development. At the completion of Phase 1, WAAS will have approximately 350,000 lines-of-code. An additional 370,000 lines-of-code will then be required to reach the FOC originally envisioned. This is a significant undertaking that will take at least 48 months and possibly 12 months or more beyond that. A high risk is implied because: 1) major software development programs that provide safety-critical functions have historically proven difficult to develop; 2) the Corrections and Verification software is behind schedule; 3) the FAA will require a rigorous safety certification before sole-means/only-means navigation is permitted; and 4) logic/algorithms for several programs such as for the ionospheric corrections have not been finalized or validated.

–**Risk Mitigation**: The FAA is using a Level 5 capable software developer (Raytheon) with proven experience in WAAS. Additionally, the recommended phased/incremental developmental approach will reduce the risk.

The FOC acquisition strategy incorporates an incremental approach that will support continuous improvement of the system as operational experience is gained. In addition, experience developing the Phase 1 software has been factored into the cost and schedule estimates for the FOC development activity to anticipate risk. Algorithm validation activities necessary to improve the ionospheric monitoring algorithm have already been initiated as part of Phase 1 sustainment.

- **WAAS Program Instability**: While WAAS has many supporters, it has been burdened by excessive expectations, created in major part by the FAA itself. These have included unrealistically optimistic schedules, inadequate cost estimates, and excessive enthusiasm about achievable technical performance. The FAA's failure to deliver on these expectations has created a continuous crisis atmosphere in both the FAA and contractor WAAS communities, signaled by intense congressional and other oversights of the program. In turn, the product team's effectiveness has been adversely affected because its resources have been diverted to responding to the criticism, rather than delivering the product.

–**Risk Mitigation**: The FAA will develop and implement strategies (e.g., high-confidence cost and schedule baselines) designed to promote program stability and minimize the need for intrusive oversight. Cost and schedule estimates have been revised to include actual cost and schedule performance data with estimates of error based on Phase 1 experience. The recommended FOC acquisition strategy is designed to provide incremental improvements to performance based on user needs, technical maturity, and affordability.

5.5.2 Product Risks

- **Avionics Equipage**: The major risk is that air carriers do not equip because new procedures for the postulated benefits do not appear.

–**Risk Mitigation**: To main the funding level for the development of new procedures (e.g., short finals).

- **Affordable Avionics/Cockpit Displays**: Generally, substantial adoption of GPS/WAAS/ LAAS by general aviation pilots will only occur if affordable avionics are available (estimated $5K or less, installed), and/or if they provide better human-focused navigation capability than current avionics - especially better cockpit displays. There is no assurance that industry, on its own, will be able and willing to produce affordable avionics for general aviation. Still, progress to date has been very promising. Without such affordable avionics, however, GPS/WAAS/LAAS growth and acceptance will be slow, sporadic, and unenthusiastic, and there will be a mixed

GPS/WAAS/LAAS and VOR/DME/ILS avionics environment far into the future. The vast majority of users will need to equip with WAAS in order to achieve the maximum level of safety and economic benefits, and to permit a transition to an RNAV system. If a large number of users do not equip, then the users who do equip will gain some benefits, but the FAA may be unable to transition the NAS away from the current VOR-based route structure. This will restrict operations of all users to some degree, at least in some airspace.

–**Risk Mitigation**: The FAA will develop strategies to gain and maintain general aviation enthusiasm and support for GPS/WAAS/LAAS, especially by ensuring that TSO-certified avionics at affordable prices, with better cockpit displays are available relatively soon. Otherwise, it will be very difficult to achieve decommissioning of existing NAVAIDs in favor of GPS/WAAS/LAAS. As the FAA actually begins to decommission NAVAIDs and moves toward the MON configuration, users will be more incentivized to move to GPS/WAAS, since the MON will provide noticeably less capability than the existing network. This transition will accelerate as even more NAVAIDs are decommissioned in moving towards a BBN configuration.

- **WAAS/LAAS Supportability**: The FAA AF workforce will maintain both systems. The transition strategy provides that the FAA workforce perform system maintenance and operation, configuration management, and first and second-level engineering support. The contractor (Raytheon) will provide additional engineering support services, software modification support, and contractor depot logistics support (CDLS). Transition to the FAA of the contracted support functions will occur approximately six months prior to acceptance of the FOC system.

  –**Risk Mitigation**: For WAAS, the GPS product team has adopted a revised transition strategy that enables the AF workforce to begin operating and maintaining the IOC system. The transition strategy also includes interim contractor maintenance and logistics support (ICMLS) for software maintenance, second-level engineering field support, and contractor logistics depot support (CLDS). Full transition to AF operation and maintenance will occur about six months prior to acceptance of the FOC system. Between IOC and FOC, the FAA WAAS operators, maintainers, and support personnel will participate in human factors studies and other product improvement activities to ensure that AF requirements are implemented properly in the FOC system.

  As to non-Federal LAAS, the FAA will only take over O&M responsibility if the original LAAS purchased conforms to FAA maintenance standards and requirements.

- **International Compatibility with other GPS Augmentation Systems**: A seamless navigation capability is required when operating with different GPS augmentation systems. GPS/WAAS/LAAS avionics must interoperate properly with the European geostationary navigation overlay service (EGNOS), the Japanese multi-functional transport satellite-base augmentation system (MSAS), the Russian Global Orbiting Navigation Satellite System (GLONASS), the DoD JPALS, and (if built) the European Galileo System. There is a risk that EGNOS and MSAS and (especially) Galileo will adopt signal specifications that are incompatible with WAAS/LAAS, inhibiting the manufacture of interoperable avionics and complicating the avionics picture for international commercial air carriers.

–**Risk Mitigation**: The risk is believed to be small. The FAA is pursuing an aggressive outreach program and has developed excellent relationships with the Europeans and Japanese through an Interoperability Working Group (IWG). It is expected that interoperability issues and timing synchronization between WAAS, MSAS, and EGNOS will be resolved prior to completion of the Phase 1 WAAS. To minimize this risk, the FAA and EGNOS are monitoring the signals of both systems and sharing the results of their data analysis activities to develop a detailed technical understanding of the implementation of the WAAS MOPS and SBAS SARPs. This approach has already rectified technical issues relating to signal synchronization between EGNOS and WAAS. Since MSAS is being implemented by the same development contractor as WAAS, the risk of interoperability problems is considered very low.

The ICAO GNSSP is also providing a forum for deliberating technical issues, helping to ensure system interoperability.

- **Threat of Interference**: All electronic radionavigation aids, including GPS, are subject to interference, which could be intentional or unintentional. Intentional interference could be caused by a variety of sources, including hackers and terrorists. Intentional interference could come from one source near the ground, multiple sources on the ground in a coordinated effort, or an airborne jammer. Unintentional interference could come from cable TV stations, from out-of-band emissions from communications equipment on the same aircraft as a GPS/WAAS/LAAS receiver or from mobile communications users on the ground. Interference from ground-based sources is limited by line-of-sight restrictions and the power of the interfering signal, as well as by receiver characteristics.

  The risk of interference is possible loss of lock by GPS/WAAS/LAAS receivers in some areas. The size of the affected area depends upon the distance and altitude difference between the interference source and the receiver and the power of the interference source. In the event of interference, suitably equipped users could revert to a backup system such as an INS or conventional NAVAIDs such as VOR/DME.

  –**Risk Mitigation**: The risk is mitigated by maintaining a BBN of conventional ground-based NAVAIDs, encouraging the development of integrated INS/GPS navigation sets, and encouraging development of improved interference rejection antennas for ground and airborne equipment. The decision criteria for continued decommissioning from the MON to a BBN of VOR/DME systems will be based on operational experience and progress achieved in developing interference rejection/mitigation capabilities. In addition, the FAA is sponsoring the development of a Security Threat Assessment for GPS to characterize the likelihood of occurrence for the jamming susceptibilities of GPS. It is expected that the assessment will enable the FAA to determine what additional capabilities are required for GPS/WAAS/LAAS to provide a sole-means navigation service with an acceptable level of residual risk.

- **Long-Term GPS Sustainment Policy**: GPS satellites can run out of fuel after eight to ten years on orbit and can also experience malfunctions, some of which require replacement. The DoD policy assumed in this analysis and currently guiding the U.S. airports is to maintain a 24 satellite (95%) constellation and to launch new GPS satellites on anticipated demand. This policy results in a range in the probabilities of having any given number of operating GPS satellites at any future time.

The converse risk is if actual GPS constellation performance is worse than the advertised DoD assurance. Then there could be a period of a few months of reduced availability while preparations are made to launch and test a new GPS satellite (or geostationary satellite). Because of the motion and changing geometry of GPS satellites, service would be provided during the majority of the day, but short daily outages could occur until replacement satellites were launched.

–**Risk Mitigation**: The FAA continues to work closely with the DOD through the IGEB to ensure an acceptable replenishment/sustainment strategy is in place for GPS to meet civil aviation requirements. In addition, the GPS product team has identified a permanent federal employee position to reside at the GPS JPO to closely monitor and coordinate future GPS sustainment/modernization activities.

- **U.S. National Plan**: The JHU/APL GPS Risk Assessment Final Report recommended that a national plan be created to, as a minimum: 1) establish the size and performance of the GPS constellation and establish characteristics of its signal structure, and 2) establish a timetable for planned improvements such as the second safety-of-life civil frequency. DoD is expected to soon publish an ORD that may include a revised commitment to support 24 operating GPS satellites with a 95% probability. This level of performance is improved relative to the presently published commitment to maintain 21 operating satellites with a 98% probability. However, the ORD does not state with what probability other numbers of satellites will be operating at any given time. Especially critical is the minimum number of operational satellites at any time and the resultant geometry. In the absence of this or other commitment, the FAA must make assumptions in order to determine the level of assets required to achieve a given level of total system performance. If FAA assumptions are overly conservative, resulting in deployment of unneeded assets, then taxpayer dollars will have been wasted. If the assumptions are not conservative enough, then required system performance will not be achieved, with possible increased costs or lost benefits. Similarly, if a timetable for GPS planned improvements is not agreed, then benefits resulting from civil aviation use may be delayed, because the FAA will not be able to prepare and plan adequately to take advantage of the additional signal or performance.

  –**Risk Mitigation**: The DoD and FAA are working closely together in the IGEB to develop a national plan that will confirm the planning assumptions.

- **Checkpoint Uncertainty**: While checkpoints are desirable for the FAA to some degree to provide a means to "bail out" of a losing strategy, they introduce uncertainty to the users who are trying to decide whether or not to equip with GPS/WAAS. Simply said, users will be very reluctant to equip if they fear that the FAA may back out of its commitment to complete the program. Users would prefer an ironclad agreement that eliminates uncertainty for them.

  –**Risk Mitigation**: The FAA will revisit the need for checkpoints as it progresses into the full WAAS program. However, even the first step should provide sufficient capability to encourage user equipage.

5.5.3 Funding Risks

- **WAAS/LAAS Capital Funding**: WAAS and LAAS are high-priority programs, but are also very costly programs at a time of great FAA budgetary constraints. The FAA must prioritize its spending to maintain current services and preserve its infrastructure, while seeking to satisfy demands for modernization. Accelerating the funding for LAAS may be a very difficult sell to the internal FAA community and to the President's OMB.

  –Risk Mitigation: The FAA has adopted a full funding approach for its capital investments. If WAAS/LAAS are approved at the investment decision, and insufficient funds are available, then other lower-priority programs will be reduced or eliminated to ensure that WAAS/LAAS are fully funded and can be executed to completion.

- **BBN and Decommissioning Funds**: Currently, only the WAAS and LAAS programs will be baselined in APB documents. However, the costs associated with establishing and maintaining the VOR/DME and ILS BBN and decommissioning those VOR/DME and ILS systems that are no longer needed will be captured in the NAS Architecture database and CIP Financial Plan — but not in the APBs. This may tend to create an atmosphere in which the BBN and decommissioning costs do not receive the same level of attention, status, funding, and management as LAAS and WAAS. BBN funding itself may be highly vulnerable to budget cuts, as there is likely to be strong resistance by OMB and others to maintaining a BBN indefinitely as WAAS and LAAS take primary roles in navigation. In any event, there will be extremely strong resistance to any program suggesting replacement or large capital expenditures for VOR/DME, ILS, or Loran-C, which are perceived as obsolete systems that should be retired.

  –Risk Mitigation: The FAA will consider establishing an APB for ground-based NAVAIDs, and will ensure a product team is designated as responsible for managing the BBN evolution, funding, and decommissioning of unneeded NAVAIDs.

- **Geostationary Satellite Lease Multiyear Funding Authority**: The FAA needs multiyear funding authority from Congress before it can enter into a 10-year lease commitment with a satellite service provider. Under current congressional budget rules, multiyear authority is limited to five years. However, no potential bidder will make a satellite commitment without having a guaranteed 10-year life in its planning. The FAA will request the 10-year multiyear funding authority coincident with the submission of the FY01 budget to Congress.

  –Risk Mitigation: None, but approval by Congress is considered low risk.

- **Lease Termination Liability**: Funding is needed up-front from Congress for lease termination liability. If the lease is considered a *capital lease*, this termination liability could be hundreds of millions of dollars, essentially equal to all 10 years of the lease. If it is considered as an *operating lease*, it might be only one year's lease payment.

  –Risk Mitigation: It appears that an operating lease will be pursued. If so, obtaining funding of possible termination liability up-front is judged relatively low.

- **O&M Out-Year Costs**: The FAA operations budget is under even greater pressure than the capital budget. There are severe annual shortfalls as new requirements (controllers' salary increases, display system replacement (DSR) software maintenance, flight inspection, etc.) are added onto an inadequate funding level base. The WAAS SatNav communications funding requirements are as much as $27M in FY01, which could be as much as 9% of the entire FAA-leased communications budget. Likewise, the WAAS flight inspection costs could approach as much as $3M in FY01, which could be as much as 5% of the entire AF flight inspection budget. Finally, ILS and VOR/DME maintenance costs are nearly $60M per year today, and these costs may not reduce much as the equipment ages, even if fewer assets are needed in the final BBN configuration. In summary, O&M affordability is very risky.

–**Risk Mitigation**: The FAA will strive for full funding, looking for offsets in other programs as needed to ensure program execution feasibility.

5.5.4 Stakeholder Risks

- **Commercial Aviation**: The air carriers generally favor the phased alternative and want both WAAS and LAAS. However, they are much less enthusiastic about WAAS than LAAS, because in aircraft equipped with an FMS, WAAS will not provide substantial added economic or operational value to them beyond what unaided GPS can provide, or beyond what they can achieve with RNAV-capable FMS equipment. They would delay retrofitting but new aircraft would be WAAS/LAAS capable. Hence, Regional Jets would benefit significantly from WAAS.

  –**Risk Mitigation**: Maintain air carrier support by transitioning as quickly as possible to a long-term sole-means/only-means GPS/WAAS/LAAS capability that can reduce air carrier costs, eliminate dependence on existing NAVAIDs, and greatly improve efficiency. Earlier LAAS development and deployment under the phased alternative should induce earlier transition to GPS/WAAS/LAAS dependence.

- **General Aviation**: Generally, general aviation also supports the phased alternative, WAAS, LAAS, and BBN. However, LAAS support is marginal, especially among low-end users who have no need for precision approach. Moreover, low-end users will resist a phase-down of NAVAIDs to the BBN level, and resent Loran-C discontinuance.

  –**Risk Mitigation**: Getting affordable GPS/WAAS avionics soon is crucial to sustaining general aviation support. This will be the focus of risk mitigation. If affordable avionics are available by the year 2005, users are less likely to resist decommissioning of VOR/DME, ILS, and Loran-C, and more likely to support GPS/WAAS/LAAS.

- **Internal FAA**: Other than AVR and certain FAA senior managers, there is little internal FAA support or enthusiasm for WAAS or LAAS. In particular, the SEOAT will resist any program that requires high capital funding needs in the near term. Essentially, the SEOAT is focussed on preserving the existing NAS infrastructure in tight budget times; the last thing it wants is an incremental requirement that adds to the NAS infrastructure and offers no offsetting funding reductions.

  –**Risk Mitigation**: Unknown

- **Department of Defense**: Although DoD funds and operates GPS, the individual services (Army/Navy/Air Force/Marines) are faced with severe funding constraints and are unable to migrate quickly to GPS/WAAS/LAAS dependence for their own aircraft. DoD equipage with GPS avionics for its own aircraft is expected to cost $18B. In particular, prolonged TACAN operation is highly desired. However, the DoD is actively spending $50M for JPALS, a militarized version of LAAS, and Naval air Warfare Center Aircraft Division (NAWCAD) has been an active DoD partner in the FAA's SatNav program because of the potential need of the Navy.

–**Risk Mitigation**: Maintain TACAN as long as needed to support DoD. Closely coordinate the NAVAID phase-down with DoD and encourage military equipage with SatNav avionics; de-couple civil transition from military transition to the degree feasible.

- **Congress**: As indicated, Congress appears ambivalent about WAAS and LAAS. It recognizes that GPS has become a national utility with broad use by many communities, not just transportation. Every indication is that Congress supports the basic GPS constellation, and that the system will be supported for many years to come. Still, there is a risk. Congress has consistently funded GPS, WAAS, and LAAS, but has also denied funding for the GPS second civil frequency and has regularly cut both WAAS and LAAS funding below Administration-requested levels.

–**Risk Mitigation**: As indicated above, proving FAA credibility is critical to congressional support. Excellent FAA performance and regular communications with Congress will mitigate this risk. In addition, a policy of regular briefings to the appropriations staffs will be adopted to establish clear expectations, to provide program status updates, and to ensure communications are maintained throughout the WAAS and LAAS development life cycles.

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6.0 ARCHITECTURE ASSESSMENT

This section describes the degree to which the preferred alternative (Alternative IV, BBN) is consistent with the NAS Architecture 4.0, January 1999, and the effects of any differences between the two on NAS-level planning. Once the FAA's JRC updates the FAA plans on SatNav implementation, the NAS Architecture will be updated to reflect the new plans.

The preferred alternative is generally consistent with the NAS Architecture in that the NAS will continue to transition to navigation services based on WAAS and LAAS and significantly reduce the number of ground-based NAVAIDs. The capabilities that both WAAS and LAAS will provide are also consistent with those described in the NAS Architecture. The funding request through FY05 is 2% greater than previously budgeted but the requested individual budgets for WAAS and LAAS are different.

With respect to WAAS, the primary difference between the preferred alternative and the NAS Architecture 4.0 is that additional F&E funding of $44M has been requested for FY04 and $43M for FY05. If approved, this request will put increased fiscal pressure on an already constrained FAA budget and force the FAA to further prioritize its CIP projects.

With respect to LAAS, the initial capability will be achieved in FY01 versus FY03 as stated in the NAS Architecture. Implementing this capability will come with an increased funding requirement of $8.8M in FY01 and $21.6M in FY02. The LAAS funding request then significantly decreases beyond FY03 and is $64M less than previously budgeted through FY05. This decrease will help offset the requested increase in WAAS funding.

The preferred alternative also recommends having future decision points on WAAS and LAAS capabilities and system development to reflect the FAA's on-going evaluations of performance and user acceptance. This recommendation will have no impact on the NAS Architecture since those decision points are implicit in the NAS Architecture.

ADS-B is the primary NAS system that will be dependent on WAAS and LAAS. ADS-B is planned for full introduction into the NAS in the year 2007, and is currently planned to rely on multiple navigation system inputs including GPS/WAAS. The greater performance of WAAS over other navigation systems should enable ADS-B to deliver increased air-to-air and ground surveillance capabilities. LAAS performance and schedule should also satisfy all ADS-B applications for surface surveillance. Like the NAS Architecture baseline, the preferred alternative satisfies all ADS-B position-velocity-time performance and schedule requirements and its selection will not adversely impact ADS-B capabilities and schedules.

Failure to implement the full WAAS or LAAS or both is likely to delay or prevent users from equipping with WAAS and LAAS avionics. Delays would adversely affect the NAS transition to Free Flight (due to decreased RNAV and ADS-B capabilities) and the planned decommissioning of most ground-based NAVAIDs. Additionally, any delays increase the likelihood that the FAA will need to replace existing NAVAIDs at an estimated cost of $2.6B and install numerous additional CAT II/III ILSs to satisfy user demand.

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7.0 AFFORDABILITY ASSESSMENT

The SatNav programs are a large part of the Agency's CIP and operations budgets. WAAS costs are currently included in the CIP budget and the proposed APB costs are less than the 1998 APB for years 2000-2020. The LAAS APB costs, on the other hand, exceed the CIP by $7-8M in FY01 and more than $20M in FY02. The budgets in FY01 and FY02 are extremely tight, and Agency management is meeting as this IAR was prepared to determine overall Agency priorities. If slippage of either program is necessary, it will negatively impact costs, benefits, and risk.

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8.0 HUMAN FACTORS AND OPERATIONAL SAFETY ASSESSMENT

The most obvious system element for SatNav is GPS and its vastly improved navigational accuracy over large distances. Accordingly, there is a need to consider a range of GPS design, user, and training issues from a human factors perspective in both the air carrier and general aviation environments.

Traditionally, aviation technology has been developed from advanced military and civil aviation research and then adopted by commercial aviation, and finally into general aviation aircraft. This has generally followed comprehensive testing, the development of regulations and procedures, and training. GPS, on the other hand, is an example of aviation technology that appears to reverse that trend. For example, GPS is being rapidly adopted for general aviation use ahead of regulatory provisions and training requirements due to the pace of commercial technological advancement, availability, and affordability.

The human factors issues that need to be considered include the design of the receiver controls and display, the extent to which GPS and GPS-based technologies create opportunities for new or unexpected sources of human error, and the effects that GPS use might have on pilot and controller decision making. Anecdotal evidence has already suggested that GPS is often being used in an improper manner and that its use may have altered some pilots' flying behavior (Nendick and St. George, 1996). That is, changes were occurring to the navigation strategies used and to the decision making that followed from these strategies.

Some specific human factors issues include:

- **GPS Receiver/Avionics General Design Features:** It has been reported that, overall, GPS units, whether panel-mounted, portable, or handheld, are relatively easy to use. That is, the ease with which you can get GPS to do what you want it to do is high. Nevertheless, there are a number of usability issues that have been raised previously and probably deserve additional consideration. These include the following:
    - –Since the accuracy of the GPS is heavily dependent on the accuracy of the information in the system, there needs to be an awareness about correctly entering data into the system. Because GPS depends on the accuracy of the data fed into it, typically with a keyboard entry device, it follows that GPS will be subject to whatever errors arise in data entry. Although relatively rare, such errors can have serious consequences, as demonstrated by the KAL 007 inadvertent entry into Soviet airspace and its subsequent shooting down.
    - –The design of controls requires attention to the issues of the size, spacing, and layout of the controls. It has been reported, for example, that more widely spaced block keyboard arrangements of controls is easier and more accurate to use than the row mounted key arrangements often found in many portable and panel-mounted GPS models (Nendrick and St. George, 1996).
    - –The design of the visual display of alphanumeric data requires attention to the readability of the displayed data which can be made difficult by the small size of displays, text density (number of letters per unit area), lighting conditions, and reading distance to the display. Nendrick and St. George (1996) report that the relatively small font sizes typically used for

function/mode indicators can also be a potential design problem. Also, it may be necessary to consider the difficulty that visual and auditory warning indicators will have in some lighting conditions and high noise environments.

- **The Effects Of GPS On User Performance**: There have been a number of concerns about the impact of GPS on the performance of pilots and controllers. These include the following:

  –The ability of pilots and controllers to spot their input errors will most likely be the result of cross-checking inputs with other navigation/surveillance information. If GPS becomes the sole-means system, there will not be any other system on board available for cross-checking. In any event, it must be recognized that this takes self-discipline, vigilance, and a good basic understanding of GPS operations. Of concern then is that effective training, as well as procedures must be developed and be in place to ensure that cross-checking becomes part of the routine behavior of all GPS users. This becomes part of a pilot's or controller's situational awareness of one's relative location.

  –Correctly perceiving and understanding displayed information is as important as being able to read the information. This requires that the displayed information map onto the users own knowledge base so as to advance the reader's ability to interpret the displayed data and avoid information overload. In short, what matters here is not how the display looks but how meaningful the displayed data is.

  –Some attention is needed to determine what, if any, impact GPS technologies have on pilot and controller workload and on risk taking performance. Although GPS may reduce map reading workload and see-and-avoid behavior for general aviation pilots, there is some uncertainty about the impact of GPS on workload for pilots flying in instrument flight conditions. Interestingly, Nendick and St. George (1996) reported that pilots, particularly general aviation pilots, would engage in bad weather flying more frequently with GPS available.

  –Besides input errors, GPS technologies may be sensitive to mode errors. For example, GPS generally provides the user with a number of basic functions, as well as deeper or more complex functions. These multiple functions or modes (letting something be done in one mode and another way in another mode) create fertile ground for mode errors; that is, committing an erroneous action by executing an intention in a way appropriate to one mode of the system when the system is actually in another mode. Note, that mode errors are inherently a computer-human system breakdown in that it requires a user who loses track of which function or mode the system is in and a computer that interprets user input differently depending on the current mode of operation. Difficulties in keeping track of system modes will vary depending on task context (time pressure, multiple task requirements, workload) and depending on how the interface signals or identifies the mode the system is in. Thus, it is essential that GPS technologies be sensitive to designs that have the potential to promote or avoid mode errors.

- **Training**: The way pilots and controller use GPS technologies and their attitudes toward the technologies are probably linked to the issue of training. Although the majority of general aviation pilots appear to be self taught, practicing with direction from the user manual, it would appear that training from other sources including formal classroom instruction, simulation/demonstrations, briefings, and videos need to be considered (Nedrick and St. George, 1996). And there is always the problem of poorly written user manuals. Training issues that appear to be particularly salient here include understanding the limitations, as well as the benefits of GPS technologies. For example, training could be used to describe the hazards associated with relying too much on the accuracy and reliability of GPS without considering backups and the tendency of increased risk taking in bad weather (e.g., going IFR with little IFR training) particularly among general aviation pilots. In short, training will need to be focused on how to use GPS, on the difficulties in learning to use GPS, and on GPS hazards to be avoided.

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9.0 RECOMMENDATION AND NEXT STEPS

The SatNav IAT recommends the following to the JRC:

- Approve the APBs for the WAAS and LAAS programs and authorize the product team for global navigational systems to execute the recommended alternative.
- Approve the FY01 satellite acquisition.
- Approve the use of F&E funds for the leased satellite services.
- Approve the transmittal of the lease versus buy and the cost-benefit analysis to Congress through the DOT.

The SatNav IAT recommends the following next steps to the JRC:

- Direct that the programs to sustain ground-based NAVAIDs be baselined within the next year.
- Direct that the WAAS Requirements Document be revised to be consistent with the AMS.

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Appendix A - Glossary

A

ADF	Automatic Direction Finder
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance – Broadcast
AF	Airway Facilities
ALSF	Approach Lighting System with Sequenced Flashing Lights
AMS	Acquisition Management System
AOPA	Aircraft Owners and Pilots Association
APB	Acquisition Program Baseline
APL	Airport Pseudolite
APO	Office of Aviation Policy and Plans
ASD	Investment Analysis and Operations Research
ATC	Air Traffic Control
AVR	FAA Office for Regulation and Certification

B

BBN	Basic Backup Network
B/C	Benefit/Cost

C

CAASD	Center for Advanced Aviation System Development
CAT	Category
CDLS	Contractor Depot Logistics Support
CDTI	Cockpit Display of Traffic Information
CFIT	Controlled Flight Into Terrain
CIP	Capital Improvement Plan
CLDS	Contractor Logistics Depot Support
CLL	Center Line Lighting
CNS	Communications, Navigation, and Surveillance
CONUS	Continental U.S.
COTS	Commercial-Off-the-Shelf
CSC	Critical System Characteristic

D

DME	Distance Measuring Equipment
DoD	Department of Defense
DOT	Department of Transportation
DSR	Display System Replacement

E

EGNOS	European Geostationary Navigation Overlay Service
ENR-NPA	Enroute through Non Precision Approach
EXOC	Expanded Operational Capability

F

F&E	Facilities and Equipment
FAA	Federal Aviation Administration
FMEA	Failure Mode and Effects Analysis
FMS	Flight Management System
FOC	Full Operational Capability
FSD	Full Scale Development

G

GAO	Government Accounting Office
GBAS	Ground-based Augmentation Systems
GES	Ground Earth Station
GIP	Government-Industry Partnership
GLONASS	Global Orbiting Navigation Satellite System
GNSS	Global Navigation Satellite System
GNSSP	Global Navigation Satellite System Panel
GPS	Global Positioning System
GST	Geostationary Satellite Transponder

I

IAR	Investment Analysis Report
IAT	Investment Analysis Team
ICAO	International Civil Aviation Organization
ICMLS	Interim Contractor Maintenance and Logistics Support
IFR	Instrument Flight Rules
IGEB	Interagency GPS Executive Board
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
IOC	Initial Operational Capability
IPT	Integrated Product Team
IRT	Integrated Requirements Team
IWG	Interoperability Working Group

J

JHU/APL	Johns Hopkins University/Applied Physics Laboratory
JPALS	Joint Precision Approach and Landing System
JPL	Jet Propulsion Laboratory
JPO	Joint Program Office
JRC	Joint Resource Council

K

KDP	Key Decision Point

L

LAAS	Local Area Augmentation System
L1	Link 1
LCB	Life Cycle Benefits
LCC	Life Cycle Cost

M

M	Million
MASPS	Minimum Aviation System Performance Standard
MHz	Megahertz
MLS	Microwave Landing System
MMR	Multi-mode Receiver
MNS	Mission Need Statement
MON	Minimum Operational Network
MOPS	Minimum Operational Performance Standards
MSAS	Multi-Functional Transport Satellite-based Augmentation System
MSL	Mean Sea Level

N

NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAVAID	Navigational Aid
NAWCAD	Naval Air Warfare Center Aircraft Division
NDB	Non-Directional Beacon
NM	Nautical Miles
NOTAMS	Notices to Airmen
NPA	Non Precision Approach
NPV	Non Precision Approach with Vertical Guidance
NPV	Net Present Value
NSTB	Navigation Satellite Test Bed

O

O&M	Operations and Maintenance
OIG	Office of Inspector General
OMB	Office of Management and Budget
ORD	Operational Requirements Document
OTA	Other Transaction Authority

P

P^3I	Pre-Planned Product Improvements
PPS	Precise Positioning Service
PRM	Precision Runway Monitor
PVT	Passenger Value of Time

R

R&D	Research & Development
RAIM	Receiver Autonomous Integrity Monitoring
RFI	Radio Frequency Interference
RFI	Request for Information
RNAV	Area Navigation
RNP	Required Navigation Performance
RVR	Runway Visual Range

S

SARPs	Standards and Recommended Practices
SatNav	Satellite Navigation
SBAS	Satellite-based Augmentation Systems
SEOAT	System Engineering Operational Analysis Team
SETA	Systems Engineering Technical Assistance
SIS	Signal In Space
SPS	Standard Positioning Service

T

TACAN	Tactical Air Navigation
TDZL	Touch Down Zone Lighting
TEC	Total Electron Count
TSARC	Transportation Systems Acquisition Review Council
TSO	Technical Standard Order

U

UDRE	User Differential Range Error
U.S.	United States
USNO	United States Naval Observatory
UTC	Universal Coordinated Time

V

VAL	Vertical Alarm Limit
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VNTSC	Volpe National Transportation System Center
VOR	VHF Omni-directional Range
VORTAC	VOR (collocated with) TACAN

W

WAAS	Wide Area Augmentation System
WMS	WAAS Master Station
WNT	WAAS Network Time
WRS	WAAS Reference Station

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Appendix B - References

The following list of documents and reports were reviewed and provided background data in the development of the SatNav IAR.

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