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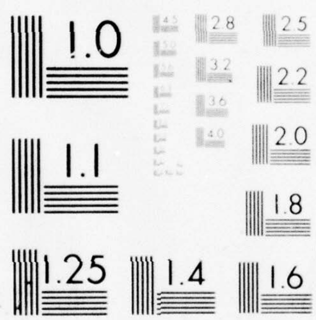

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AIRPORT SURFACE TRAFFIC CONTROL TAGS PLANNING ALTERNATIVES AND COST/BENEFIT ANALYSIS

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JANUARY 1977

FINAL REPORT

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16. Abstract

The findings of a cost/benefit analysis of the deployment of a new airport ground surveillance system TAGS (Tower Automated Ground Surveillance) are presented. TAGS will provide a plan view display of aircraft on the airports taxiways and runways like ground surveillance radar (ASDE); but unlike ASDE, TAGS will perform in heavy precipitation and automatically acquire and display aircraft flight identity. The findings indicate that a TAGS deployment of between four and nine systems is cost/beneficial. The development plan, system costs, analysis approach and sensitivity analysis supporting the findings are provided.

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PREFACE

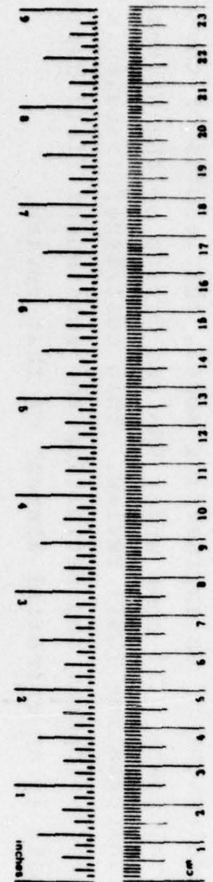
This work was performed as part of the Airport Surface Traffic Control (ASTC) Program at the Transportation Systems Center. This program is sponsored by the Department of Transportation through the Federal Aviation Administration (FAA), Systems Research and Development Service (SRDS).

The work consists of a cost/benefit analysis of the deployment of a new airport ground surveillance system, TAGS (Tower Automated Ground Surveillance). TAGS is currently in an exploratory development phase including preliminary system design, feasibility analyses and component field testing. Prior to initiating advanced system development of an engineering model, the results of the exploratory development will come under FAA and Office of the Secretary of Transportation (OST) review. This cost/benefit analysis supporting the development and estimating the subsequent field deployment costs is an essential element of that review.

METRIC CONVERSION FACTORS

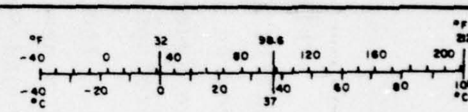
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ABBREVIATIONS AND GLOSSARY

Air Carrier Operation (A/C) - Aircraft operating under certificates of public convenience and necessity, issued by the Civil Aeronautics Board, authorizing the performance of scheduled air transportation over specified routes and a limited amount of nonscheduled operations.

Air Taxi Operation (A/T) - Air taxi and commuter airline operations carrying passengers, mail and cargo for revenue in accordance with FAR Part 135 or Part 121.

Air Traffic Control Radar Beacon System (ATCRBS) - The present beacon surveillance system which depends upon a network of ground interrogators and aircraft equipped with transponders.

Airport Surface Detection Equipment (ASDE) - A passive skin tracking ground surveillance radar. Maximum range about 3 n mi.

Airport Surveillance Radar (ASR) - A passive skin tracking radar designed for use by a terminal radar approach control facility. Maximum range about 60 n mi.

ATL - Atlanta International Airport.

Automated Radar Terminal System (ARTS) - A digital processing and display system for terminal air traffic control.

BOS - Boston-Logan International Airport.

Busy Hours - The number of hours in the busy period at an airport during a typical weekday. At large air commerce airports the busy hours number from 13 to 15 hours.

Busy Period - That portion of a day in which the operations rate is within 40 percent of the peak hour operations rate. At large air commerce airports the busy period is from approximately 0700 to 2200 hours and accounts for 80 to 90 percent of all daily traffic.

CAT - Category of weather in visibility and ceiling.

DEN - Stapleton International Airport, Denver, Colorado.

DFW - Dallas-Fort Worth Airport.

DTW - Detroit-Metropolitan Wayne County Airport.

EWR - Newark International Airport.

Itinerant Operations (ITN) - All aircraft arrivals and departures other than local operations. Local operations are performed by aircraft which (a) operate in a local traffic pattern or within sight of the airport, (b) are known to be departing for, or arriving from, flight in local practice areas located within a 20-mile radius of the airport, or (c) execute simulated instrument approaches or low passes at the airport.

JFK - J. F. Kennedy International Airport, New York, New York.

LAX - Los Angeles International Airport.

LGA - LaGuardia Airport, New York, New York.

Metering and Spacing (M&S) - Automation aids to terminal approach control.

MIA - Miami International Airport.

ORD - Chicago O'Hare International Airport.

Peak Hour - The hour of day during a typical weekday in which the most operations take place.

PHL - Philadelphia International Airport.

PIT - Greater Pittsburgh International Airport.

SFO - San Francisco International Airport.

STL - Lambert-St. Louis International Airport.

TAGS - Tower Automated Ground Surveillance.

TCA - Terminal Control Area.

UG3RD - Upgraded Third Generation Air Traffic Control System.

EXECUTIVE SUMMARY

This report presents the findings of a cost/benefit analysis and planning alternatives performed for the development, deployment and field operation of a Tower Automated Ground Surveillance (TAGS) system. TAGS is a proposed surveillance aid for airport traffic control tower cab controllers in conditions of poor visibility. It is planned for deployment in the 1980's, at which time ASDE-3 (the new ground surveillance radar) will be the primary ground surveillance aid. The report describes the capabilities which the ASTC system will have once ASDE-3 is deployed and the additional impact TAGS will have on the system beyond the capabilities of ASDE-3. TAGS will be an advancement over ground surveillance radar, but it is more expensive and is intended for application only at the busiest airports. The major advantages of TAGS over ASDE-3 are:

1. Its performance is immune to bad weather (e.g., heavy rainfall)
2. It provides flight identity on all cab-controlled aircraft.

The baseline TAGS program for which the cost/benefit analysis was performed calls for the development of a TAGS engineering model at Chicago O'Hare airport between FY77 and FY80, with the engineering model being commissioned for use between 1980 and 1985. In 1986, four production units would be deployed on a single buy to Chicago O'Hare (replacing the engineering model), Atlanta, Los Angeles, and New York (JFK) airports and operated through the year 2000. Benefits in reduced surface delays accrued by the system engineering model at O'Hare between 1980 and 1985 would pay for the entire TAGS cost of development. The baseline program would accrue a present value (base year FY76) net benefit of $18.7 million, with a benefit/cost ratio of 2.9.

A sensitivity analysis was performed to determine the impact of variations in several basic study parameters. Parameters considered included development, production and installation costs, service demand (i.e., which users required service during bad cab visibility conditions), forecast traffic growth, and control system capacity assumptions. In addition, an alternative to commissioning the engineering model at O'Hare was considered. In each instance, the results indicated a solid requirement for system development and a production deployment potential of up to nine airports. Even the worst case scenario was cost beneficial. The worst case scenario assumed the development would begin at O'Hare but:

1. Traffic would grow as forecast only through 1980 and then would level off.
2. Development would slip by 2 years with a 50 percent cost increase.
3. Production costs would be 50 percent higher than estimated.
4. Cost of passenger delay would be 50 percent lower than estimated.

With these assumptions it was found that only O'Hare would need TAGS but that commissioning the development model would pay for all development costs by the mid-1990's. Accrued costs and benefits for both the baseline program and the worst case scenario are shown in Figure S-1.

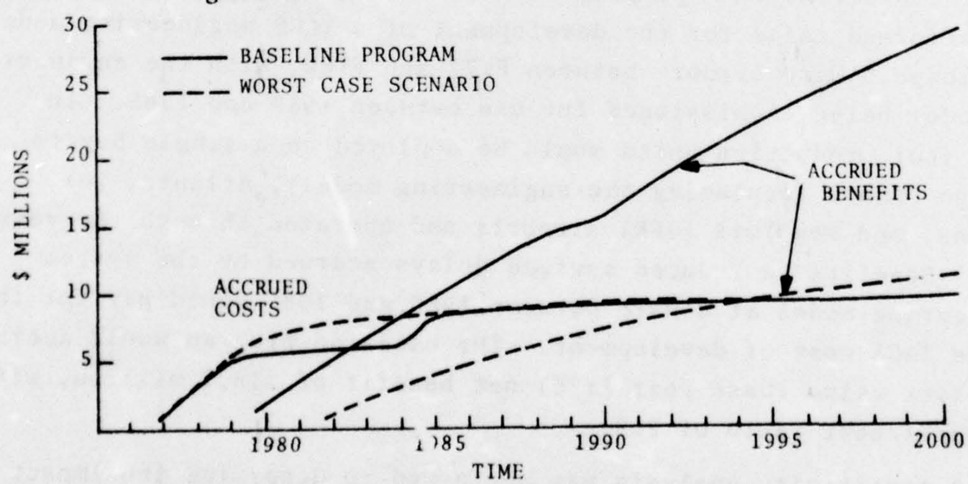

FIGURE S-1. ACCRUED BENEFITS AND COSTS FOR TAGS

1. INTRODUCTION

1.1 CURRENT SYSTEM DESCRIPTION

Control of aircraft on final approach and initial departure paths and on the surface of the airport is currently managed manually by controllers stationed in the cab of the airport control tower. At the major airports, the control function is usually divided into local control, for management of the runways, approach, and initial departure; and ground control, for management of the taxiways. Each position is staffed by one or more controllers. Communications between pilot and controller are by voice radio. The location of aircraft is obtained by the controllers visually, when weather permits, or by pilot position reports via voice radio when the controllers are unable to see. The only controller aids currently available are the analog ground surveillance radar (ASDE-2) at 11 airports, television cameras at a few airports to cover blind spots due to physical obstructions, and the Airport Surveillance Radar (ASR), which covers airborne aircraft between 1 and 60 miles of the airport.

The ASDE-2 radars were installed in the early 1960's. ASDE-2 has had several limitations and problems over the years. Attempts to overcome these limitations have been and continue to be made, but limitations will remain even when the improvements are completed. For this reason, ASDE-2 will not be a part of the UG3RD system but will be replaced by a new radar, ASDE-3.

1.2 UG3RD IMPROVEMENTS

ASDE-3 will be a new analog ground surveillance radar. It will be a "skin tracking" radar, like ASDE-2, with a bright scan converted PPI display. Solid state components will result in high reliability and low maintenance. New antenna design and a drop in operating frequency to 16 GHz will give improved rainfall penetration. The unit will be available for deployment as required in the late 1970's. The FAA has approved ASDE-3 establishment criteria which reflect a 1976 requirement for approximately 23 ASDE-3's, with approximately 14 more required by 1986 (Reference 1).

While ASDE-3 will meet the needs of most airports, a more sophisticated system is required at the major airports. This new system, TAGS (Tower Automated Ground Surveillance), will likely be cooperative, locating each aircraft by receiving a signal transmitted by the aircraft at several receivers and solving trilateration equations. The sensor will use the existing ATCRBS transponder onboard each aircraft but will be DABS-compatible. Because it is cooperative the sensor will be weather immune. Since it is inherently a multi-sensor system, it will provide a simple means for reducing blind spots to the cab caused by physical obstructions. However, most importantly, the system will be able to receive the coded aircraft identity from each beacon, correlate the code with flight identity, and automatically display flight identity as well as aircraft location.

A candidate TAGS display format is shown in Figure 1-1 for O'Hare Airport. The TAGS display shown is a wholly synthetic computer-driven display, although consideration is being given to combining analog radar targets with computer-generated identity. The targets in the example are simple circles with a trail drawn in a direction opposite to the direction of travel with a length proportional to the aircraft's speed.

1.3 BENEFITS OVERVIEW

When the cab controllers cannot see the airport surface (e.g., during Cat II), they must rely on pilot position reports to get a "picture" of the surface traffic. Such position reports tend to saturate the voice radio channel and the controllers' information processing capabilities, especially for ground control. In addition, the reports can come late (e.g., an arrival reporting clear of a runway a few seconds after clearing), which has a pronounced effect on the local controllers' operation of the runways. In both instances the capacity of the controllers is diminished.

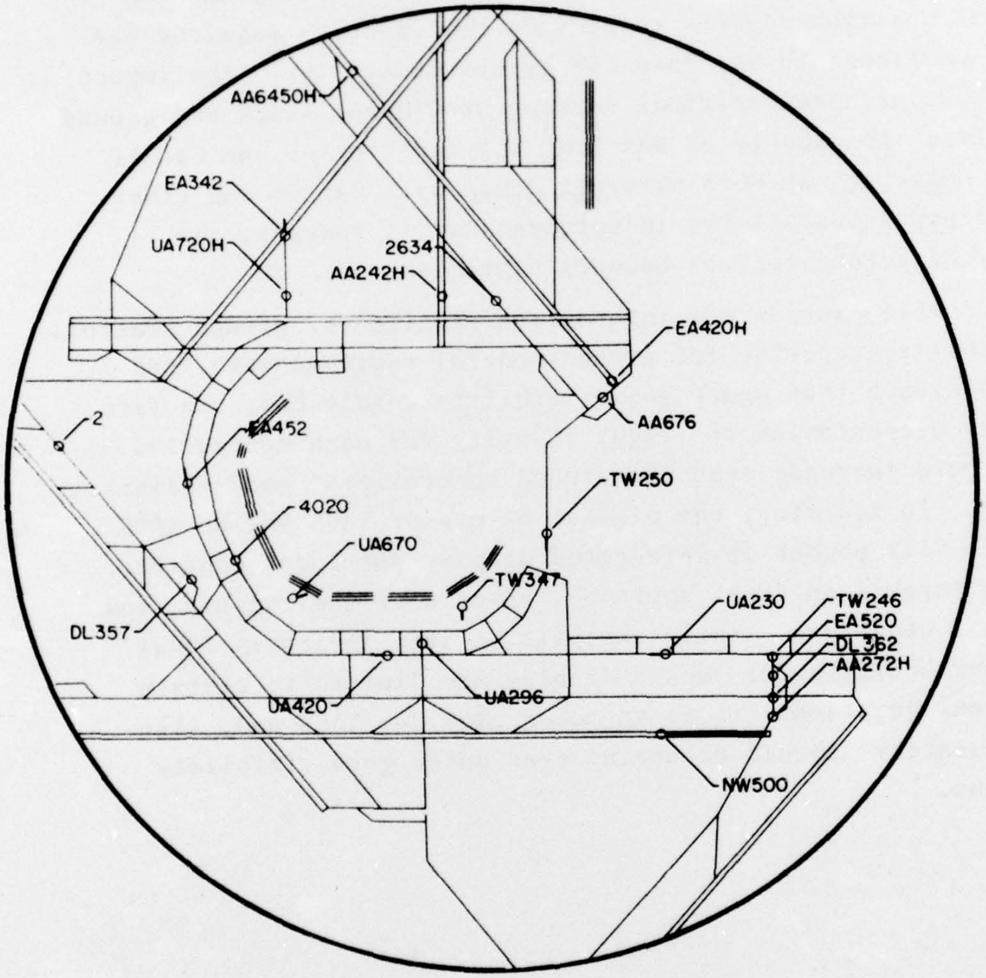

FIGURE 1-1. CANDIDATE TAGS DISPLAY FOR O'HARE AIRPORT

Experience with ASDE-2 indicates that although position reports continue to play an important role in the control function, the availability of a good radar presentation can provide good runway clearance assurance and can restore nearly all the capacity lost to local control. However, such is not the case with ground control. Even with an ASDE presentation, the use of verbal position reports to provide the identity required for control continues to bog down the ground controller. The impact to date has not been critical (except at O'Hare) since two ground controllers are capable of matching the capacity of one Cat II runway. However, as more aircraft equip with Cat II and other major airports install two independent Cat II runways, the capacity of ground control becomes a problem.

TAGS will provide the information required by ground control. Bad visibility capacity for ground control equipped with TAGS should approach that under good visibility conditions. In fact, the clear presentation of flight identity for each controlled target could increase even the ground controllers' good visibility capacity. In addition, the digital nature of TAGS and an ARTS interface will permit an integrated display for local control covering targets on final approach, on or near the runways, and on initial departure. While analysis to date indicates local controller benefits for such a display are limited to certain runway configurations, it is an added plus for TAGS and, like flight identity, should be useful even under good visibility conditions.

2. COST/BENEFIT ASSUMPTIONS

This section sets forth the assumptions of the analysis and their rationale and references. To summarize,

1. The average capacity of two ground controllers in good visibility is 175 operations per hour (see Section 2.2.1).

2. Even with an ASDE in operation, the average capacity of two ground controllers in bad cab visibility falls to 85 operations per hour (see Section 2.1).

3. TAGS, with a clear, uncluttered presentation of each target and its identity, will permit ground control capacity in bad cab visibility equal to that in good visibility.

4. Traffic will grow in accordance with the most recent FAA (AVP) terminal area forecast, dated October 1975.

5. Bad cab visibility is equated to Cat II or Cat IIIa conditions and its frequency and duration obtained from past climatological data sources (see Section 2.5).

6. TAGS benefits will accrue by eliminating delays which would otherwise result from traffic demand exceeding ground control capacity during conditions of bad cab visibility.

7. Delay reductions due to TAGS can be converted to dollar benefits by estimating user costs of delay. User costs include airline operating costs and passenger costs (see Section 2.7).

8. The TAGS cost estimate is $4 million for development and $1.4 million per production unit (installed)(see Section 2.6).

9. The analysis follows a 10 percent discount procedure (see Section 3.3.1).

2.1 GROUND CONTROL PERFORMANCE WITH ASDE

While a good ASDE presentation tends to restore nearly all capacity lost by local control due to bad visibility, this is not the case for ground control. In References 2 and 3, the workload of ground control during bad visibility was examined. In both studies, two ground controllers operating with an ASDE-2 were forecast to saturate at operations rates as low as 65 operations/hour. The saturation would occur for at least 5 minutes out of an hour, and beyond saturation the controllers would be forced either to withhold clearances to taxi or reduce requests for pilot position reports (which the controller uses to correlate the ASDE presentation with aircraft identification in order to maintain a "picture" of his traffic).

Denying taxi requests results in aircraft delays. These delays can be readily computed with a simple delay model, but the effect of reduced position reports and saturated information processing is more difficult to measure. During such busy periods, the ground traffic can become congested and quite mixed up (arrivals with departures, etc.). Even when targets would normally be recognizable their identity can become confused. Position reports are useful to help draw the controller's attention to an aircraft at a critical location, as well as to provide identity and an open communication link just when he needs it. Cutting back on such reports can increase the possibility of lost targets, missed critical events, and mistaken indentities. The impact of saturation, therefore, has the dual role of causing delays and possibly impacting on safety.

Although the dual role of the saturated capacity estimates in References 2 and 3 is recognized, here the capacities are applied to a simple delay model as if the total penalty of saturation was delay. The resulting delay costs will then represent a combination of actual delay costs and the pressure brought to bear on the controller to operate at and beyond his saturated capacity.

The capacity estimate of 65 operations/hour for two ground controllers with ASDE in bad visibility given in References 2 and 3 is a worst case estimate. It represents the operations levels for which saturation began to be observed, although some cases were observed with higher operations rates without saturation. In this analysis, a less conservative capacity estimate of 85 operations/hour is used. This represents the mean value between when saturation will first show up and when saturation is virtually guaranteed. This was done so as to present a more average situation in which a limited degree of saturation is permitted without delay costs being accrued. The more conservative estimate of 65 operations/hour is examined in the sensitivity analysis.

2.2 TAGS BENEFITS

2.2.1 Primary Benefits

The basic TAGS display will present a clear, uncluttered picture of the location and identity of all surface vehicles under control. The major user of the system will be ground control in bad cab visibility conditions. This study will assume that the display is of sufficient quality to restore virtually all capacity lost to ground control in bad visibility. As with the ASDE capacity estimate, the mean between the capacity at onset of saturation and the capability which will guarantee saturation given in Reference 3 is used to present an average situation. That mean capacity is 175 operations/hour for two ground controllers in good visibility.

2.2.2 Secondary Benefits

Although only improvements to ground control during bad visibility will be considered in this analysis, TAGS will provide features which will be of added benefit to the controllers. First, the identity feature so useful in bad visibility to ground control will also be useful to local control. In addition, it will be useful to ground control in good visibility conditions as a quick-look reference on identity for use in conjunction with visual observation. As previously stated, TAGS will also be capable of covering blind spots to the cab.

Next, the TAGS receivers will be capable of detecting activation of the Ident button on the ATCRBS beacon in each aircraft. Activation can be displayed to the controllers (e.g., by a flashing identity leader) and will provide a digital downlink from pilot to cab controllers. This link could be used in place of verbal taxi requests and to acknowledge ground/local handoffs. This would reduce voice communication loading in all visibility conditions and provide a more efficient method of operation. However, since ground control capacity in good visibility conditions is not currently a limiting factor, this improvement was not considered in this study.

Finally, TAGS will be capable of presenting an integrated display to local control covering aircraft on final approach, on and near the runway, and on initial departure. It is possible that it will be able to fill in the airborne coverage within a mile or so of the airport currently lost to the ASR, thus improving safety. Airborne data will be supplied to TAGS from ARTS on an automated data transfer until coverage is lost. The key information to be displayed to local control is estimated time-to-threshold for the arrival stream. The TAGS processor will utilize position, speed, and aircraft type to provide the estimate. When factored into controller strategies, it has been estimated (Reference 3) that accurate time-to-threshold information could increase local control/runway capacity by about 10 percent on certain difficult-to-operate runway configurations with strong arrival/departure dependence. On configurations where arrivals and departures are fairly independent, no improvement would currently be realized.

Because airports try to avoid the difficult-to-operate dependent configurations, many of the high volume airports would not currently benefit from the local control feature (e.g., Los Angeles, Atlanta, New York (JFK)). For this reason, although some airports might make use of the feature (e.g., O'Hare, approximately 50 percent of the time, Reference 3), the benefits were not included in this analysis. However, when Advanced Metering and Spacing is installed and the minimum interarrival separation standard is reduced, the timing on arrivals and departure releases will become much more critical than is currently the case. TAGS may be required to aid local control even on the less dependent configurations and to provide M&S with real time departure demand.

Therefore, this analysis should be considered as presenting a minimum requirement for TAGS (based upon current procedures and equipment), and a revised analysis should be conducted when Advanced Metering and Spacing is better defined.

The omission of local controller benefits is the major difference between this study and Reference 2. In Reference 2, a 10 percent capacity improvement was ascribed to TAGS for even weakly dependent configurations (e.g., dual lane runways). This led to a relatively wide TAGS deployment (i.e., 15 systems) for local control in good visibility conditions. However, the analysis in Reference 2 was based upon limited data available at the time of the study. Since that study, added data and analysis done in Reference 3 indicate that the improvement estimate was quite good when applied to strongly dependent configurations (e.g., single runway-mixed arrivals and departures) but was not applicable to the weakly dependent configurations.

2.3 DELAY MODEL

The delay model used is similar to that used in Reference 2. The model assumes that f times a year a period of bad cab visibility of duration t hours occurs during the airport's busy period (i.e., roughly 0700-2200). Prior to the occurrence the airport is operating in good cab visibility at a capacity of P_2 (175 operations/hour) with no delays. The good visibility mean busy hour demand, N_2, is assumed to be sufficiently below the good visibility capacity to prevent delays. When bad visibility sets in, the capacity falls to P_1 (85 operations/hour). While some demand is also likely to drop out (e.g., unequipped general aviation aircraft), it is assumed that the resulting bad visibility demand, N_1, will exceed bad visibility capacity and delays will begin to accrue. For ground control these delays would be in the form of departure gate holds or arrival holds just off the active runway(s) in some holding station (e.g., an unused runup pad). When the bad visibility lifts, the demand and capacity revert to N_2 and P_2, and the excess capacity, P_2-N_2, is used to clear up traffic holds accumulated during the bad visibility period.

The resulting delay equation for the model is:

$$\text{Delay (minutes)} = \frac{30\ t^2 f\ (N_1 - P_1)(N_1 - P_1 + P_2 - N_2)}{(P_2 - N_2)}$$

Demand and capacity are specified in operations/hour. The various factors in the equation are $t^2 f$, the bad cab visibility factor; $N_1 - P_1$, the bad cab visibility excess demand; and $P_2 - N_2$, the good cab visibility excess capacity.

2.4 DEMAND

2.4.1 Good Cab Visibility Demand (N_2)

The demand used in the analysis is based upon the most recent FAA (AVP) terminal area forecasts portion of the UG3RD Baseline Scenario (dated October 1975). Only the top 15 air carrier traffic airports (as of 1990) were considered in the analysis. The forecast information for each is presented in Table 2-1. In computing the mean demand over each airport's busy period, three types of traffic were considered. These were air carrier (local, domestic, and international), air taxi, and itinerant general aviation. Non-itinerants were insignificant at the major airports and would be more a problem to local control (e.g., with touch-and-gos) than ground. Itinerant general aviation was taken to be the total forecast itinerant less the air carriers and air taxis.

The estimate of the busy period for each airport was made using the Profiles of Scheduled Air Carrier Airport Operations (Reference 5). For each airport the peak hour was determined. Then those hours for which the operations rate was within 40 percent of the peak were determined and used for the busy hour period. This 40 percent definition produced a busy period of approximately 0700 to 2200 hours but allowed airports to begin somewhat later and/or end somewhat earlier without a severe reduction in mean demand. Using mean demand and not accounting for peak periods is quite conservative in itself, and an added reduction in demand was deemed inappropriate. The busy hours are given in Table 2-2.

TABLE 2-1. FORECAST DATA

AIRPORT AND SERVICE TYPE	OPERATIONS PER YEAR (IN THOUSANDS)					
	1974	1980	1985	1990	1995	2000
ORD						
A/C	573	656	658	660	662	664
A/T	59	79	85	90	95	97
ITN	680	735	743	750	757	761
Total	681	735	743	750	757	761
ATL						
A/C	422	515	565	607	659	700
A/T	18	23	30	35	40	45
ITN	488	587	640	685	720	745
Total	502	590	640	685	720	745
JFK						
A/C	306	376	425	453	475	490
A/T	30	40	48	56	64	70
ITN	360	434	485	525	565	600
Total	360	434	485	525	565	600
LAX						
A/C	351	431	442	445	448	451
A/T	54	72	85	95	100	105
ITN	460	513	539	572	590	600
Total	466	515	539	572	590	600
SFO						
A/C	275	344	389	438	450	467
A/T	16	21	28	38	49	55
ITN	336	407	442	500	530	550
Total	338	407	442	500	530	550
DFW						
A/C	283	340	384	430	477	525
A/T	45	57	67	72	77	82
ITN	346	422	481	532	584	607
Total	346	422	481	532	584	607
MIA						
A/C	232	281	318	351	381	413
A/T	23	30	40	54	68	82
ITN	327	363	402	447	476	500
Total	327	363	402	447	476	500
DEN						
A/C	196	245	276	310	341	375
A/T	15	25	33	41	50	67
ITN	345	391	411	427	442	458
Total	379	401	420	440	460	480

TABLE 2-1. FORECAST DATA (CONTINUED)

AIRPORT AND SERVICE TYPE	OPERATIONS PER YEAR (IN THOUSANDS)					
	1974	1980	1985	1990	1995	2000
LGA						
A/C	265	300	303	306	309	312
A/T	15	21	27	33	40	45
ITN	339	360	380	390	395	400
Total	339	360	380	390	395	400
PIT						
A/C	185	227	257	288	320	350
A/T	40	53	70	94	100	110
ITN	277	353	400	450	475	500
Total	288	360	405	450	475	500
BOS						
A/C	199	234	260	282	307	331
A/T	51	60	73	78	84	89
ITN	295	349	370	380	391	420
Total	295	349	370	380	391	420
STL						
A/C	168	206	230	253	279	300
A/T	30	40	52	70	82	90
ITN	323	378	428	478	528	540
Total	334	399	448	488	528	540
DTW						
A/C	169	203	227	252	277	300
A/T	15	21	27	32	37	42
ITN	257	313	340	350	360	370
Total	257	313	340	350	360	370
PHL						
A/C	160	195	216	238	262	288
A/T	66	88	100	110	115	120
ITN	316	393	415	450	475	500
Total	316	393	415	450	475	500
EWR						
A/C	150	180	220	217	236	255
A/T	24	31	42	57	73	89
ITN	210	250	292	330	375	400
Total	220	260	310	340	385	410

TABLE 2-2. BUSY HOUR ESTIMATION

AIRPORT	BUSY PERIOD	BUSY HOURS	% A/C IN BUSY PERIOD	% A/T IN BUSY PERIOD
ORD	0700-2200	15	93	87
ATL	0600-2100	15	78	100
JFK	0800-2200	14	84	90
LAX	0800-2100	13	80	82
SFO	0700-2200	15	88	88
DFW	0800-2100	13	79	77
MIA				
DEN	0800-2000	12	86	89
LGA	0700-2200	15	95	100
PIT	0800-2200	14	88	84
BOS	0700-2100	14	84	92
STL	0700-2000	13	82	91
DTW	0800-2100	13	83	72
PHL	0700-2200	15	88	95
EWR	0700-2100	14	82	79
Mean		13	85	88

They generally begin between 0700 and 0800 and run to 2100 or 2200. The mean busy period is about 13 hours, although it is higher for the busier airports.

After the busy period was established, the fraction of daily air carrier and air taxi operations which occurred during the busy period was computed (again using Reference 5). These are given in Table 2-2 and average 85 and 88 percent respectively. The mean hourly demand in good visibility during busy hours was then estimated using the following equation:

$$\text{(Mean hourly Demand)} = \frac{\text{Annual A/C Operations}}{\text{365 days per year}} \times \frac{\text{Fraction daily A/C in busy period}}{\text{Number of busy hours}}$$

$$+ \frac{\text{Annual A/T Operations}}{\text{365 days per year}} \times \frac{\text{Fraction daily A/T in busy period}}{\text{Number of busy hours}}$$

$$+ \frac{\text{Annual Itinerant G/A Operations}}{\text{365 days per year}} \times \frac{\text{Fraction daily G/A between 0700-2200}}{(15)}$$

In this equation annual operations divided by 365 days gives an average daily demand. This demand averages high weekday traffic and will tend to give a conservative demand estimate. However, the weather data were taken over the entire week, and while occurrences during the week might be somewhat worse than the delay equation might indicate, occurrences on weekends would be less significant. Since these differences tended to be offsetting, the simple yearly average was considered acceptable. Also in the equation, the fraction of daily general aviation between 0700 and 2200 was taken as approximately 0.9, following the CONUS air traffic activity reported on in Reference 1.

2.4.2 Bad Cab Visibility Demand (N_1)

The good cab visibility demand equation is composed of three products involving air carrier operations, air taxi operations, and general aviation operations. For bad cab visibility demand it was assumed (following Reference 1) that 60 percent of the general aviation traffic would drop out as unequipped for Cat II and IIIa operation. The bad cab visibility demand equation, therefore, is the same as for good cab visibility except a 0.4 factor is applied to the general aviation operations product. It was further assumed that the ajoining ATC elements would have a capacity adequate to pass on the bad cab visibility demand to ground control. This appears to be the case for local control with an ASDE (Reference 3) and is forecast for the terminal area with ARTS enhancements (Reference 7).

2.5 WEATHER DATA

The delay equation calls for two weather parameters, the yearly frequency of bad cab visibility and the mean duration of each occurrence. Since the weather must be quite severe for surface (i.e., taxiways) visibility from the cab to be impaired, bad cab visibility for ground control is taken as Cat II or Cat IIIa weather conditions. Worse than Cat IIIa were not considered due to the improbability of such operations even in the 1990 time frame. In addition, only periods with duration exceeding 90 minutes were included to avoid brief periods of bad visibility which could be local to the RVR instrumentation and/or present little or no problem to ground control. The estimates were taken from Reference 2, a 10-year data base. The parameters cover the period from 0700 to 2200. The basic source for the data is Reference 6. The estimates are given in Table 2-3.

2.6 SYSTEM COSTS

The system costs are for a TAGS system based upon an ATCRBS multilateration sensor. The costs are summarized in Reference 3. The system is composed of three basic subsystems, as shown in

TABLE 2-3. WEATHER DATA

AIRPORT	LONG DURATION CAT II AND IIIA (>90 MIN)		BAD VISIBILITY FACTOR (t^2f)
	AVERAGE DURATION (HR)	YEARLY FREQUENCY	
ORD	2.8	4.9	38
ATL	3.0	11.3	102
JFK	2.6	13.4	91
LAX	2.7	8.3	61
SFO	2.8	3.7	29
DFW	2.2	1.9	9
MIA	1.8	0.5	2
DEN	2.1	1.3	6
LGA	2.7	5.2	38
PIT	2.9	4.6	39
BOS	2.2	10.9	53
STL	3.1	3.0	90
DTW	3.3	7.3	79
PHL	3.1	6.2	60
EWR	2.8	6.1	48

Figure 2-1. For this analysis the configuration made use of five combination interrogator/receiver stations, four receive-only stations, and four display and data entry units (two for ground and two for local). This configuration is applicable to Chicago O'Hare but could be somewhat expensive for smaller airports. The production and development cost estimates are given in Table 2-4.

For TAGS to be able to display all controlled vehicles, controlled vehicles will have to be equipped with an inexpensive beacon. A low cost commercial Mode A transponder could be used and would cost approximately $500 installed. Tower and regional estimates of the maximum number required at the likely TAGS sites are 40 vehicles. This would add at most $20,000 to the TAGS

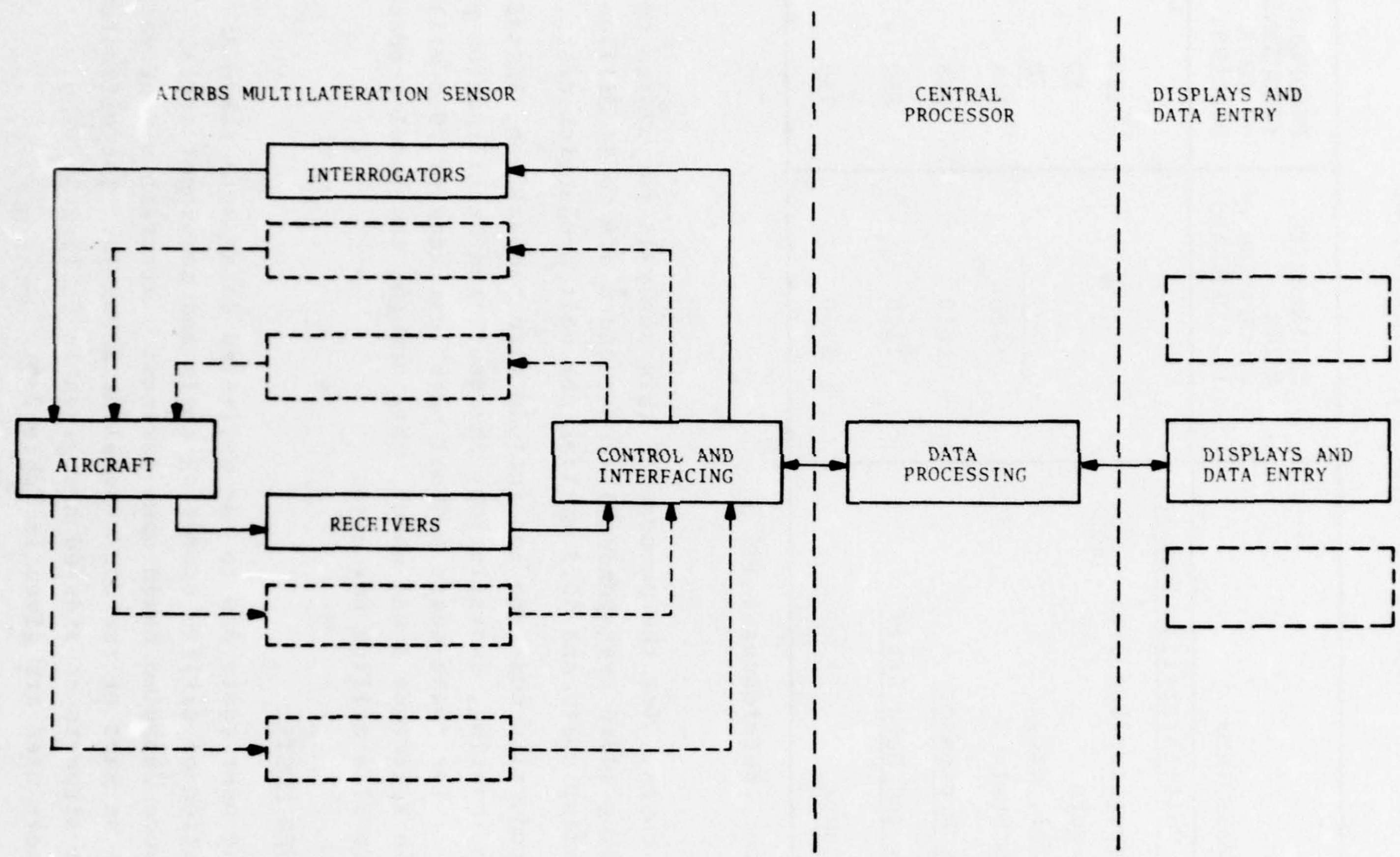

FIGURE 2-1. TAGS SUBSYSTEMS

TABLE 2-4. SYSTEM COST BREAKDOWN

TAGS SUBSYSTEMS	ENGINEERING MODEL (THOUSANDS OF 1975 DOLLARS)	PRODUCTION (THOUSANDS OF 1975 DOLLARS)
ATCRBS Multilateration Sensor		
Interrogator/Receivers	-	225
Receivers	-	80
Control, etc.	-	30
Subtotal	1000	335
Central Processor	1670	165
Display and Data Entry	1300	250
Total Costs	3970	750

Source: References 4 and 5

system costs. For the purpose of this analysis the system costs (including added transponders) were rounded off to $4 million development costs and $0.8 million per unit production costs.

Production costs do not include site preparation, installation engineering, installation, checkout, and certification procedures. For these costs a "ball park" estimate of $0.6 million given in Reference 3 was used. This brought the total production costs to $1.4 million per unit.

2.7 USER COSTS

The user costs due to the estimated delay were taken as a combination of airline operating costs and passenger costs. The costs were computed based upon forecast aircraft mix at each airport as part of the UG3RD Baseline Scenario. The estimates for the airports considered are given in Table 2-5. The parameters used are given in Table 2-6.

TABLE 2-5. USER COSTS

AIRPORT	COSTS PER MINUTE OF DELAY - 1975 DOLLARS					
	1975	1980	1985	1990	1995	2000
	AIRCRAFT OPERATING COSTS					
ORD	16.98	17.75	18.80	20.11	21.36	22.46
ATL	15.13	15.79	16.57	17.43	18.54	19.91
JFK	19.06	21.01	22.25	23.60	25.07	26.62
LAX	19.41	20.27	21.52	23.17	24.32	25.71
SFO	17.10	18.10	19.05	20.43	21.80	23.19
DFW	15.76	15.95	16.33	16.94	17.83	18.94
MIA	17.79	18.74	19.59	20.45	21.40	22.78
DEN	15.93	15.94	16.23	17.07	18.00	19.33
LGA	13.90	14.30	14.94	15.66	16.24	16.88
PIT	14.19	14.09	14.66	15.51	16.39	17.32
BOS	16.01	16.91	17.31	17.81	18.33	19.87
STL	14.52	15.45	16.47	16.53	17.57	18.91
DTW	16.91	17.24	18.11	19.03	20.29	21.92
PHL	15.67	15.57	15.75	16.65	17.17	17.99
EWR	15.22	15.35	16.19	17.13	18.47	19.18
	PASSENGER COSTS					
ORD	14.42	15.36	16.52	17.43	18.33	19.13
ATL	13.51	14.04	14.70	15.31	16.06	17.03
JFK	16.38	16.79	18.86	19.95	21.18	22.38
LAX	16.67	17.44	18.42	19.70	20.60	21.64
SFO	14.53	15.44	16.05	17.15	18.19	19.32
DFW	13.70	14.05	14.49	14.97	15.57	16.38
MIA	15.26	16.08	16.86	17.53	18.25	19.98
DEN	13.29	13.71	14.47	15.08	15.71	16.66
LGA	11.74	12.29	12.84	13.30	13.67	14.05
PIT	11.95	12.62	13.59	14.20	14.79	15.42
BOS	13.21	14.34	15.00	15.78	16.17	17.23
STL	12.72	13.96	14.95	14.74	15.44	16.39
DTW	14.07	14.91	15.79	16.51	17.78	18.66
PHL	12.79	13.44	14.26	14.96	15.26	15.83
EWR	12.42	12.96	13.73	14.48	15.61	16.04
TOTAL (AIRCRAFT OPERATING AND PASSENGER) COSTS						
ORD	31.40	33.11	35.32	37.54	39.69	41.59
ATL	28.64	29.83	31.27	32.74	34.60	36.94
JFK	35.44	37.80	41.11	43.55	46.25	49.00
LAX	36.08	37.71	39.94	42.87	44.92	47.35
SFO	31.63	33.54	35.10	37.58	39.99	42.51
DFW	29.46	30.00	30.82	31.91	33.40	35.32
MIA	33.05	34.82	36.45	37.98	39.65	42.76
DEN	29.22	29.65	30.70	32.15	33.71	35.99
LGA	25.64	26.59	27.78	28.96	29.91	30.93
PIT	26.14	26.71	28.25	29.71	31.18	32.74
BOS	29.22	31.25	32.31	33.59	34.50	37.10
STL	27.24	29.41	31.42	31.27	33.01	35.30
DTW	30.98	32.15	33.90	35.54	38.07	40.58
PHL	28.46	29.01	30.01	31.61	32.43	33.82
EWR	27.64	28.31	29.92	31.61	34.08	35.22

TABLE 2-6. USER COST PARAMETERS

AIRCRAFT TYPE	DOC-LESS FUEL ($/MIN.)	FUEL CONSUMP. RATE (GAL./MIN.)	FUEL COST @24.977¢/GAL. ($/MIN.)	TOTAL ($/MIN.)
Air Carrier				
4 Engine				
Wide Body	25.61	56.3	14.06	39.67
Conventional	11.68	29.1	7.27	18.95
3 Engine				
Wide Body	20.17	37.7	9.42	29.59
Conventional	9.47	21.7	5.42	14.89
2 Engine	7.82	15.0	3.75	11.57
Turboprop	13.23	10.6	2.65	15.88
Air Taxi	4.53	2.32	.58	5.11
General Aviation				
Single Engine, 1-3 pax	.63	.17	.12*	.75
Single Engine, 4+ pax	.90	.22	.15*	1.05
Multi Engine	2.28	.55	.39*	2.67
Turbine	9.51	5.25	3.56**	13.07

*Fuel cost 70¢ per gallon.
**Fuel cost 68¢ per gallon.

TABLE 2-6. USER COST PARAMETERS (CONTINUED)

AIR CARRIER	AVG. NO. PAX.	PAX. COST* ($/MIN.)	AOC ($/MIN.)	TOTAL DELAY COST ($/MIN.)
4 Engine				
Wide Body	166.5	34.69	39.67	74.36
Conventional	77.0	16.04	18.95	34.99
3 Engine				
Wide Body	110.7	23.06	29.59	52.65
Conventional	63.7	13.27	14.89	28.16
2 Engine	55.6	11.58	11.57	23.15
Turboprop	41.6	8.67	15.88	24.55
General Aviation				
Single Engine 1-3 pax	1.4	.29	.75	1.04
Single Engine, 4+ pax	2.3	.48	1.05	1.53
Multi Engine	3.4	.71	2.67	3.38
Turbine	3.8	.79	13.07	13.86

*@$12.50 per hour.

3. BENEFITS ANALYSIS

3.1 PROGRAM DEFINITION

A preliminary screening of airports was made to develop a set of candidates for which cost/benefit analysis should be done. First, the bad visibility demand at the top 15 air carrier airports between 1975 and the year 2000 was estimated. Then, the years when the hourly rate would (1) just reach saturation (85 operations/hour) and (2) exhibit an over-demand of 5 operations/hour were estimated. The results are given in Table 3-1. Only seven airports (excluding MIA) even reach saturation in the UG3RD time frame (i.e., through the year 2000) and since some over demand is required to justify deployment it would appear that operations rates alone narrow the candidates to five key airports - ORD, ATL, JFK, LAX, and DFW. If the amount of prolonged bad cab visitility is also considered, even DFW becomes questionnable. Table 3-1 shows the average yearly frequency and duration of long duration bad cab visibility conditions at each airport, along with the bad visibility factor of the delay equation. MIA, DEN, and DFW all experience very few long duration bad cab visibility conditions. MIA and DEN were not considered further in the baseline analysis. DFW was considered but was expected to drop out with inadequate cost savings.

From Table 3-1 it is seen that only O'Hare now requires TAGS and will have the most severe requirement through the early 1980's. Therefore, the baseline program in this analysis will deploy, test, and evaluate the TAGS engineering model at O'Hare. Further, since we are dealing with only four likely sites in all, it will be assumed that (1) a single production buy will be made for all sites, (2) the engineering model will be commissioned for use at O'Hare until the production buy is made, and (3) the timing of the production buy will be established by the requirements of the likely TAGS sites other than O'Hare. Using 90 operations/hour as a screening criterion, it appears that two of the three likely sites will require TAGS by 1986.

TABLE 3-1. PRELIMINARY SCREENING

AIRPORT	YEARLY OPERATIONS IN 1990 (THOUSANDS)			YEAR WHEN BAD VISIBILITY DEMAND=		LONG DURATION CAT II AND IIIA (>90 MIN.)		BAD VISIBILITY FACTOR (t^2f)	LIKELY[b] TAGS SITES
	AIR CARRIER	AIR TAXI	ITINERANT	85 OPS/HR	90 OPS/HR	AVE. DUR-ATION (HR)	YEARLY FREQUENCY		
ORD	660	90	750	1974	1974	2.8	4.9	38	Yes
ATL	607	35	640	1983	1986	3.0	11.3	102	Yes
JFK	453	56	525	1989	1994	2.6	13.4	91	Yes
LAX	445	95	572	1980	1984	2.7	8.3	61	Yes
SFO	438	38	500	2000	-	2.8	3.7	29	No
DFW	430	72	532	1989	1992	2.2	1.9	9	(c)
MIA	351	54	447	(a)	(a)	1.8	0.5	2	No
DEN	310	41	427	1997	-	2.1	1.3	6	No
LGA	306	33	390	-	-	2.7	5.2	38	No
PIT	288	94	450	-	-	2.9	4.6	39	No
BOS	282	78	380	-	-	2.2	10.9	53	No
STL	253	70	478	-	-	3.1	3.0	90	No
DTW	252	32	350	-	-	3.3	7.3	79	No
PHL	238	110	450	-	-	3.1	6.2	60	No
EWR	217	57	330	-	-	2.8	6.1	48	No

[a] MIA not computed due to low bad visibility factor.
[b] Demand exceeds capacity by at least 5 ops/hr.
[c] Unlikely but included in the analysis.

Rather than wait for the requirement to materialize at JFK, a 1986 production deployment was assumed. The baseline program considered in this study is defined as follows:

Engineering Model Developed at O'Hare	1977-80
Engineering Model Operational	1980-86
Production Buy (4 units)	1985-86
Production Units Operational	1986-2000

3.2 PROGRAM COSTS

The costs for the baseline program are given in Table 3-2. While the base year for the TAGS program is taken to be FY76, no costs are assigned to the TAGS program, since funding through FY76 has been appropriated and is considered spent. A FY76 decision will little effect these funds. The cost assumptions are described in footnotes to the table. In general, they reference Section 2.6, System Costs.

3.3 BASELINE ANALYSIS

3.3.1 Development at O'Hare

The cost/benefits analysis in this study will follow the discount procedure in Reference 4. Table 3-3 shows the yearly cost/benefits for the engineering model development at O'Hare. An example of the benefits computation for 1985 is given in the appendix. The table indicates that because of the severe demand at O'Hare, the use of the engineering model for 6 years pays for the entire TAGS development activity, with a present value (base year 1976) net benefit of about $3 million and a benefit/cost ratio of about 1.5. This result provides a strong incentive to develop TAGS at O'Hare.

3.3.2 Production Units

Table 3-4 shows the yearly cost/benefits for the production units at each of the candidate airports. Development costs are not

TABLE 3-2. TAGS BASELINE PROGRAM COSTS

TAGS COSTS PER YEAR (THOUSANDS OF 1975 DOLLARS)

YEAR	E AND D COSTS	# UNITS INSTALLED	F AND E COSTS	O AND M COSTS	TOTAL COSTS
1976	-				750
77	750[a]				2750
78	2750[b]				2750
79	2750[b]				970
1980	750[a]	1[c]	100[d]	120[e]	120
81				↓	↓
82					
83					
84					
85			5600[f]		5720
86		4		480	480
87				↓	↓
88					
89					
1990					
91					
92					
93					
94					
95					
96					
97					
98					
99					
2000					
TOTAL	7000		5700	7920	20620

[a] $750K/year average costs for government support personnel (approximately 15 manyears).

[b] Government support personnel plus half of the required development contract costs (see Section 2.6).

[c] Engineering model to be commissioned.

[d] 25% of commissioning and installation costs estimated for the production model (see Section 2.6).

[e] 15% of production model basic equipment costs (Reference 2).

[f] $800K basic equipment costs plus $600K installation cost estimate (see Section 2.6).

TABLE 3-3. DEVELOPMENT BENEFITS AT O'HARE

		YEARLY VALUE[a]					PRESENT VALUE[a]	
YEAR	R&D COSTS	COMMISSION COSTS	O&M COSTS	TOTAL COSTS	BENEFITS	DISCOUNT FACTOR[b]	COSTS	BENEFITS
1977	750			750		.909	682	
78	2750			2750		.826	2272	
79	2750			2750		.751	2065	
1980	750	100	120	970	2613	.683	663	1785
81			120	120	2700	.621	75	1677
82			120	120	2787	.564	68	1572
83			120	120	2875	.513	62	1475
84			120	120	2962	.466	56	1380
85			120	120	3050	.424	51	1293
Total	7000	100	720	7820			5994	9182

[a]Thousands of 1975 dollars
[b]FY76 base year

Present Value Net Benefit = $3,188,000
Benefit/Cost Ratio = 1.53

TABLE 3-4. PRODUCTION BENEFITS AT CANDIDATE AIRPORTS

YEAR	PRESENT VALUE[a] (THOUSANDS OF 1975 DOLLARS)					
	COSTS	ORD BENEFITS	ATL BENEFITS	JFK BENEFITS	LAX BENEFITS	DFW BENEFITS
1985	596	-	-	-	-	-
86	46	1192	179	-	197	-
87	42	1094	221	-	194	-
88	38	1006	253	-	190	-
89	35	925	278	-	186	-
1990	32	853	297	32	181	2
91	29	791	322	62	181	6
92	26	733	340	86	179	9
93	24	679	352	106	176	12
94	21	629	359	121	172	13
95	20	584	363	133	168	15
96	18	544	368	146	157	16
97	16	506	368	157	148	17
98	15	462	363	163	138	17
99	13	428	359	168	129	18
2000	12	397	352	171	121	18
Total	983	10,823	4,774	1,345	2,517	143

[a]FY76 base year.

considered in this table. As with Table 3-3, the base year is 1976. It is evident that the four likely sites all pay for a production unit. In descending order of payoff they are ORD, ATL, LAX, and JFK. As was anticipated DFW does not justify a production unit due to the infrequent bad visibility conditions.

3.3.3 Program Cost/Benefits

Table 3-5 summarizes the overall program cost/benefits. If the baseline program given in Section 3.1 is followed with development at O'Hare and production units to ORD, ATL, LAX, and JFK, the program's present value net benefit is $18.7 million and the benefit/cost ratio is 2.9. The cost savings are substantial.

TABLE 3-5. BASELINE PROGRAM BENEFITS/COSTS

PROGRAM ITEM	PRESENT VALUE[a] (THOUSANDS OF 1975 DOLLARS)			BENEFITS/ COSTS
	COSTS	BENEFITS	NET BENEFITS	
O'Hare Development	5,994	9,182	3,188	1.5
O'Hare Production Unit[b]	983	10,823	9,840	11.0
Atlanta Production Unit[b]	983	4,774	3,791	4.9
Los Angeles Production Unit[b]	983	2,517	1,534	2.6
New York Production Unit[b]	983	1,345	362	1.4
Total Program (Baseline)	9,926	28,641	18,715	2.9

[a]Base year FY76.
[b]Production buy for all four sites in FY86.

3.4 SENSITIVITY ANALYSIS

If the engineering model is not developed at O'Hare, or for some reason cannot be commissioned for use, the baseline program must be altered. Two production buys would be required, the first to satisfy O'Hare's pressing need as soon as possible (FY81) and the second to satisfy the remaining airports requirements (in FY86). The resulting cost/benefits are shown in Table 3-6. The present value net benefit is $16.3 million and the benefit/cost ratio is 2.5. These are still substantial benefits. The chief penalty is the added complication of two production buys.

The sensitivity to system cost is shown in Table 3-7 for a 50 percent increase in development, production, and installation costs. These cost increases are very extreme but serve to show the strength of each program item. Even with the extreme increase each program item pays for itself and in the worst case (development not at O'Hare) the program obtains a present value net benefit of $11.9 million at a benefit/cost ratio of 1.8.

TABLE 3-6. SENSITIVITY TO DEVELOPMENT SITE

PROGRAM ITEM	PRESENT VALUE[a] (THOUSANDS OF 1975 DOLLARS)			BENEFITS/COSTS
	COSTS	BENEFITS	NET BENEFITS	
Development	5,994	0	-5,994	0
O'Hare Production Unit FY81 Deployment	1,655	18,220	16,565	11.0
Atlanta Production Unit FY86 Deployment	983	4,774	3,791	4.9
Los Angeles Production Unit FY86 Deployment	983	2,517	1,534	2.6
New York Production Unit FY86 Deployment	983	1,345	362	1.4
Total Program	10,598	26,856	16,258	2.5

[a]Base Year, FY76.

TABLE 3-7. SENSITIVITY TO COST

PROGRAM ITEM	PRESENT VALUE[a] (THOUSANDS OF 1975 DOLLARS)			BENEFITS/COSTS
	COSTS	BENEFITS	NET BENEFITS	
O'Hare Development	8,991[b]	9,182	191	1.0
O'Hare Production Unit	1,282[c]	10,823	9,541	8.4
Atlanta Production Unit	1,282	4,774	3,492	3.7
Los Angeles Production Unit	1,282	2,517	1,235	2.0
New York Production Unit	1,282	1,345	63	1.1
Total Program	14,119	28,641	14,522	2.0
Total Program (Development at Other Than ORD)	14,970	26,856	11,886	1.8

[a]Base Year FY76.
[b]50% increase in development over baseline.
[c]50% increase in production and installation over baseline.

The sensitivity to service demand is shown in Table 3-8. As with cost an extreme position is taken. Rather than including all air taxi and 40 percent of general aviation traffic in the bad cab visibility demand, all air taxi and general aviation traffic is assumed to drop out as unequipped for low visibility operations. The result is quite significant – New York (JFK) and Los Angeles (LAX) drop out of the program. As can be seen in Table 3-1, New York and Los Angeles air carrier traffic is well below that of O'Hare and Atlanta (approximately 450,000 operations/year versus 600,000 in 1990). However, the remaining program remains cost-beneficial whether or not development is performed at O'Hare. Savings acrued by the baseline program amount to a present value net benefit of \$3.9 million, with a benefit/cost ratio of 1.5.

TABLE 3-8. SENSITIVITY TO SERVICE DEMAND

PROGRAM ITEM	PRESENT VALUE[a] (THOUSANDS OF 1975 DOLLARS) COSTS	BENEFITS	NET BENEFITS	BENEFITS/COSTS
O'Hare Development	5,994	4,796[b]	-1,198	0.8
O'Hare Production Unit	983	5,448[b]	4,465	5.5
Atlanta Production Unit	983	1,652[b]	669	1.7
Los Angeles Production Unit	-	-	-	-
New York Production Unit	-	-	-	-
Total Program	7,960	11,896	3,936	1.5
Total Program (Development at Other Than ORD)	8,632	10,948	2,316	1.3

[a]Base Year FY76.

[b]No air taxis or general aviation traffic in bad visibility.

The sensitivity to forecast data is examined in Table 3-9. Cost/benefit analysis was not performed for all conditions. Instead, the preliminary screening criterion (demand exceeds capacity by 5 operations/hour), which worked quite well for the baseline case, was examined for various differences in traffic growth rate. Column 1 simply repeats the baseline screening with four airports requiring TAGS prior to 1995. DFW was not included because of infrequent bad visibility conditions and the late requirement date. The next three columns give the requirement dates for reductions in the growth forecast at each airport. It was assumed that airports with an excess demand of 5 operations/hour prior to 1995 would accrue adequate benefits to warrant a TAGS. On this basis, with a 10 percent reduction in growth JFK would be dropped from consideration. Deployment at ATL and LAX could be delayed until the late 1980's if the engineering model could be commissioned at O'Hare. The same conditions are generally true for a 25 percent reduction in growth, except that the ATL and LAX deployments could be delayed to the early 1990's. A 50 percent reduction in growth produces the same result as a no growth situation; only at O'Hare will the TAGS remain a potential requirement.

TABLE 3-9. SENSITIVITY TO FORECAST DEMAND AND SYSTEM CAPACITY

AIRPORT	YEAR BAD VISIBILITY DEMAND = 90 OPS/HR					=70 OPS/HR
	BASELINE	90% GROWTH	75% GROWTH	50% GROWTH	125% GROWTH	BASELINE
ORD	1974	1974	1974	1974	1974	1974
ATL	1986	1988	1990	1998	1984	1974
JFK	1994	1998			1988	1978
LAX	1984	1988	1995		1980	1974
SFO					1995	1985
DFW	1992	1995			1988	1981
DEN					1996	1987
LGA						
PIT					1999	1990
BOS						2000
STL						
DTW						1992
PHL						1996
EWR						

While the baseline program appears strong with respect to each parameter considered separately, a worst case scenario involving several parameters together was hypothesized. The worst case assumed that:

1. Development would be initiated on the baseline program at O'Hare.
2. Traffic would grow as forecast for a few years (i.e., through 1980) but would then level off.
3. Development would slip 2 years with a 50 percent increase in cost.
4. At development completion, production costs would be 50 percent greater than currently estimated.
5. Passenger time cost savings per hour would be 50 percent lower than those used in the baseline analysis

With these assumptions, only O'Hare could warrant TAGS. Therefore, it was further assumed that:

6. No production models would be built and O'Hare would operate with the engineering model. Maintenance costs of TAGS were doubled to reflect the long term operation of an engineering model.

The worst case scenario results in a program which costs approximately $9 million and accrues approximately $11 million in benefits for a benefit/cost ratio of 1.2. The accrued costs and benefits for both the baseline and worst case scenario are shown in Figure S-1. The figure indicates that the development program will likely begin accruing net benefits by 1983 and in the worst case by the mid-1990's. The probability for net loss is low.

To examine the effect of higher than forecast growth, the screening criterion was applied to a demand resulting from a 25 percent increase in growth. The results are given in Table 3-9. It appears that SFO would be added to the program. In addition, although bad visibility is infrequent, DFW might also be added because of the early requirement date; the early date would indicate severe problems (delays) in the 1990's whenever the bad visibility conditions did occur. Total deployment, therefore, would be increased from four to six systems.

Finally, the sensitivity to the capacity estimate of 85 operations/hour (for 2 ground controllers in bad cab visibility conditions with ASDE) was examined. As mentioned in Section 2, it could be argued that this estimate is high. Saturation of ground control can occur with operations as low as 65 operations/hour in bad visibility conditions. When it does, operations in excess of this capacity will increase the likelihood of missed targets and problem situations. To examine the impact of using the more conservative capacity the screening criterion was applied to the airports of Table 3-1 for 70 operations/hour (5 above the more conservative capacity estimate). The results are given in the last column of Table 3-9.

The results indicate that three airports presently require TAGS: ORD, ATL, and LAX. By 1995 six additional airports would require TAGS: JFK, SFO, DFW, DEN, PIT, and PHL. While the inclusion of DEN might be questionnable because of its infrequent bad weather, the early date, as with DFW, would indicate severe problems in the 1990's whenever the bad visibility did occur. On that basis the total TAGS deployment could reach nine airports.

4. HYBRID SYSTEM CONCEPT

In Reference 1, an ASDE-3 cost/benefit analysis was performed based upon improvements only to local control. In that analysis 37 airports were found to require ASDE-3 by 1986. This deployment covered all likely TAGS sites.

The analysis contained herein has been for an ATCRBS multilateration-based TAGS and depended upon improvements only to ground control. This analysis and the ASDE-3 analysis, therefore, are independent, implying that both systems could exist at the TAGS sites and be cost-effective. At first glance however, this would seem foolish, since TAGS can provide the same kind of information to local control as ASDE-3. It would seem reasonable to remove each ASDE-3 once TAGS is installed and use the unit at another ASDE-3 designated airport. In this way the local control benefits of the ASDE-3 (less its movement costs) could be added to the ground control benefits of TAGS, resulting in a more cost-beneficial TAGS deployment. However, TAGS, based solely on ATCRBS multilateration, does not provide as much information as an ASDE-3.

The most notable differences between TAGS and ASDE-3 are that TAGS displays only ATCRBS-beacon-equipped vehicles and does not display a target image (e.g., vehicle shape, heading and location of nose, tail, wing tips). At the TAGS sites all aircraft will be beacon-equipped (i.e., Terminal Control Airspace (TCA) airports) but not all surface vehicles can be. If a "hybrid" system combining radar-derived targets and the special TAGS features (e.g., vehicle identity for beacon equipped targets) were employed all of the advantages of both systems would be realized. In addition, the cost of the hybrid would be cheaper than the sum of the two individual systems due to shared displays and less stringent requirements on the TAGS vehicle positional accuracy. Accurate position and target image would be provided by ASDE-3, not the TAGS trilateration sensor.

The Transportation Systems Center is currently analyzing and evaluating the TAGS hybrid concept. It is likely that the TAGS engineering model will be installed at an ASDE site (e.g., O'Hare with an ASDE-2) and have a hybrid option for evaluation. The development cost impact should be negligable. When a hybrid system is defined well enough to estimate its cost, if it is found advantageous, a revised cost/benefit study will be done for TAGS on a hybrid implementation basis to ascertain whether or not a wider deployment is warranted.

5. CONCLUSIONS

1. The baseline TAGS program calls for the development of a TAGS engineering model at Chicago O'Hare Airport between FY77 and FY80, with the engineering model being commissioned for use between 1980 and 1985. In 1986, four production units would be deployed on a single buy to Chicago O'Hare (replacing the engineering model), Atlanta, Los Angeles, and New York (JFK) airports and operated through the year 2000. Benefits accrued by the system engineering model at O'Hare between 1980 and 1985 would pay for the entire TAGS cost of development. The baseline program would accrue a present value (base year 1976) net benefit of $18.7 million with a benefit/cost ratio of 2.9.

2. If, for any reason, the engineering model cannot be commissioned at O'Hare, two production buys are assumed, one for a FY81 deployment at O'Hare and the second for a FY86 deployment at Atlanta, Los Angeles, and New York (JFK). This alternative program would accrue a present value net benefit of $16.3 million, with a benefit/cost ratio of 2.5. This is slightly less cost-beneficial than the baseline program, but benefits are still substantial.

3. If the development, production, and installation costs should run 50 percent over the current estimates, the baseline program would accrue a present value net benefit of $14.5 million, with a benefit/cost ratio of 2.0. Savings remain substantial in spite of the drastic assumption in cost errors.

4. If only air carriers equip for Cat II and/or Cat IIIa, and if all general aviation and air taxi traffic is eliminated, New York (JFK) and Los Angeles would not require TAGS. However, the baseline program for O'Hare and Atlanta would accrue a present value net benefit of $3.9 million, with a benefit/cost ratio of 1.5. Such a drastic decision on the part of general aviation and air taxi users would substantially reduce overall savings; however, the development program with a limited production deployment would remain cost-beneficial.

5. Should the growth in air traffic be 10 to 25 percent less than forecast, New York (JFK) would not require TAGS. O'Hare would need TAGS as soon as possible since it has a current need. Atlanta and Los Angeles would require TAGS by the late 1980's.

6. If development at O'Hare is initiated and a worst case situation should develop,

a. No traffic growth after 1980

b. Two year development slip

c. 50 percent increase in system costs

d. Loss of 50 percent of baseline passenger cost savings

use of the engineering model at O'Hare with no production buy would accrue adequate benefits to pay off development costs by the mid-1990's.

7. Should the growth in air traffic be 25 percent greater than forecast, San Francisco and Dallas-Ft. Worth would likely become TAGS sites, and the total deployment would increase from four to six.

8. Should a more conservative capacity estimate be made for ground control under bad visibility conditions in order to virtually guarantee elimination of bad visibility problems, the deployment of TAGS would extend to nine systems. TAGS sites would consist of the baseline four plus San Francisco, Dallas-Ft. Worth, Denver, Pittsburgh, and Philadelphia.

APPENDIX
O'HARE BENEFITS, 1985 (EXAMPLE COMPUTATION)

P_1	(Bad visibility capacity of two ground controllers with ASDE; assumed for this study from previous analyses)	= 85 $\frac{Ops}{Hr}$
P_2	(Good visibility capacity of two ground controllers; assumed for this study from previous analyses)	= 175 $\frac{Ops}{Hr}$
O_1	(Annual air carrier operations; from forecasts - Table 2-1)	= 658,000 Ops.
F_1	(Fraction of daily air carrier operations in busy period; from current traffic profiles - Table 2-1)	= 0.93
O_2	(Annual air taxi operations; from forecasts - Table 2-1)	= 85,000 Ops.
F_2	(Fraction of daily air taxi operations in busy period; from current traffic profiles - Table 2-2)	= 0.87
O_4	(Annual itinerant operations; from forecasts - Table 2-1)	= 743,000 Ops.
O_3	(Annual itinerant general aviation operations) = $O_4 - (O_1 + O_2)$ =	0 Ops.
F_3	(Fraction of daily itinerant general aviation operations in busy period; approximated from Reference 1)	= 0.9
B	(Number of busy hours; from current traffic profiles - Table 2-2; 0700-2200)	= 15 Hr

N_2 (Mean hourly demand in good cab visibility conditions; from Section 2.4.1 equation) = $\frac{O_1}{365} \times \frac{F_1}{B} + \frac{O_2}{365}$

$$\times \frac{F_2}{B} + \frac{O_3}{365} \times \frac{F_3}{15} \qquad = 126 \frac{\text{Ops}}{\text{Hr}}$$

N_1 (Mean hourly demand in bad cab visibility conditions; from Section 2.4.2) =

$$\frac{O_1}{365} \times \frac{F_1}{B} + \frac{O_2}{365} \times \frac{F_2}{B} + 0.4 \times \frac{O_3}{365} \times \frac{F_3}{15} \qquad = 126 \frac{\text{Ops}}{\text{Hr}}$$

t (Mean duration of each long term (i.e., >90 min.) bad visibility occurrence; from climatological summaries) = 2.8 Hrs

f (Yearly frequency of long term (i.e., >90 min.) bad visibility between 0700 and 2200; from climatological summaries) = 4.9

D (Yearly delay experienced during long term bad visibility; from Section 2.3 equation) =

$$\frac{30t^2 f\,(N_1 - P_1)(N_1 - P_1 + P_2 - N_2)}{(P_2 - N_2)}$$

= 86,346 Aircraft Mins.

C_T (Total cost per aircraft minute of delay; from Table 2-5) = \$35.32/Aircraft Min.

C_D (Yearly delay cost = 60 C_T D) = \$3,050,000

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