A National Airspace System Performance Analysis Capability (NASPAC) Evaluation of the Impacts of the Center-TRACON Automation System (CTAS) on Airport Capacity

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May 1996
DOT/FAA/CT-TN96/14

Usual Tech Note cover with NTIS statement.

Technical **Report Documentation Page**

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-TN96/14		

4. Title and Subtitle
A National Airspace System Performance Analysis Capability Evaluation of the Impacts of the Center-Terminal Radar Approach Control Automation System on Airport Capacity

5. Report Date
May 1996

6. Performing Organization Code
ACT-520

7. Author(s)
Joseph M. Richie and Douglas Baart, ACT-520

8. Performing Organization Report No.
DOT/FAA/CT-TN96/14

9. Performing Organization Name and Address
Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
F2006X

12. Sponsoring Agency Name and Address
Federal Aviation Administration
Operations Research Service
800 Independence Avenue, S.W.
Washington, DC 20591

13. Type of Report and Period Covered
Technical Note

14. Sponsoring Agency Code
ASD-410

15. Supplementary Notes

16. Abstract
This report documents the results and analysis of the Center-Terminal Radar Approach Control (TRACON) Automatic System (CTAS) on National Airspace System (NAS) performance. The NAS Performance Analysis Capability (NASPAC) Simulation Modeling System (SMS) was used to evaluate the impact CTAS would have on system level performance. Simulations were developed that included the effects CTAS would have on airport capacity and compared against simulations that did not include CTAS. Measures of delay and cost of delay were used as key metrics in the analysis. The results indicate that the deployment of CTAS would reduce operational delay and passenger delay by 34,405 and 2,277 hours respectively in 2005. These savings translate into nearly 100 million dollars.

17. Key Words

National Airspace System Performance Analysis Capability (NASPAC)
CTAS
Operational Delay
Passenger Delay

18. Distribution Statement

This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	35	

ACKNOWLEDGEMENTS

The authors of this report thank Willie Wiess of CSSI, Inc. for sharing his work on National Airspace System Precision Approach and Landing System (NASPALS). This enabled us to accurately estimate airport capacities for the year 2005.

We also acknowledge the support of Art Politano, National Airspace System Performance Analysis Capability Program Manager, ASD-410, for his advice and technical leadership.

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EXECUTIVE SUMMARY

INTRODUCTION

A system performance team from the Operations Analysis Division (ASD-410) analyzed the quantitative impacts of Traffic Flow Management (TFM) products for the year 2005. Estimates of delay were compared to a previous National Airspace System Performance Analysis Capability (NASPAC) study that included TFM products. Measures of delay and cost of delay were used in a quantitative assessment of TFM products on National Airspace System (NAS) performance.

INTRODUCTION

The objective of this study is to evaluate the impacts that Center-Terminal Radar Approach Control (TRACON) Automation System (CTAS) have on National Airspace System (NAS) performance for the year 2005. The study provides a quantitative analysis by comparing measures of delay and cost of delay between a scenario that includes CTAS and one that does not. This was done at the airport level and for the entire NAS by phase of flight. The study includes technological advances and airfield improvements planned to be completed by the year 2005. The Aviation System Capacity Plan outlines all proposed airport improvements intended to be completed by year the 2005.

METHODOLOGY

NASPAC was used to simulate the NAS for the year 2005. Annualization techniques were employed. Airport capacity estimates and technological advances expected to be completed and implemented in the NAS by the year 2005 were derived from the 1993 Aviation System Capacity Plan. Traffic projections at all NASPAC-modeled airports (see Appendix A for airport identifiers) were derived from the 1993 Terminal Area Forecasts (TAF). New airport capacity estimates were derived for the scenario that excluded the TFM product Center-Terminal Radar Approach Control (TRACON) Automation System (CTAS).

New technologies designed to increase system capacity used in the baseline (2005 with CTAS) scenario include CTAS, Dependent Converging Instrument Approach (DCIA), Simultaneous Converging Instrument Approach (SCIA), Precision Runway Monitor (PRM), and Airport Surface Traffic Automation (ASTA).

METHODOLOGY

The National Airspace System Performance Analysis Capability (NASPAC) Simulation Modeling System (SMS) was used to simulate the future NAS. Six scenario days from 1990 were simulated and weighted to produce annual results. Traffic profiles for the year 2005 were developed at each of the 58 modeled airports using the 1993 Terminal Area Forecasts (TAF). See Appendix A for airports and their identification. Airport capacity estimates were derived by a system performance team from the Operations Analysis Division (ASD-410) for 16 airports that were affected by CTAS.

New technologies and improved procedural changes in the baseline scenario (year 2005 with CTAS) include the CTAS, Dependent Converging Instrument Approach (DCIA), Simultaneous Converging Instruments Approach, (SCIA), Precision Runway Monitor (PRM), and Airport Surface Traffic Automation (ASTA). These technologies were designed to increase system capacity.

RESULTS

The study suggests that CTAS can save the aviation community almost 100) million dollars (1993 dollars) in the year 2005.

RESULTS

The study suggests that the deployment of CTAS would reduce annual operational delay in the NAS by

Simulations of the NAS have shown significant reductions in operational delay attributed to the deployment of CTAS. The largest reduction in delay was recorded by the airborne phase of flight, where 26,747 hours (65.5 million dollars) or 71 percent of the total savings were realized.

34,405 hours in 2005. These reductions translate into cost savings to the airlines of 92,789,092 million dollars. CTAS is designed to improve the spacing between flights on approach in terminal airspace, and thus increase the airports arrival rate. Although most of the delay savings were attributed to arrivals, some of the reductions were observed for passenger delay. Annual delay savings for passengers system wide amounted to $1,757,514 for the NAS in year 2005. Passenger delay is the difference between the scheduled arrival time and simulated arrival time. Operational delay is the delay that flights accumulate when they compete for Air Traffic Control system resources.

AIRPORT LEVEL

LGA (see Appendix A for airport identifiers) recorded the largest reduction in passenger delay (6 percent), followed by FLL and LAX (1 percent). Largest reductions in operational delay was recorded at DFW (3.4 percent), followed by PHX (3 percent), DCA (2 percent), and SFO (1 percent).

AIRPORT LEVEL

From the 12 airports (See Appendix A for airport identifiers) identified in the baseline (year 2005 with CTAS) scenario, LGA recorded the largest reduction in passenger delay (6 percent), followed by FLL and LAX (1 percent). The operational delay reductions were recorded at DFW (3.4 percent), followed by PHX (3 percent), DCA (2 percent), and SFO (1 percent). From the 16 airports slated for CTAS, the simulation results indicate that the increased airport capacity provided by the implementation of CTAS results in significant reductions in operational delay. Twelve out of the 16 airports recorded reductions in operational delay totaling 40.8 percent.

CONCLUSIONS

The study suggests that, given the significant level of annual delay savings, deployment of CTAS should be accelerated.

CONCLUSIONS

Annual savings, system wide, in operational delay was estimated to be 34,405 hours. This translates into 92,789,092 million dollars in delay savings. Most of these savings were attributed to the airborne phase of flight. Passenger delay reductions, system wide, were recorded at 2,277 hours. The combined savings for the airlines and the traveling public was estimated at 93,546,606 million dollars.

1. INTRODUCTION

A system performance team from the Operations Analysis Division (ASD-410) provided support to the Traffic Flow Management (TFM) Integrated Products Mission Needs Program. In this report, the team identifies the system-wide quantitative impacts of TFM products for the year 2005. A scenario was generated to reflect the future National Airspace System (NAS) without TFM products. This scenario was compared to a previous one that included TFM products. Delay estimates are provided between the two scenarios to assess the impact TFM products would have on NAS performance for the year 2005.

The National Airspace System Performance Analysis Capability (NASPAC) Simulation Modeling System (SMS) was used to assess the impact of TFM products on NAS performance. The following factors have been included in the determination of airport capacity for the scenario that included TFM products:

a. new airport construction;

b. separation of 1.5 nmi for dependent parallel instrument approaches;

c. additional Instrument Landing Systems, as called for in Federal Aviation Administration (FAA) plans;

d. minimum longitudinal separations of 2.5 nmi on final approach where supported by acceptably low runway occupancy times;

e. dependent converging instrument approaches (DCIA);

f. simultaneous converging instrument approach (SCIA);

g. Precision Runway Monitor (PRM) and Final Monitor Aid (FMA), as called for in FAA plans; and

h. Center-Terminal Radar Approach Control (TRACON) Automation System (CTAS).

Of the previous factors, only CTAS is considered to be a TFM integrated product. Thus, airports that were scheduled to have CTAS operational by the year 2005 were modified to reflect the absence of CTAS to produce the non-TFM scenario. This task was conducted by reducing the acceptance rates at those airports modeled by NASPAC. The results of the 2005 scenario that include the effects of TFM products are published as a technical note (Baart & Cheung, 1994).

Cost of delay was estimated using the NASPAC Cost of Delay Module (Baart, Richie, & May, 1991). System-wide delay and cost of delay were recorded by location. The following list describes where flights may accumulate delay:

a. departure fix crossing,

b. arrival fix crossing,

c. miles-in-trail restriction,

d. sector entry crossing,

e. airport arrival,

f. airport departure, and

g. at-gate arrival (passenger delay).

1.1 BACKGROUND

The existing methods of controlling arriving aircraft as they approach and traverse the terminal area can result in aircraft spacing that is less than optimal. Controllers must solve the problem of achieving optimum separations between aircraft arriving at different altitudes and on different approach paths, taking into account the speed and space restrictions of the terminal area. Under these conditions, controllers must work harder and aircraft may burn more fuel to maintain the required separation. As a result, aircraft may be bunched together or have significant gaps between them. If significant gaps occur, the capacity of the airport will be reduced.

CTAS is expected to improve system performance, while maintaining the current level of safety, by helping controllers smooth out and coordinate traffic flows. There are several CTAS products that are designed to increase airport capacity.

a. Traffic Management Advisor (TMA) determines the optimum sequence and schedule for arrival traffic. Coordination between air traffic control (ATC) facilities is managed via the TMA in each facility. The use of TMA is expected to increase capacity by two percent in all weather conditions.

b. Descent Advisor (DA) assists center controllers in meeting arrival times efficiently while maintaining separation. The use of DA is expected to increase capacity by 1.5 percent in all weather conditions.

c. Final Approach Spacing Tool (FAST) helps TRACON controllers merge arrivals into an efficient flow on the final approach path. It also helps controllers merge missed-approach and "pop-up" traffic into the final approach stream. The use of FAST is expected to increase capacity in instrument meteorological conditions (IMC) by eight percent.

2. METHODOLOGY

A scenario was developed to simulate traffic flows as they are expected to exist in the year 2005 without CTAS. This scenario was compared to a previous one that included CTAS. Airport capacity estimates used in both scenarios were based on airfield improvements that were outlined in the Aviation System Capacity Plan for the year 2005. In addition, advances in technology expected to be completed by the year 2005 were also included, minus the contributions CTAS would make for the no-CTAS scenario. These technological improvements, designed to increase airport capacity, are summarized in Section 4 of this report. In review of the proposed expenditures contained in the Aviation System Capacity Plan, 24 airports modeled by NASPAC were identified to receive funding for either new runways or runway extensions. Funding for these airport improvements is derived from local, state, and federal agencies. Table 1 lists all of the airport improvements that were modeled. Three runs of the model were averaged for each scenario to account for statistical variations associated with one run.

TABLE 1. AIRPORT IMPROVEMENTS MODELED

Identification	Type of Improvement	Specifics
ATL	New commuter runway	3,000 ft south (5th parallel).
BWI	New parallel runway	10R/28L.
CLT	New parallel runway	18W/36W, assume Instrument Flight Rule (IFR).
DEN	New Denver Airport	(DIA)
DFW	Two new runway	16/34 and 18/36.
DTW	Two new runways	9R/27L and 4/22.
FLL	Runway extension	9R/27L.
IAD	New runway	1W/19W.
IAH	Two new runways	8L/26R and 9L/27R.
IND	New runway	5R/23L.
MCO	New runway	17L/35R.
MEM	New runway	18L/36R.
MKE	New Runway and extension	7L/25R and 1L/19R.
MSP	New runway	11/29W.
MSY	New runway	1L/19R.
PHL	New runway	8/26.
PHX	New runway	8S/26S (3rd parallel).
PIT	New runway	10S/28S.
SDF	Two new runways	17L/35R and 17R/35L (parallels).
SEA	New runway	16W/34W.
SLC	New runway	16W/34W.
STL	New runway	12L/30R, 4,300 ft from parallel.
SYR	New parallel runway	10L/28R.
TPA	New parallel runway	18/36.

The MITRE Corporation developed a method for computing annual results of NASPAC-based analysis. Six scenario days were selected as representative of varying levels of IMC and visual meteorological conditions (VMC) across the 58 NASPAC airports. To compute the annual results, weighting factors for each scenario day were applied according to the frequency of occurrence of similar days that were observed in year 1990. Table 2 shows the weights applied to the six scenario days.

As a means of determining where the majority of the delay was occurring, ground and airborne delays were summarized and presented on a system level and for individual airports. Ground delay consists of pushback delay at a gate, taxi delay to and from active runways, and arrival delay caused by occupied runways. Airborne delay is caused by airspace capacity limitations. Airborne delay accumulates when flights compete for arrivals and departures at ATC resources, such as flow control restrictions, arrival and departure fixes, and sectors.

TABLE 2. WEIGHTING FACTORS FOR THE SIX WEATHER SCENARIOS

Percent (%) VMC	Scenario Day Chosen	Weighting Factor
95% - 100%	January 13, 1990	80.00
90% - 95%	September 27, 1990	127.50
85% - 90%	May 16, 1990	86.25
80% - 85%	March 10, 1990	23.75
70% - 80%	March 31, 1990	17.50
< 70%	December 22, 1990	30.00

3. NATIONAL AIRSPACE SYSTEM PERFORMANCE ANALYSIS CAPABILITY OVERVIEW

The NASPAC SMS is a discrete event simulation model that tracks aircraft as they progress through the NAS and compete for ATC resources. Resources in the model include airports, sectors, flow control restrictions, and arrival and departure fixes. NASPAC evaluates system performance based on the demand placed on resources modeled in the NAS and records statistics at the 50 busiest national airports and 8 associated airports. See Appendix A for a complete list of airports and identifiers. NASPAC simulates system-wide performance and provides a quantitative basis for decision making related to system improvements and management. The model supports strategic planning by identifying air traffic flow congestion problems and examining solutions.

NASPAC analyzes the interactions between many components of the airspace system and the system reaction to projected demand and capacity changes. The model was designed to study nation-wide system performance rather than localized airport changes in detail, therefore, airports are modeled at an aggregate level. The model shows how improvements to a single airport can produce effects on delay that ripple through the NAS. Each aircraft itinerary consists of many flight legs that an aircraft will traverse during the course of a day. If an aircraft is late on any of its flight legs, successive flight legs may be affected. This is the way passenger delay accumulates.

NASPAC records two different types of delay, passenger and operational. Passenger delay is the difference between the scheduled arrival time contained in the Official Airline Guide (OAG) and the actual arrival time as simulated by NASPAC. Operational delay is the amount of time that an aircraft spends waiting to use an ATC system resource.

Traffic profiles consist of scheduled and unscheduled demand for each modeled airport. Scheduled demand is derived from the OAG and is used as the baseline from which future growth is projected. Unscheduled demand is determined from daily and hourly distributions taken from tower count. Projected traffic growth is provided by the TAF.

Key output metrics recorded in the model include delay and throughput at airports, departure fixes, arrival fixes, restrictions, and sectors, system wide and at all modeled airports. Operational delay consists of airborne and ground delay. Airborne operational delay is the delay that a flight experiences from takeoff through navigational aids, sectors, and static and dynamic flow control restrictions. Ground operational delay accumulates when an aircraft is ready to depart but has to wait for a runway to taxi on or take off from or when airfield capacity limitations prohibit the aircraft from landing. Operational delay contributes to passenger delay and is assigned to the airport that the flight is destined. Sector entry delay occurs when the instantaneous aircraft count or hourly aircraft count parameters for that sector are exceeded. Monetary assessments are derived by translating delay into measures of cost to the user by using the Cost of Delay Module. The Cost of Delay Module was incorporated into version 3.1 of the NASPAC SMS.

The Cost of Delay Module was used to translate delay into measures of cost to the airlines and user community. The Origin and Destination Survey, Form 41, for the last quarter of 1993, acquired from the Office of Airline Statistics (K-25), was used to calculate operational and passenger delay cost estimates. Operational costs include crew salaries, maintenance, fuel, equipment, depreciation, and amortization and are reported by the airlines on a quarterly basis. The data are disseminated into airborne and ground delay costs by carrier and aircraft type. Passenger costs are derived from the expected number of passengers on a flight multiplied by the FAA-endorsed value of $40.50 per hour of delay, multiplied by delay hours. Form 41 was used to estimate aircraft occupancy values.

4. ASSUMPTIONS AND CAVEATS

All of the airport capacity estimates used in the analysis for the year 2005 are based on airport airfield improvements projected in the Aviation System Capacity Plan and new technologies expected to be implemented by the year 2005. The 1993 TAF (FAA, 1991) were used to project traffic growth for the year 2005. These forecasts depend on many factors that are subject to change, such as economic and technological. The annualization method used in the 2005 scenario is an approximation and is based on weather observations taken from the year 1990. The model does not include rerouting or other methods used to minimize the impacts of adverse weather.

New technologies likely to be in place by the year 2005 are designed to increase airport capacity without adding or extending new runways. The following is a list of future improvements that were modeled.

a. Precision Runway Monitor (PRM)
This would allow simultaneous parallel IFR arrivals on runways spaced between 3,000 and 4,300 ft. ATL, CLT, MSP, RDU, CLE, JFK, and PHL are likely to be equipped with PRM by year 2005. See Appendix A for airport identification.

b. Final Monitor Aid (FMA)
Improved resolution would allow simultaneous parallel IFR approaches on dual runways spaced between 4,000 and 4,300 ft without full PRM. Those airports that would take advantage of this technology are FLL and DEN.

c. Airport Surface Traffic Automation (ASTA)
This technology is designed to optimize surface operations through improved sequencing of departures and more tactical management of aircraft movement. All NASPAC-modeled airports were affected by this improvement.

In addition to improvements in technology, procedural changes for the future system have been considered for this study for the baseline scenario (2005 with CTAS). The 2005 no-CTAS scenario provides quantitative estimates of the TFM products removed from the system, which is the main objective of this study. The following is a list of the procedural changes designed to increase airport capacity.

a. CTAS
NAS-wide implementation of CTAS would optimize final approach separations by more efficiently distributing en route delay.

b. DCIA
The reduction of terminal separation minima may be realized by monitoring aircraft approaching converging runways more accurately. Those airports affected include BOS, CLE, CLT, CVG, MEM, MKE, PHL, SFO, and STL. See Appendix A for airport identification.

c. Reduced Diagonal Separation for Parallel Approaches
The reduction of diagonal separation from 2 nmi to 1.5 nmi may be realized for parallel runways not eligible for independent parallel approaches and that are 2,500 ft apart. Affected airports include DAL, PHX, PHL, SLC, SJC, SEA, MSP, STL, and DEN.

5. CAPACITY

The system performance team identified 16 major airports that are directly affected by CTAS. As a result, new airport capacities were derived for those airports so that NASPAC simulations could be used to assess the system impact of CTAS. Table 3 shows the capacity values in the simulation under VMC for these airports. Table 4 shows the capacity values that were used under IMC for the same airports.

TABLE 3. CAPACITY UNDER VISUAL METEOROLOGICAL CONDITIONS FOR THE 16 AIRPORTS AFFECTED BY CENTER-TRACON AUTOMATION SYSTEM (CTAS)

Airport	Maximum	Minimum	Minimum	Maximum	0/50	0/50

	Arrival	Departure	Arrival	Departure	Arrival	Departure
ATL	123	134	90	160	123	134
BNA	70	23	35	105	56	56
BOS	43	28	00	62	35	35
BWI	58	16	22	66	40	40
DCA	34	8	16	48	26	26
DEN	90	120	90	120	90	120
DFW	120	104	112	137	117	117
DTW	78	44	35	105	64	64
EWR	35	22	27	39	31	31
IAD	89	2	14	81	47	47
IAH	96	57	66	94	79	79
JFK	57	12	22	67	40	40
LAX	68	75	55	88	68	75
LGA	34	37	00	51	34	37
ORD	91	20	56	78	64	64
SEA	40	34	26	72	38	38

TABLE 4. CAPACITY UNDER INSTRUMENT METEOROLOGICAL CONDITIONS FOR THE 16 AIRPORTS AFFECTED BY CTAS

Airport	Maximum Arrival	Minimum Departure	Minimum Arrival	Maximum Departure	0/50 Arrival	0/50 Departure
ATL	109	79	45	157	95	95
BNA	55	19	28	83	44	44
BOS	62	52	00	120	57	57
BWI	82	43	49	82	64	64
DCA	50	17	25	75	40	40
DEN	111	150	111	150	111	150
DFW	160	136	118	178	148	148
DTW	96	54	35	105	73	73
EWR	50	48	46	57	49	49
IAD	97	37	15	97	62	62
IAH	108	136	108	136	108	136
JFK	74	15	16	80	46	46
LAX	84	60	60	84	60	60
LGA	44	35	17	51	38	38
ORD	102	52	52	108	78	78
SEA	88	31	68	70	69	69

These values represent the maximum, minimum, and 50/50 mix of the hourly departure and arrival rates at these airports. The minimum departure capacity is the hourly departure rate when arrivals are given highest priority (arrival priority). Conversely, minimum arrival capacity exists when departures are given higher priority (departure priority). The minimum service time between successive arrivals and departures are determined from these hourly rates and the subsequent arrival and departure queue lengths. As experienced from previous studies, the largest contributor of delay culminates at airports where aircraft compete for runway usage.

6. RESULTS

6.1 PASSENGER DELAY AND COST OF DELAY AT THE TWELVE AIRPORTS

The baseline scenario (2005 with CTAS) showed that 12 out of the 58 major airports modeled recorded large passenger delay. These include BOS, DCA, DFW, FLL, LAX, LGA, MIA, ORD, PHX, SAN, SFO, and SNA. Of these airports, only DFW and PHX are expected to add runways to increase airport capacity. Since operational delay is relatively small at these airports, most of the passenger delay propagates from other airports that share traffic with DFW and PHX. Results of the simulation indicate that only 6 out of the 12 airports have benefited from the implementation of CTAS. The "-" sign in all of the figures throughout this report indicates an increase in delay.

Figure 1 describes the difference in passenger delay between the CTAS and no-CTAS scenarios. As observed, LGA recorded the largest reduction in passenger delay (6 percent), followed by FLL and LAX (1 percent), PHX (0.3 percent), SFO (0.2 percent), DFW and SNA (0.1 percent each). Passenger delay cost differences between the two scenarios are shown in Figure 2, with LGA again showing the largest reduction.

6.2 OPERATIONAL DELAY AND COST OF DELAY AT THE TWELVE AIRPORTS

Figure 3 describes the operational delay differences between the two scenarios for those airports listed. Results indicate that DFW recorded the largest reduction in delay (3.4 percent), followed by PHX (3 percent), DCA (2 percent), SFO (1 percent), LAX (0.4 percent), and SNA (0.1 percent). Results indicate that the implementation of CTAS will increase operational delay at MIA and FLL by 2 percent each, followed by ORD (0.6 percent), SAN (0.4 percent), LGA, (0.3 percent), and BOS (0.1 percent). Total percentage reduction in operational delay at the six airports that benefited from CTAS is 9.9 percent. The total benefit of CTAS at these 12 airports out weighs the increase in operational delay even though only BOS, DCA, DFW, LAX, LGA, and ORD were directly affected by CTAS.

As one would expect, operational delay costs for the 12 airports follow the same pattern as measures of operational delay. Figure 4 shows the operational delay cost savings at these airports. As observed, LGA recorded the largest reduction (6 percent), followed by DCA and DFW (4 percent each), LAX, PHX, and SFO (1 percent each). Operational delay cost at FLL increased by 6 percent, followed by MIA (2 percent), ORD and SAN (0.4 percent each), and BOS (0.2 percent). The total percentage of delay savings with CTAS is 17.1 percent at DCA, DFW, LAX, LGA, PHX, SFO, and SNA. A 9 percent increase in delay was recorded at BOS, FLL, MIA, ORD, and, SAN. Again, the benefit in cost savings due to CTAS outweighs the increase in delay cost at these airports without CTAS.

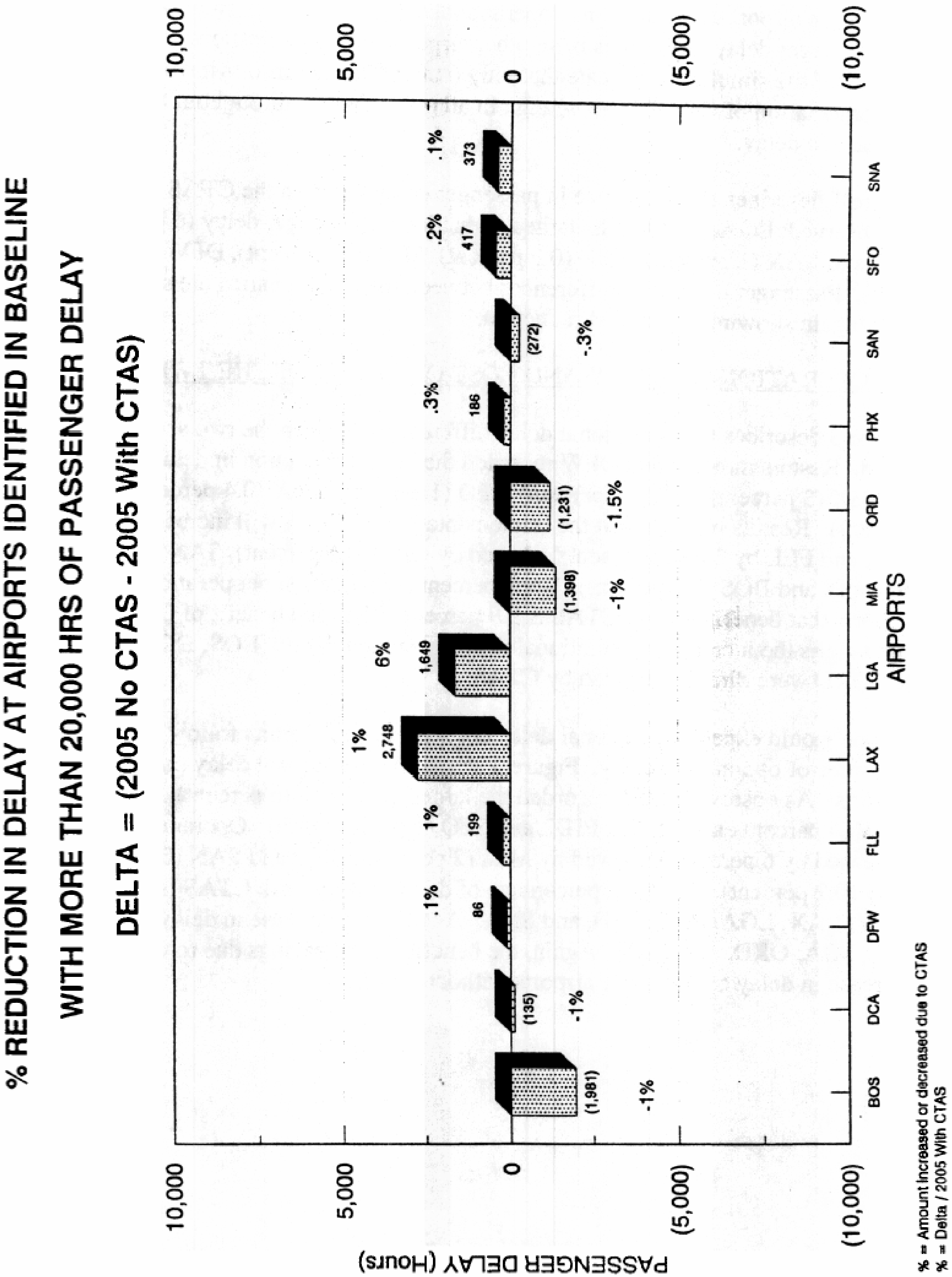

FIGURE 1. TWELVE AIRPORTS IDENTIFIED IN BASELINE
WITH LARGE PASSENGER DELAY

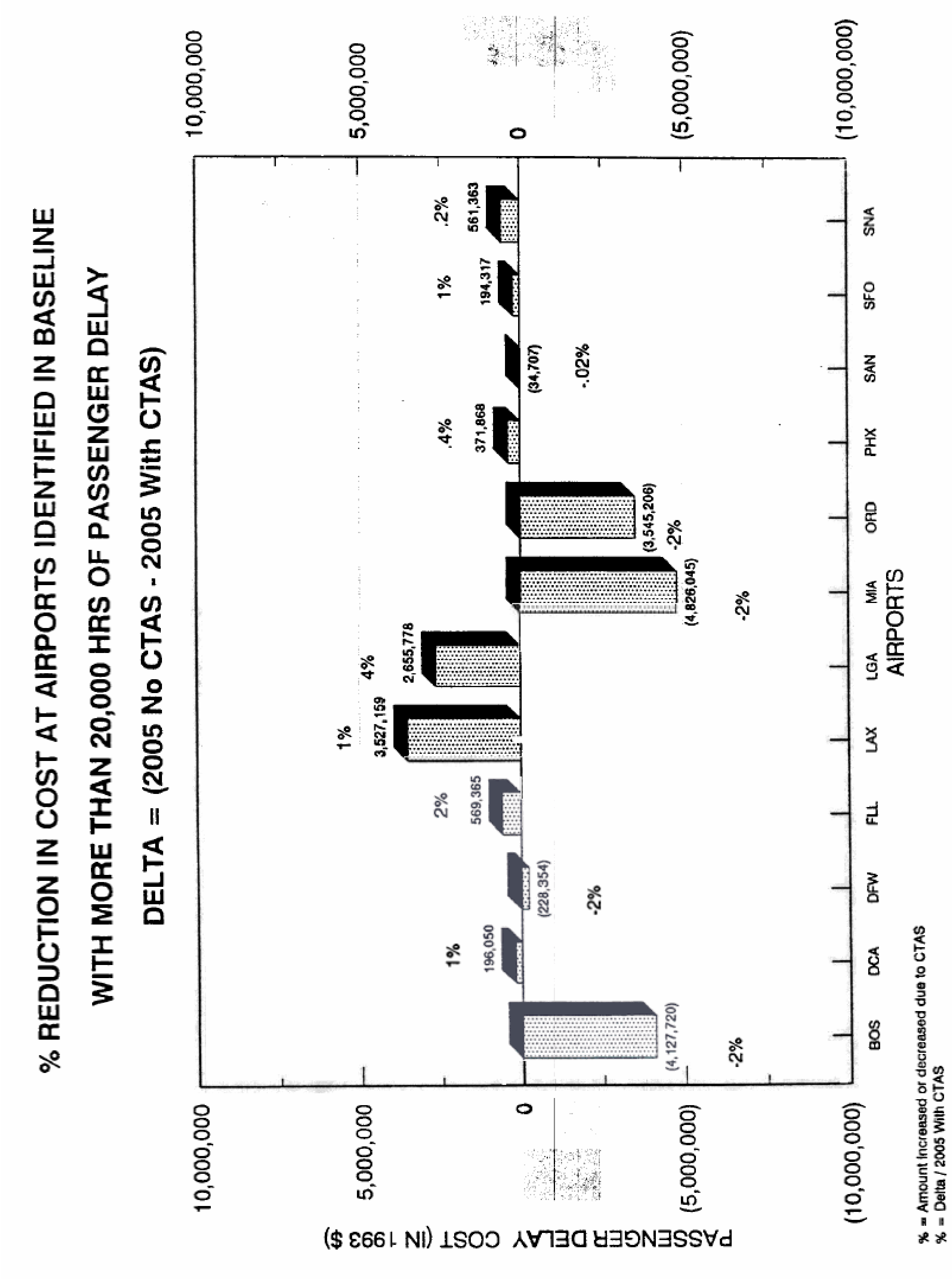

FIGURE 2. TWELVE AIRPORTS IDENTIFIED IN BASELINE
WITH LARGE PASSENGER DELAY COST

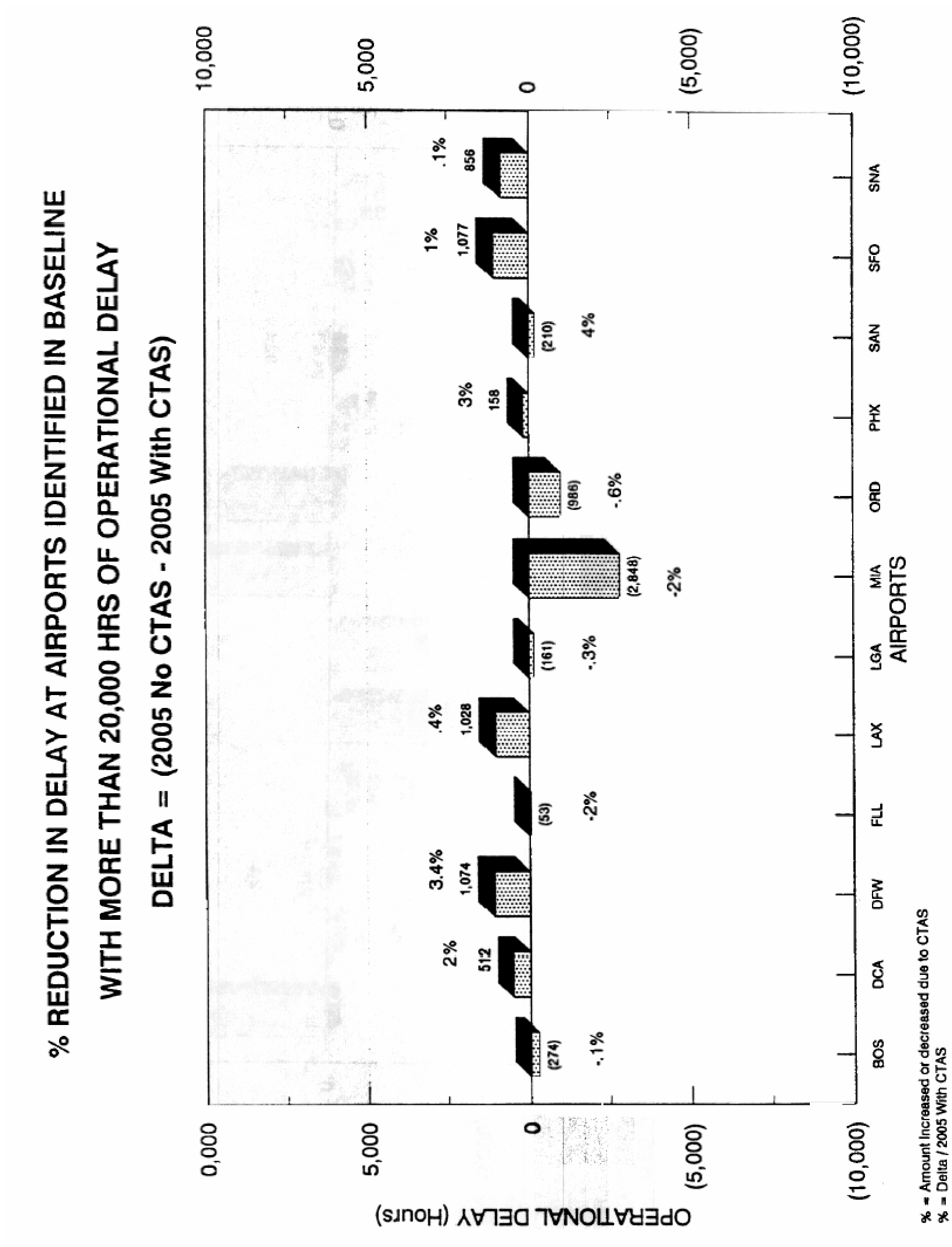

FIGURE 3. REDUCTION IN OPERATIONAL DELAY AT THE 12 AIRPORTS

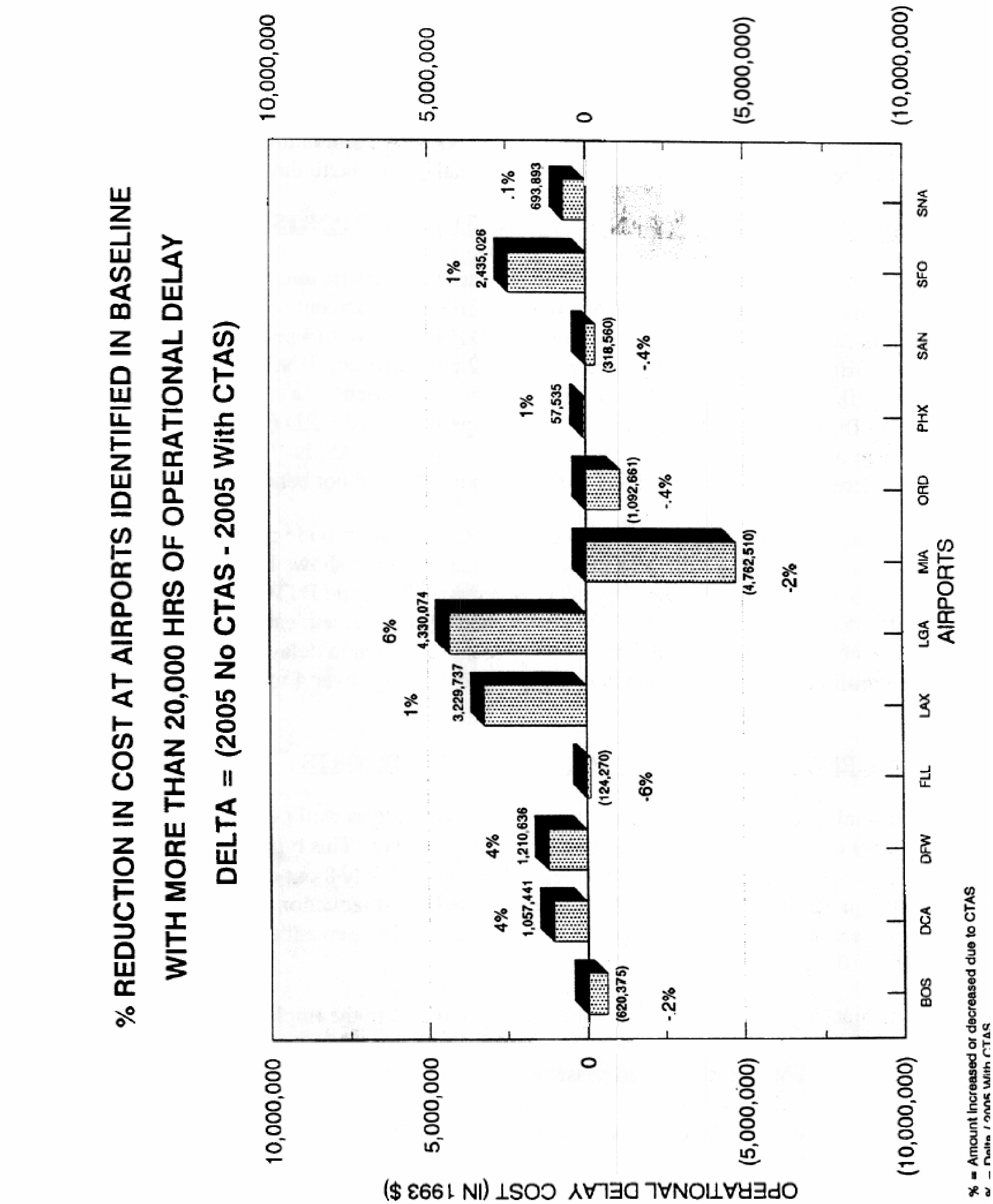

FIGURE 4. REDUCTION IN OPERATIONAL DELAY COST AT THE 12 AIRPORTS

6.3 AIRPORTS DIRECTLY AFFECTED BY CENTER-TERMINAL RADAR APPROACH CONTROL AUTOMATION SYSTEM

The following 16 airports were identified by the system performance team to be directly affected by CTAS in the year 2005: ATL, BNA, BOS, BWI, DCA, DEN, DFW, DTW, EWR, IAD, IAH, JFK, LAX, LGA, ORD, and SEA. Results of the NASPAC simulations show that 12 out of the 16 airports recorded annual reductions in operational delay due to the implementation of CTAS.

6.4 OPERATIONAL DELAY AND COST AT THE 16 AIRPORTS

Figure 5 shows the operational delay reductions at these airports due to the implementation of CTAS. The results suggest that DEN would experience 12 percent reduction in operational delay in the year 2005, followed by ATL (6 percent), DTW and EWR (4 percent each), DFW (3.4 percent), SEA (3 percent), DCA, IAD and IAH (2 percent each), BNA and BWI (1 percent each), and LAX (0.4 percent). Only 4 out of the 16 airports experienced a slight increase in delay. These are BOS and JFK (0.1 percent), LGA (0.3 percent), and ORD (0.6 percent). The total percentage of reduction in delay at the 12 airports, due to CTAS, is 40.8 percent compared to 1.1 percent increase in operational delay at the 4 airports that did not benefit from CTAS.

Operational delay cost comparisons indicate that CTAS can provide monetary benefits as shown in Figure 6. Cost saving estimates recorded in the simulation shows DEN with a 16 percent reduction in delay costs, followed by ATL (9 percent), BWI and DTW (7 percent), LGA (6 percent), SEA (5 percent), DCA, DFW, EWR, and IAH (4 percent each), BNA and IAD (2 percent each), and LAX (1 percent). The 4 percent reduction in delay at EWR translates into over 19 million dollars in savings, and LGA will experience over 4 million dollars in delay savings.

6.5 PASSENGER DELAY AND COST AT THE 16 AIRPORTS

Total annual passenger delay at these airports does not fare as well as the operational delay. This is probably caused by the rippling effect of passenger delay. This type of delay may accumulate at other airports than the ones listed. Figure 7 shows that only 8 out of the 16 airports show any reduction in passenger delay. LGA experiences the largest reduction (6 percent), followed by EWR (4 percent), ATL (3 percent), BNA, BWI and LAX (1 percent each), DEN (0.4 percent), and DFW (0.1 percent).

Airports that show an increase in the passenger delay due to the implementation of CTAS are: IAH and JFK (3 percent each), IAD, ORD and SEA (2 percent each), and BOS and DCA (1 percent each). Total percentage in passenger delay reduction is 16.5. Those airports that did not benefit from CTAS experienced a 14.1 percent increase in passenger delay. This suggests that the difference between the CTAS scenario and the no-CTAS scenario is negligible.

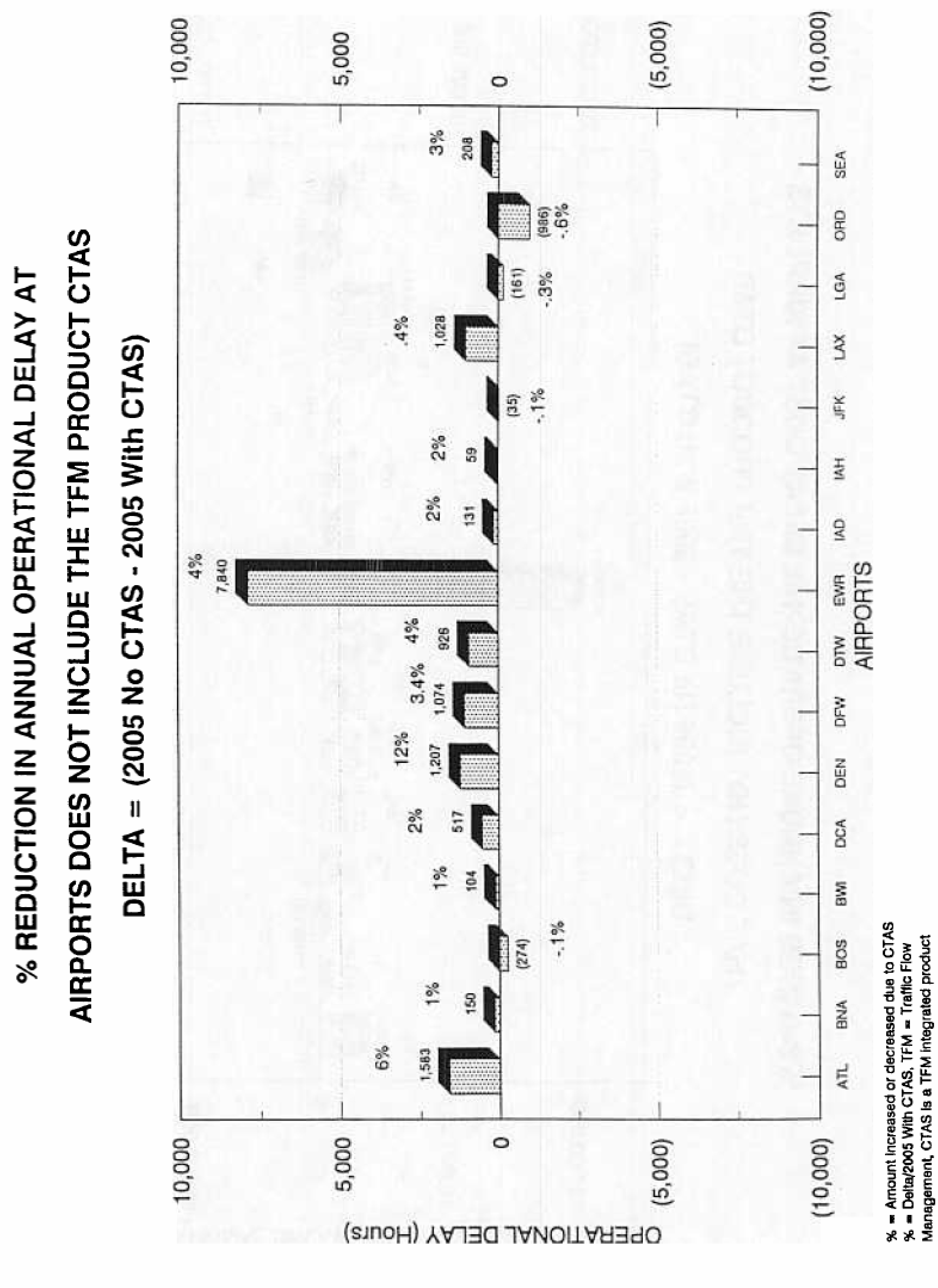

FIGURE 5. REDUCTION IN ANNUAL OPERATIONAL DELAY
AT THE 16 AIRPORTS WITH CTAS

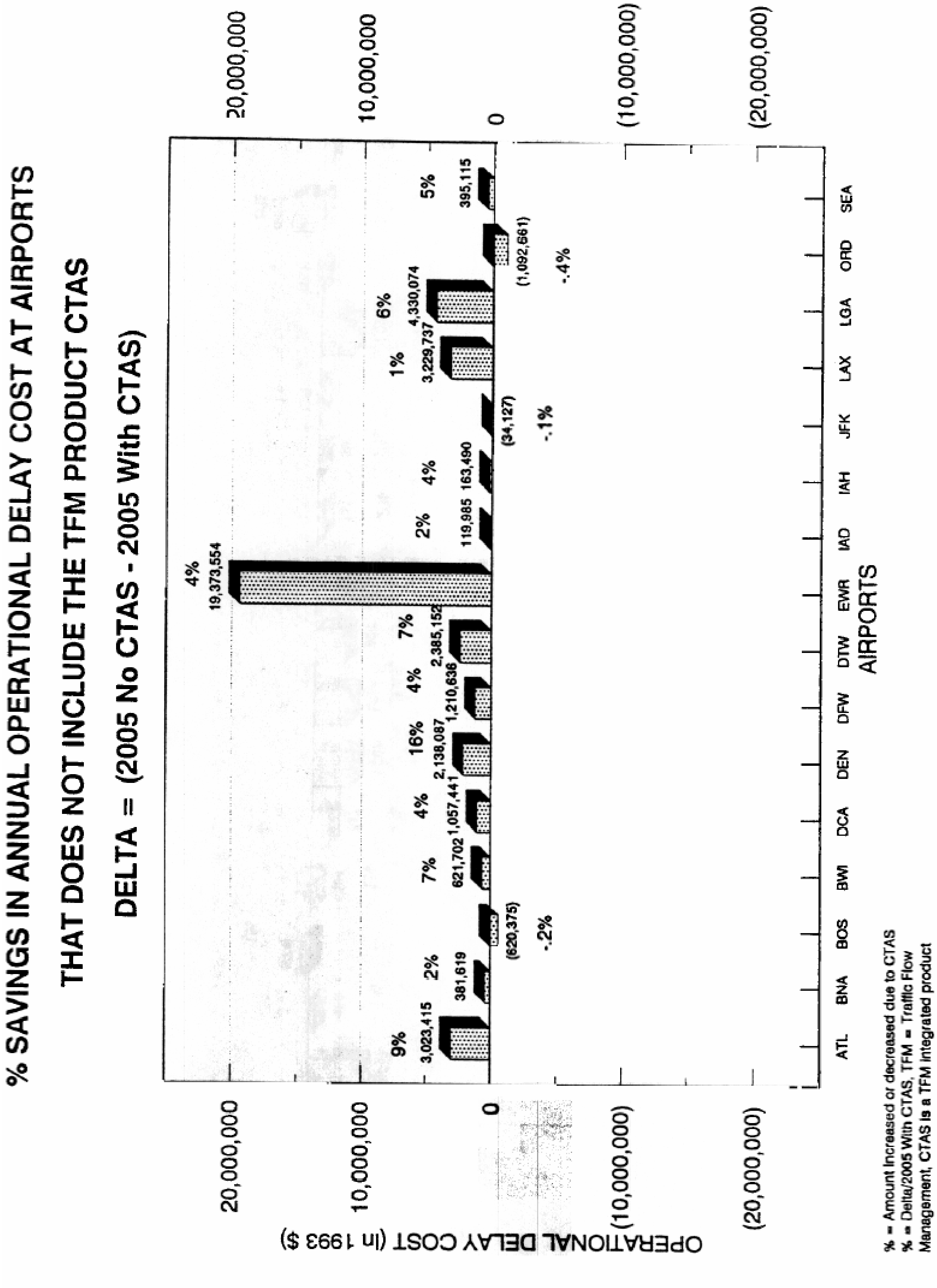

FIGURE 6. REDUCTION IN ANNUAL OPERATIONAL DELAY COST AT THE 16 AIRPORTS WITH CTAS

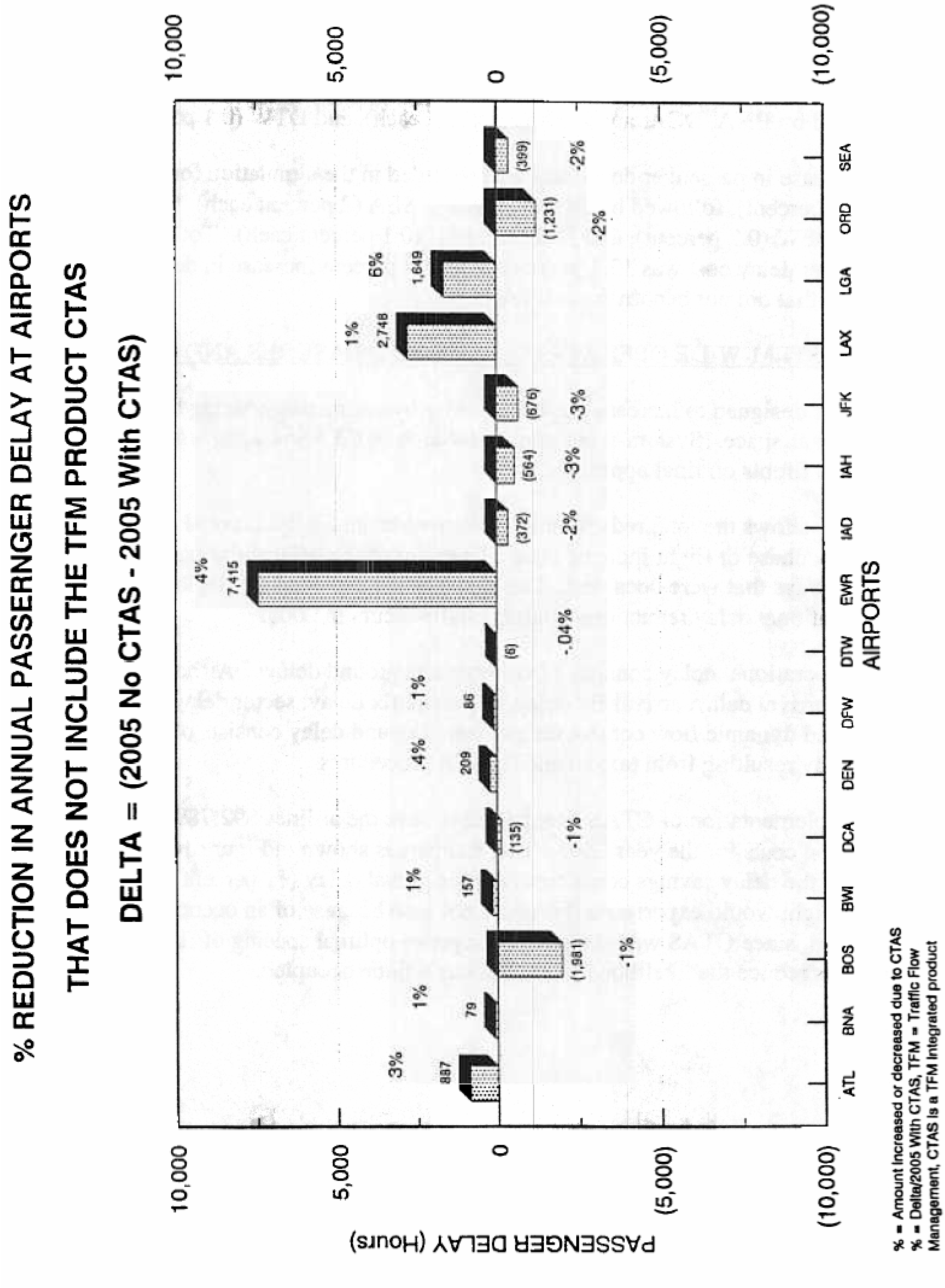

FIGURE 7. REDUCTION IN ANNUAL PASSENGER DELAY
AT THE 16 AIRPORTS WITH CTAS

As one would expect, passenger delay cost estimates follow the same pattern as the measures of passenger delay. Figure 8 shows the total annual delay cost estimates for the airports listed. EWR and LGA show the largest reduction in passenger delay (4 percent each). The reduction in delay at EWR translates into a 20 million dollar savings. ATL shows a 2 percent reduction, followed by BNA, DCA, and LAX (1 percent each), and DTW (0.1 percent).

An increase in passenger delay cost was recorded in the simulation for the following airports: IAD (3 percent), followed by BOS, ORD, and SEA (2 percent each), BWI and JFK (1 percent each), DFW (0.2 percent), and DEN and IAH (0.1 percent each). Total percentage reduction in passenger delay cost was 13.1 percent. An 11.2 percent increase in delay was recorded at those airports that did not benefit from CTAS.

6.6 SYSTEM-WIDE OPERATIONAL DELAY MEASURES AND COST BREAKDOWN

CTAS is designed to increase airport capacity by optimizing spacing between flows of traffic in terminal airspace. System-wide implementation of CTAS is designed to optimize spacing between flights on final approach.

Figure 9 shows the total reduction in system-wide annual operational delay. A breakdown of the delay by phase of flight indicates that 61 percent of the delay culminates from flights waiting to use runways that were occupied. The simulation shows that the deployment of CTAS will result in operational delay reductions totaling 38,404 hours in 2005.

Total operational delay consists of airborne and ground delays. Airborne delay is the sum of airport arrival delay, arrival fix delay, departure fix delay, sector delay, and delay resulting from static and dynamic flow control restrictions. Ground delay consists of pushback from gate delay and delay resulting from taxi-in and taxi-out procedures.

The implementation of CTAS is expected to save the airlines $92,789,092 (1993 dollars) in operation costs for the year 2005. This estimate is shown in Figure 10. Results indicate that most of the delay savings come from airport arrival delay (71 percent). This is the type of delay that a flight would experience if it could not land because of an occupied runway. This is expected, since CTAS was designed to improve optimal spacing of flights in terminal airspace and thus reduce the likelihood that a runway will be occupied.

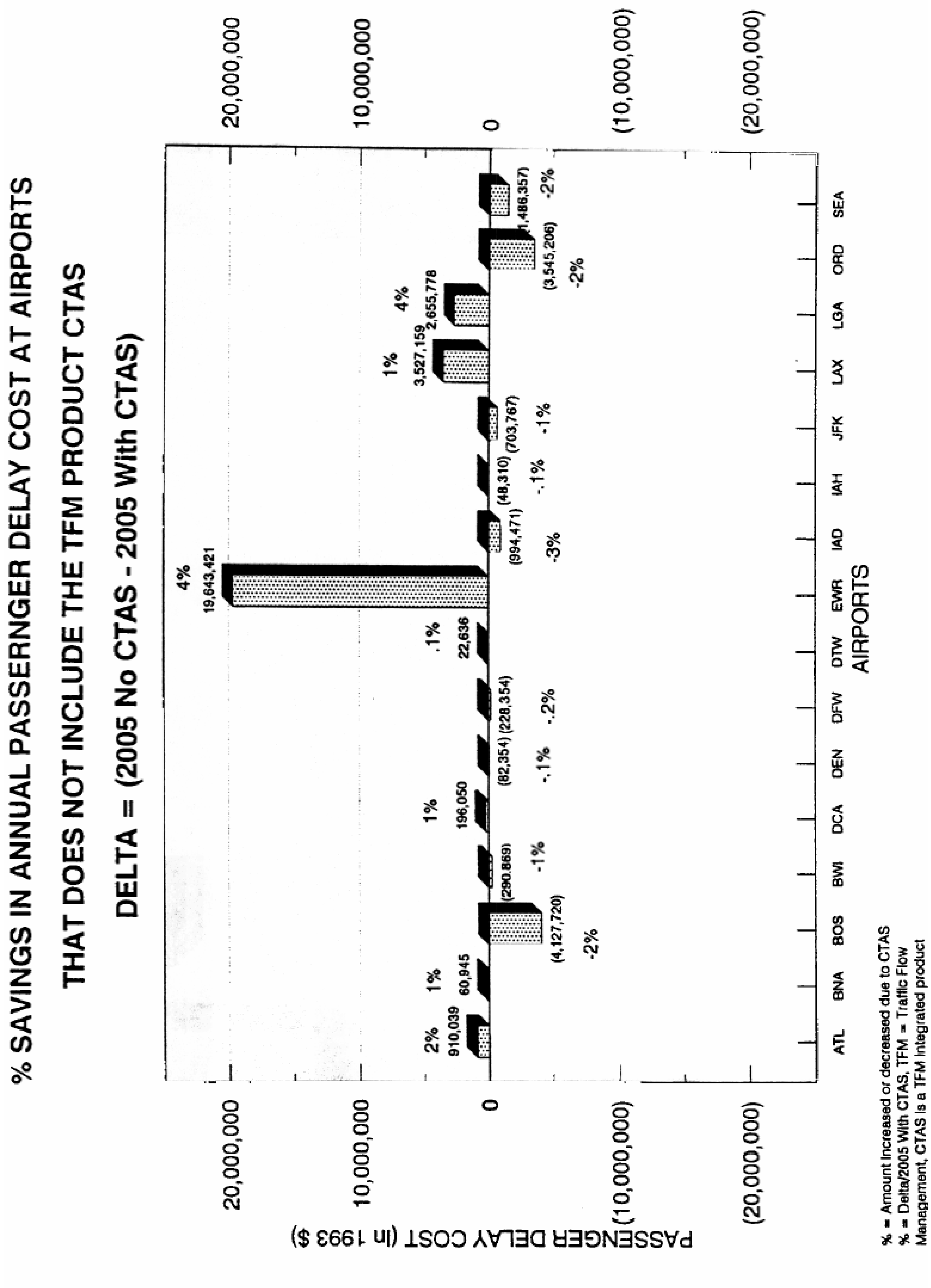

FIGURE 8. REDUCTION IN ANNUAL PASSENGER DELAY
COST AT THE 16 AIRPORTS WITH CTAS

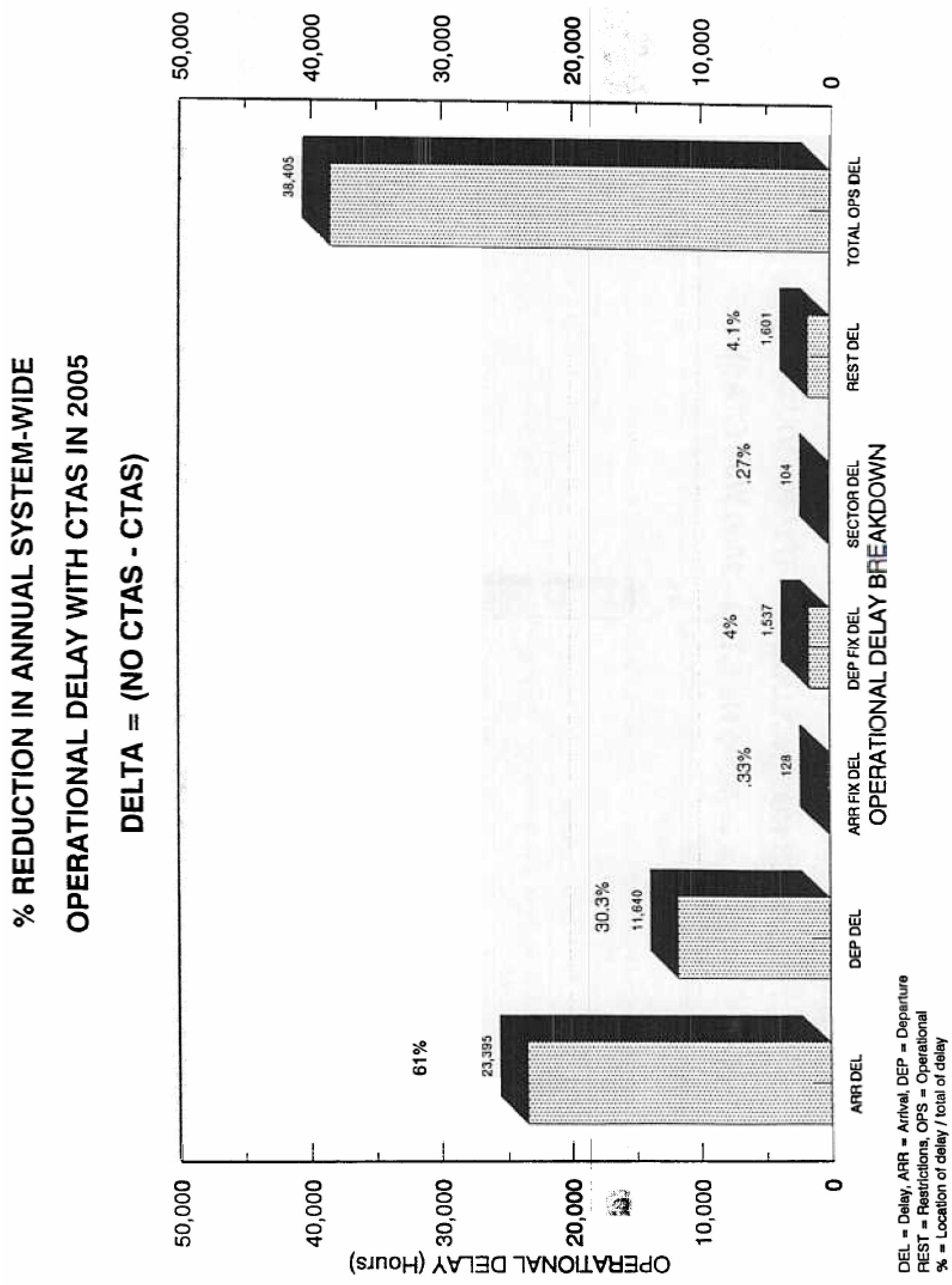

FIGURE 9. REDUCTION IN ANNUAL SYSTEM-WIDE OPERATIONAL DELAY WITH CTAS

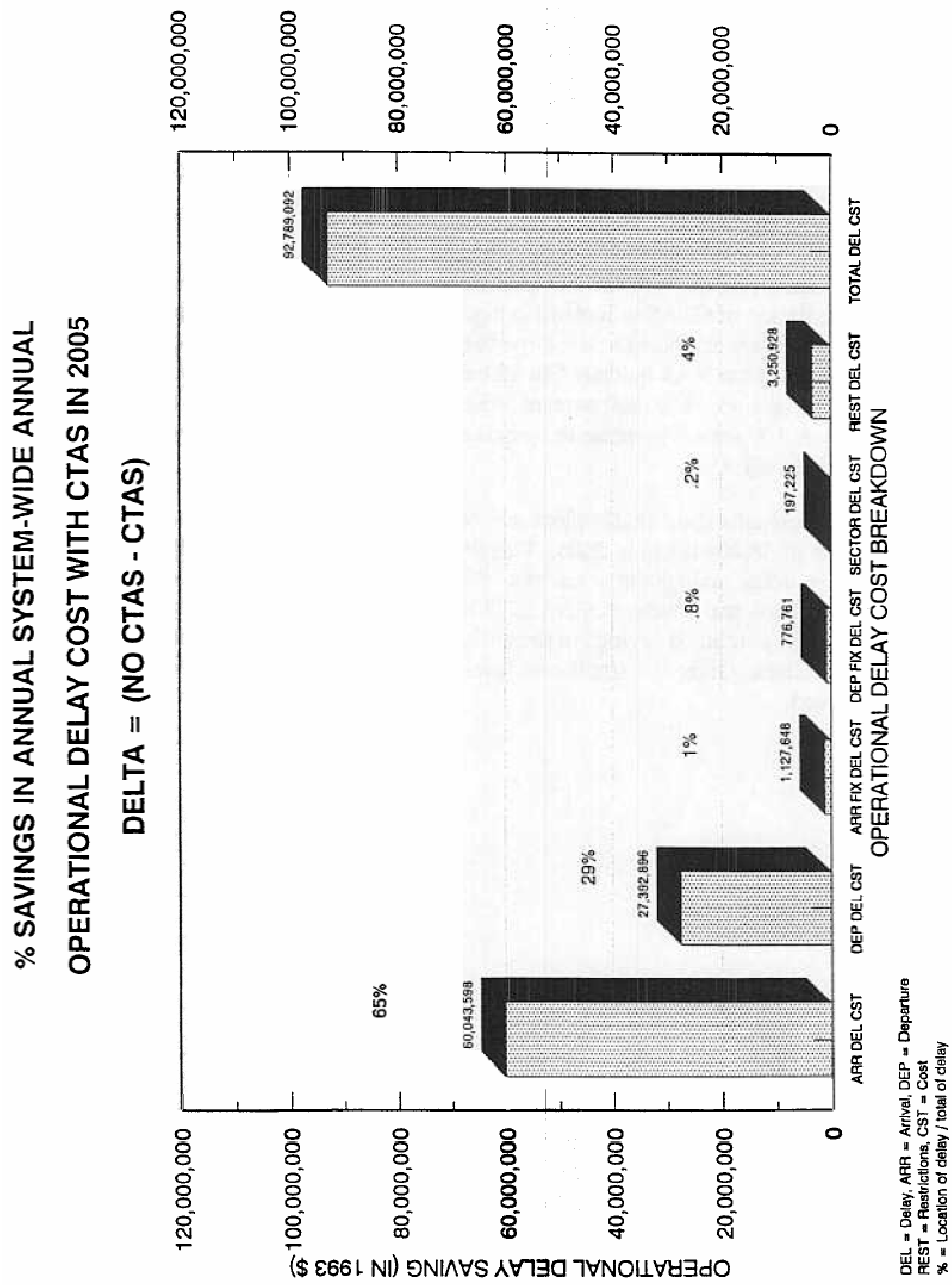

FIGURE 10. REDUCTION IN ANNUAL SYSTEM-WIDE OPERATIONAL DELAY COST WITH CTAS

6.7 SYSTEM-WIDE PASSENGER DELAY BENEFITS

As evidenced from the individual airports, total annual system-wide passenger delay reductions were smaller than the operational delay reductions. This was expected because CTAS was designed to improve the spacing of flights on final approach, which would reduce operational arrival delay. Simulation results showed that the total passenger delay reduction system wide was 2,277 hours. This translates to only 1,757,514 million dollars in savings.

7. CONCLUSIONS

The simulation results indicate that an increase in airport capacity provided by the implementation of CTAS will result in significant reductions in operational delay. Most of these delay savings are attributed to the airports that will have CTAS operational by the year 2005. Simulations of the NAS indicate that 12 out of the 16 airports slated for CTAS will have significant savings. The total percent reduction in operational delay at these 12 airports is 40.8 percent. A 1.1 percent increase in operational delay was observed at the four airports that did not benefit from CTAS.

Simulation results show that deployment of CTAS will result in a system-wide operational delay reduction of 38,404 hours in 2005. This delay translates into 92,789,092 million dollars (1993 dollars) in delay savings to the airlines. On the other hand, the annual system-wide passenger delay reduction was much smaller (2,277 hours). This translates to only 1,757,514 million dollars. The combined savings to the airlines and the traveling public is estimated at 93,546,606 million dollars. Given the significant level of annual savings, deployment of CTAS should be accelerated.

8. REFERENCES

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APPENDIX A

AIRPORTS MODELED BY NATIONAL AIRSPACE SYSTEM PERFORMANCE ANALYSIS CAPABILITY

Airport Identifier	Airport	Airport Identifier	Airport
ABQ	Albuquerque International	MCI	Kansas City International
ATL	Atlanta International	MCO	Orlando International
BDL	Bradley International	MDW	Chicago Midway
BNA	Nashville International	MEM	Memphis International
BOS	Logan International (Boston)	MIA	Miami International
BUR	Burbank-Glendale-Pasadena	MKE	Milwaukee International
BWI	Baltimore/Washington	MSP	Minneapolis St. Paul International
CLE	Clevland-Hopkins International	MSY	New Orleans Moisant Field
CLT	Charlotte/Douglas International	OAK	Metropolitan Oakland
CVG	Cincinnati/Northern Kentucky	ONT	Ontario International
DAL	Dallas Love Field	ORD	Chicago O'Hare International
DAY	Dayton International	PBI	Palm Beach International
DCA	Washington National	PDX	Portland International
DEN	Denver International	PHL	Philadelphia International
DFW	Dallas/Fort Worth International	PHX	Phoenix Sky Harbor
DTW	Detroit Metropolitan	PIT	Pittsburgh International
EWR	Newark International	RDU	Raleigh Durham International
FLL	Fort Lauderdale/Hollywood	SAN	San Diego Lindbergh Field

HOU	Houston Airport	SAT	San Antonio International
HPN	White Plains Airport	SDF	Louisville Standiford Field
IAD	Washington Dulles International	SEA	Seattle-Tacoma International
IAH	Houston Intercontinental	SFO	San Francisco International
IND	Indianapolis International	SJC	San Jose International
ISP	Islip (Long Island MacArthur)	SLC	Salt Lake City International
JFK	New York (John F. Kennedy)	SNA	Santa Anna (John Wayne)
LAS	Las Vegas International	STL	Lambert St. Louis
LAX	Los Angeles International	SYR	Syracuse Hancock
LGA	New York (La Guardia)	TEB	Teterboro
LGB	Long Beach/Dougherty Field	TPA	Tampa