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AIRPORT SURFACE TRAFFIC CONTROL SYSTEMS DEPLOYMENT ANALYSIS

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16. Abstract

This report summarizes the findings of an analysis of ASTC (Airport Surface Traffic Control) system requirements and develops estimates of the deployment potential of proposed system alternatives. The tower control problem areas were investigated by a survey of 19 airports including: visual observations, interviews with tower personnel, collection of data of record and an analysis of tower communication tape recordings at selected airports. Data were also collected from regional FAA authorities and airport authorities on facility expansion and improvement plans aimed at meeting the projected air traffic demand.

A preliminary requirements analysis was performed for three baseline airports to quantify the control tower problems, establish the degree of relief achievable with alternate conceptual ASTC systems, and to establish physical limits on airports operational capacity.

This report summarizes the requirements analysis and extends the analysis to the remainder of airports surveyed and establishes a tentative deployment schedule of system alternatives. The deployment schedule is established on the basis of a capacity/demand ratio criterion aimed at limiting the delays encountered by aircraft to reasonable levels when the required systems are available.

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PREFACE

The work described in this report was performed in the context of an overall Airport Traffic Control program at the Transportation Systems Center, designed to develop and demonstrate a family of systems compatible with the ground surveillance, control, communication and guidance requirements of the individual airport. This program is sponsored by the Department of Transportation through the Federal Aviation Administration, Systems Research and Development Service. The program supports Government activities designed to expedite traffic flow on airport runways and taxiways safely under prevailing airport weather conidtions.

The TSC Airport-Surface-Traffic-Control Program Office contracted with the MITRE Corporation of McLean VA, to perform this analysis as a first step in proposing solutions to problems in controlling airport surface traffic.

CONCLUSIONS

1. The primary requirement for improving the performance capabilities of both the local and ground controller under both good and bad visibility conditions was determined to be improved surveillance. The two candidate systems defined to meet this requirement are the ASDE (Airport Surface Detection Equipment) and the ASE (Advanced Surveillance Equipment). The ASDE is presently in use at seven commercial airports. An improved ASDE should be available by 1976. The ASE should be available by 1980 and it will provide the controller with aircraft location and an alphanumeric presentation of aircraft identity, aircraft type, destination, etc.

2. In comparing FAA projections of airport demand with expansion plans for the airports, most airports become runway limited in good weather operations before the ground controller capacity or gate capacity restrict the operations rate of the airport. As a result, the potential deployment dates for the ASE are primarily based on improving the local controller's performance to increase runway capacities. Also, given the deployment of the ASE, the airports become limited at an operations rate lower than required to justify the deployment of any control improvements for the ground controller.

3. Of the 19 airports studied, it was found that, at 12 airports, the Advanced Surveillance System could be justified to improve the good visibility performance of the local controller before it could be justified for either controller in bad visibility conditions.

4. For the 16 airports with high incidences of bad visibility weather (Category II and III A), 13 of the airports can justify the deployment of an ASDE now. Nine are already installed, and seven are in use.

5. By the time the ASE System is available in 1980, it appears that eight airports can justify the system. If the initial deployment is to all airports which will justify the system prior to 1985, then in 1980-1985, thirteen airports will receive the ASE. Of the 19 airports surveyed, the total deployment for the ASE System appears to be 18 through the year 2001.

RECOMMENDATIONS

1. The ASDEs currently installed should be used; when the improved ASDE becomes available, it should replace the current ASDEs unless an ASE is scheduled for deployment at about the same time.

2. When the new ASDE is available in 1976, an initial deployment of the new ASDE should be made at five airports that will not warrant the deployment of an ASE in 1980.

3. When the ASE is available in 1980, the system should be immediately deployed at eight airports, five more should be deployed by 1985 and two more by 1990.

4. Because improvement of the local controller's performance in good weather is a prime determinant on the deployment schedule, it is recommended that a follow-on study be performed to determine the expected deployment of ASTC Systems under the assumption that the candidate systems will not improve the local controller's good weather performance.

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1. INTRODUCTION

This paper summarizes the findings of an analysis of ASTC system requirements and develops estimates of the deployment potential of proposed system alternatives. The motivation for the initiation of the studies, summarized here, was as follows:

1. Tower control workload overloads due to increasing air traffic demand and restricted runway/taxiway/ramp facilities under normal operating conditions (good visibility weather). This item includes the potential deterioration of the level of service provided to surface traffic as control workloads reach critical levels as well as the increased difficulty of controlling surface traffic due to visibility obstructions resulting from expansion of terminal buildings in the direction of the taxiways and, in some cases, runways.

2. Tower control workload overloads and restricts capability to handle traffic safely under reduced visibility weather conditions. The prime motivation in this area is to match the tower control system capability with present and planned improvements in the operational capability of landing systems.

The tower control problem areas were investigated by a survey of 19 airports. The data included: visual observations, interviews with tower personnel, collection of data of record and an analysis of tower communication tape recordings at selected airports. Data were also collected from regional FAA authorities and airport authorities on facility expansion and improvement plans aimed at meeting the projected air traffic demand.

A preliminary requirements analysis (Reference 1) was performed for three baseline airports to: quantify the control tower problems, establish the degree of relief achievable with alternate conceptual ASTC systems, and to establish physical limits on airports' operational capacity. The analysis conclusions were essentially that:

1. Significant performance improvements could be achieved by deployment of ASDE (Airport Surface Detection Equipment) with an improved (bright) display under bad visibility conditions. However, the performance would fall short of that achievable under good visibility conditions without any controller aids. Consequently, ASDE should be considered to be only an interim improvement at airports where a large number of aircraft can be expected to land in Cat II and

III weather conditions. The major improvement needed in bad visibility operations is a reduction of workload involved in surface traffic control and the creation of a control environment independent of visibility conditions. This would require a superposition of a data block (identity, aircraft type and possibly destination on the airport surface) on a planar display covering the tower control area (outer marker to airport surface and airport surface).

2. Major performance improvements, independent of tower visibility, can be attained by the introduction of ASE (Advanced Surveillance Equipment) providing the controllers with a planar display of traffic (to outer marker) including data block and a system for calling controller attention to aircraft requiring control services.

3. Additional, less pronounced, improvements of performance capability can be achieved, if needed, by introduction of STR (Standard Traffic Routing) patterns and AICS (Autonomous Intersection Control Systems) to further reduce routine and conflict workloads, respectively, and to provide for smoother traffic flow patterns.

This paper extends the above three-airport analysis to the remainder of airports surveyed and establishes a tentative deployment schedule of system alternatives. The deployment schedule is established on the basis of a capacity/demand ratio criterion, derived in this paper, aimed at limiting the delays encountered by aircraft to reasonable levels when the required systems are available. Otherwise the demand growth is assumed to be limited until the required system becomes available and normal growth is assumed to resume following the removal of the capacity limiter.

2. AIRPORT SURFACE TRAFFIC CONTROL SYSTEMS DESCRIPTION

The following description of the proposed system modules was abstracted from Reference 2. The functional requirements for the conceptual design were previously established by the analysis from Reference 1 and the descriptions are presented at this point to establish a correlation between the estimated benefits (summarized in section 3) and proposed system implementations.

2.1 Functional Module Descriptions

2.1.1 Airport Surface Detection Equipment (ASDE) Module

This module consists of three items. First, modifications will be made to the current ASDE-2 as a short term measure to improve its performance and to reduce its maintenance costs at those sites at which it is installed. A new ASDE-3 radar will be developed to replace the ASDE-2. Thirdly, a new bright display will be developed for use with the ASDE-2 and ASDE-3 as it is deployed.

2.1.2 Improved Visual Guidance Module

Improved runway and taxiway lights will be developed. The objective is to correct any maintenance problems which exist with the current lights, to extend the useful operational range of lights as far down in visibility conditions as feasible, to provide a light for runway exit ramp notification to landing aircraft, and to provide a Clearance Bar Light (see ICAO International Standards and Recommended Practices Annex 14).

Improved runway and taxiway signs will be developed. The objective is to extend the useful operational range as far down in visibility conditions as feasible, to provide runway exit angle and demarcation at each runway exit ramp and to provide comprehensive taxiway demarcation at the entrance to an intersection and an active runway. An example of how the improved visual guidance equipment might be mechanized is shown in Figure 2-1. The signs are expected to be externally front lit, retro reflective highway type signs showing the demarcation and angle of taxiways exiting the intersection. Runway lighting is white inset, except that a green light is placed at the intersection of each runway and exit ramp centerline. In addition, a wide aperture (possibly omnidirectional) lead-in light is shown on the exit ramp. Upon entrance into the taxiway network, the yellow Taxi Holding Position Marking (i.e. painted line) is augmented by a Clearance Bar. In Figure 2-1, EA 101

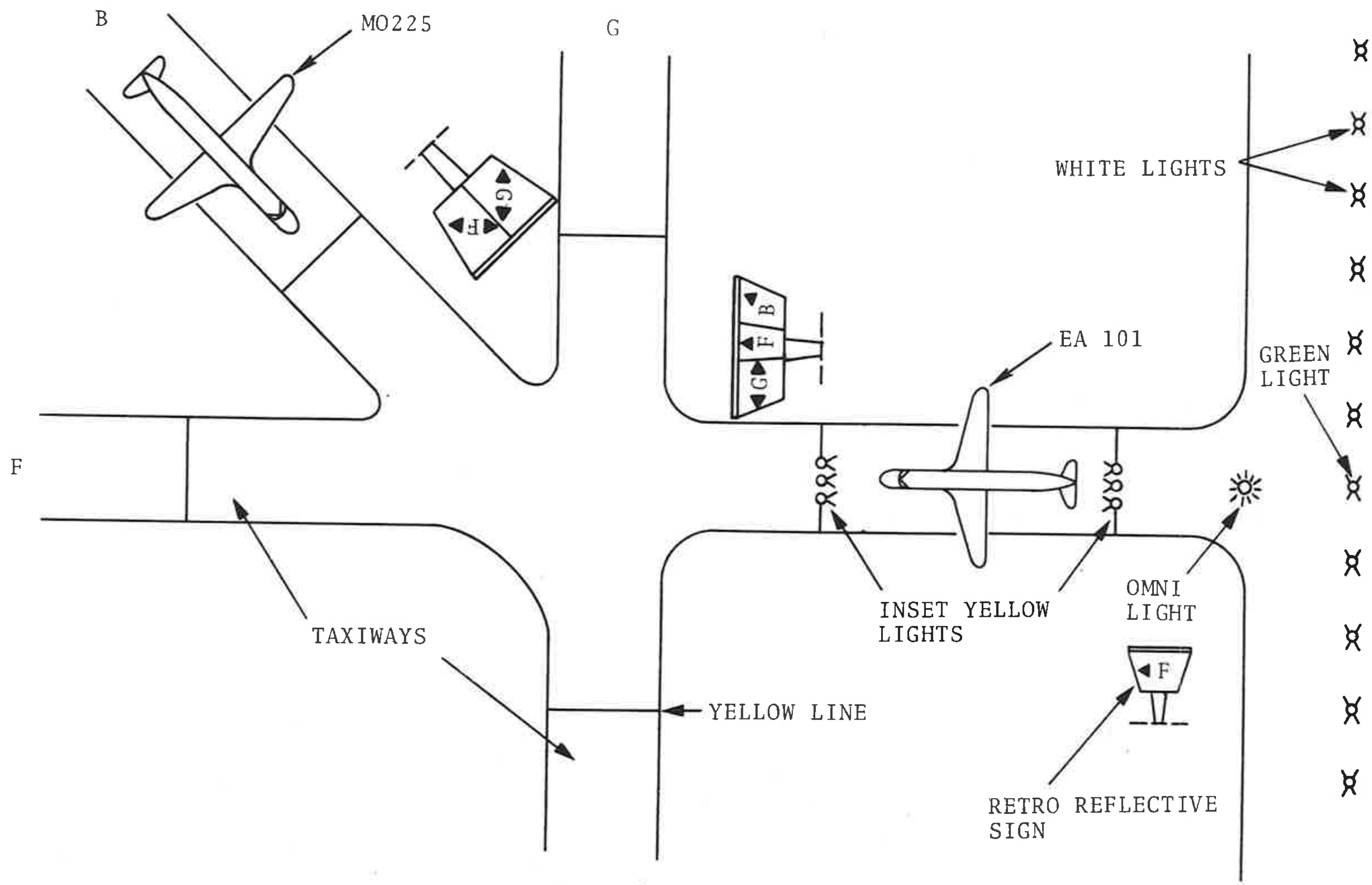


FIGURE 2-1
EXAMPLE OF IMPROVED VISUAL GUIDANCE

is holding short of the Clearance Bar. In addition, a Clearance Bar would exist on all taxiway entrances to the active runways. The Clearance Bar would clearly indicate a warning to the pilot that he should not cross the bar prior to receiving a positive controller command. The Clearance Bar would be particularly valuable in poor visibility when a pilot could become disoriented and might blunder into an unsafe area (e.g., intersection or active runway).

2.1.3 Advanced Surveillance Equipment (ASE)

The Advanced Surveillance Equipment would provide coverage of the final approach, the initial airside departure, the runways, the taxiways and the ramps. The data for airborne coverage will be taken from ARTS III. The displays for Local Control and Ground Control would be specially tailored to their needs. An example of the Ground Control display is given in Figure 2-2. The display would be all synthetic (computer driven). The aircraft (vehicle) symbol would be an image of the aircraft whose size would be scaled to aircraft type if a flight plan had been filed, or a triangle if the flight plan was not filed. The data block for filed aircraft would contain aircraft identity, weight class (e.g., Heavy, Medium or Light), airport destination (e.g., runway 24 or gate area A with a 10 minute gate hold) and any related flow control restriction (e.g., flight to Denver one every 10 minutes - see "D-10" on Figure 2-2). Non-filed aircraft would show only beacon code and take-off runway. Aircraft entering the ground control area would flash in order to cue the Ground Controller. Aircraft in the Ground Control area would show bright to contrast to the background and aircraft outside the ground area which would show more dimly.

An example of the Local Control display is given in Figure 2-3. The display would depict the final approach path, the initial departure area, the active runways, and the adjacent taxiways. Data blocks would be similar to those on the Ground Display. Runway occupancy would be denoted by a flashing symbol and data block.

The advantages of such a system over ASDE are obvious. The ASDE clutter is eliminated and clear background and targets portrayed. Aircraft identity is furnished in a manner even superior to out of tower cab surveillance. This assists the controller in performing the communication of commands. Aircraft size and weight aids the controller in satisfying taxiway and runway

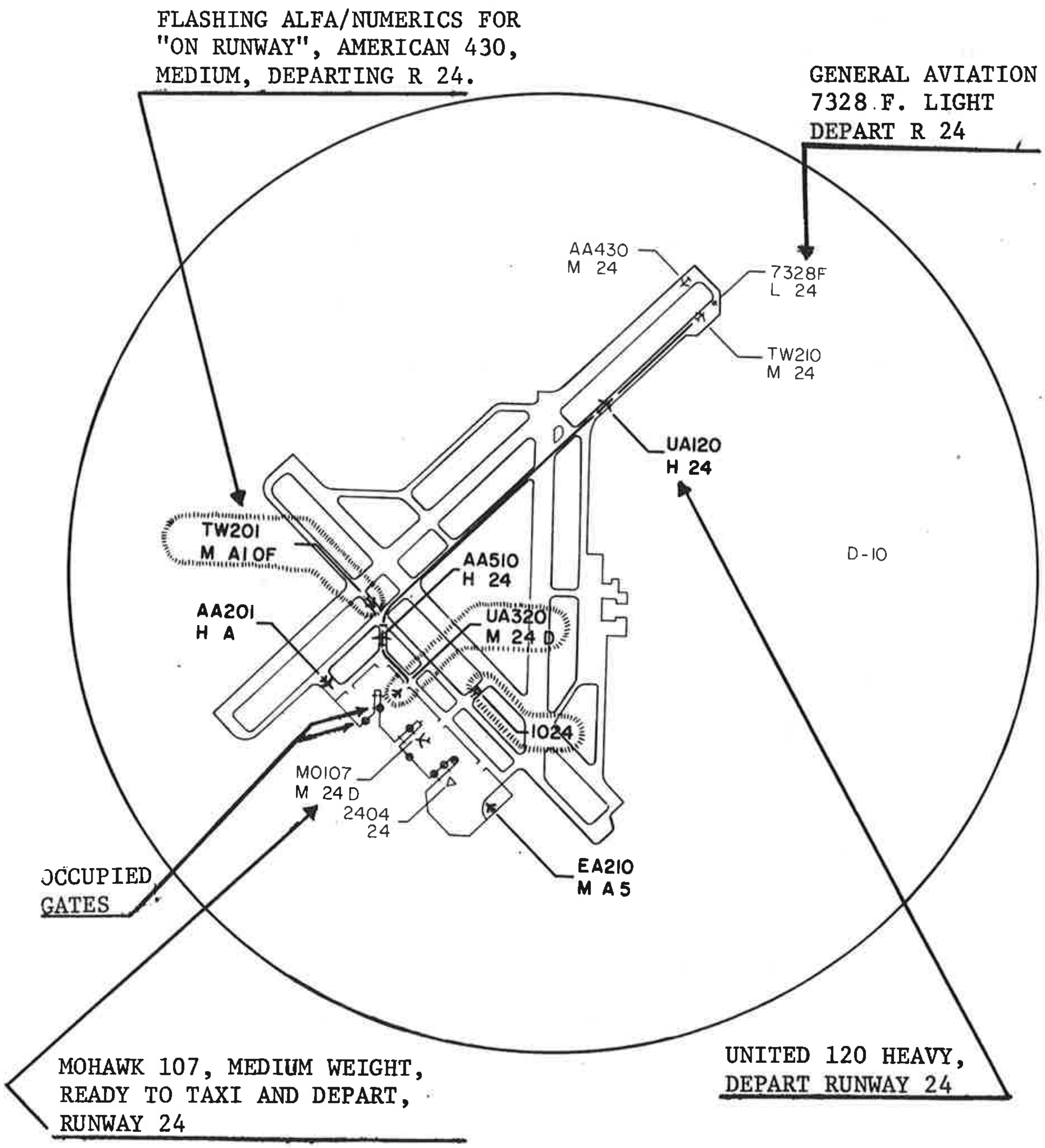


FIGURE 2-2
ADVANCED SURVEILLANCE EQUIPMENT DISPLAY FOR GROUND CONTROL

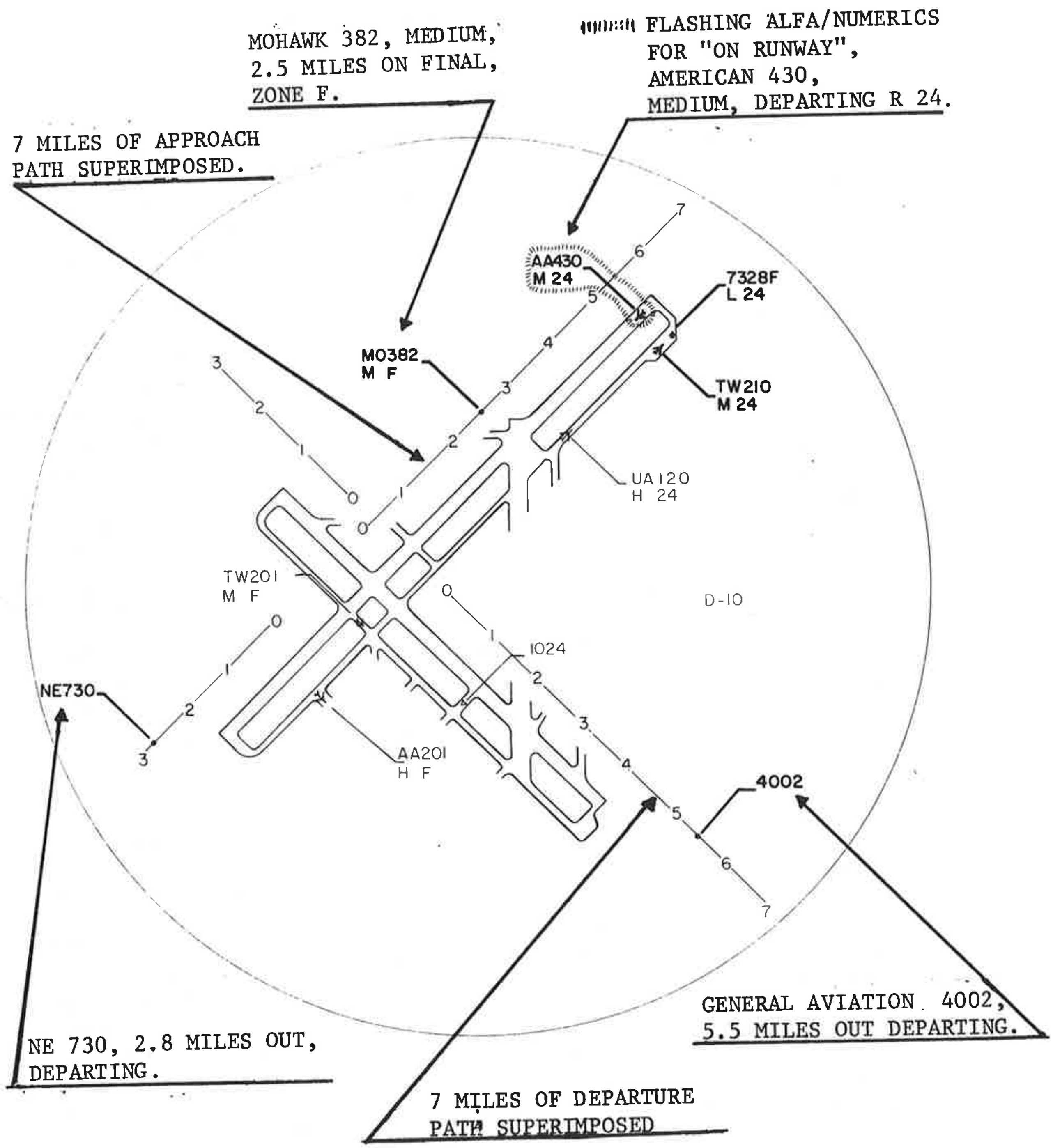


FIGURE 2-3
ADVANCED SURVEILLANCE EQUIPMENT FOR LOCAL CONTROL

utilization restrictions. Airport destination, gate delay and flow control restrictions aid in route determination. The technical means for implementing the Advanced Surveillance Equipment are discussed in Section 2.2.

2.1.4 Standard Taxiway Routing (STR)

Current procedures call for the Ground Control position to route each aircraft at the time of taxi clearance. This is in spite of the fact that most of the aircraft can take standard routes based upon destinations (e.g., takeoff runway), points of origin (e.g., gates) and the runway configuration in use. As the traffic builds up, the ground controller may tend to keep the voice communications terse. This together with what may be a rapid message delivery rate can possibly lead to misunderstanding by a pilot. In order to circumvent the latter and mainly to unburden the ground controller communications workload, an optional procedure proposed herein would permit the Clearance Delivery position in addition to transmitting the clearances to also give simple, standard taxi routings (STR's). Then, when the departure is ready to enter the taxiway system, Ground Control indicates the first communications by granting a "clear to taxi" at the proper time. Infrequent changes to the taxi routing can be handled by the Ground Control. The accompanying off-loading to the Ground Control communication channel will in-turn increase that on the Clearance Delivery communication channel. This can be reduced by the Improved Communication System module described in Section 2.1.5.

2.1.5 Improved Communication System Module

Certain operational or procedural changes may be required to implement this concept. The module consists of two items, Automatic Clearance Transmission Equipment (ACTE) and Automatic Gate Status Equipment (AGSE). Both communication systems will serve as a digital data link alternative to current voice communications. ACTE will utilize the data link (being developed under other programs) to automatically (on pilot request) transmit Departure Clearances and Standard Taxiway Routes to outbound aircraft, thus off-loading Clearance Delivery of this function for all equipped aircraft. In addition, a clear, easy to read, hard copy of departure clearance and taxi route will be printed out in the cockpit for pilot use. This equipment will also permit the concept of standard taxiway routes to be extended to inbound aircraft since they may use this secondary communication link to request inbound routes while still in the air. This would allow the VHF voice channel to be dedicated to control. AGSE will consist of a new data transmission system between airline dispatch and the tower cab. This system would replace the use of the telephone to determine gate availability, gate assignment and gate delays. The data transmission system would use telephone lines. The human interface would be a data entry keyboard and display. Airlines would be required to input gate delays and unavailability of gates for inbound aircraft. This would be displayed to the Ground Controller to be factored into his route determination (see Section 2.1.3).

2.1.6 Automatic Intersection Control Module (AIC)

The objective of this module is to automatically (no controller action required) control critical taxiway intersections at an airport. This function is currently shared by the pilot and Ground Control in a satisfactory fashion. However, when poor visibility conditions begin to shift the task burden from the pilot to the controller and as the volume of operations increases the workload associated with the control of critical intersections will become higher. To off-load this work, it is proposed that certain critical intersections be equipped with automatic control systems. An illustrative example of an intersection control system is given in Figure 2-4. The system is implemented with inductive loops to detect the presence of an aircraft, a computer to determine the control command, red stop bar lights to communicate stop commands to the aircraft and a Ground Control monitor display and override console. The loops are installed in pairs for reliability. As aircraft approach the intersection they trigger the outer set of loops. The first to trigger the loops would be cleared into the intersection, the second would receive a red stop signal. If the stopping aircraft overruns the bar, the second set of loops would alarm the controller. As the cleared aircraft crossed the exit loops (set "D") the holding aircraft would be cleared to enter the intersection (i.e. the red stop bar would go out).

2.2 Technical Alternatives

There exists a great many technical alternatives for mechanizing the modules defined in Section 2.1. The ASTC program has considered and will continue to consider these alternatives, however, it is not the intent of the program to develop a family of technical alternatives but rather to select viable technical approaches to system/subsystem development, conduct selected technology activities which support system development and then proceed with development, test and evaluation of systems, subsystems, and equipments for introduction into the ASTC

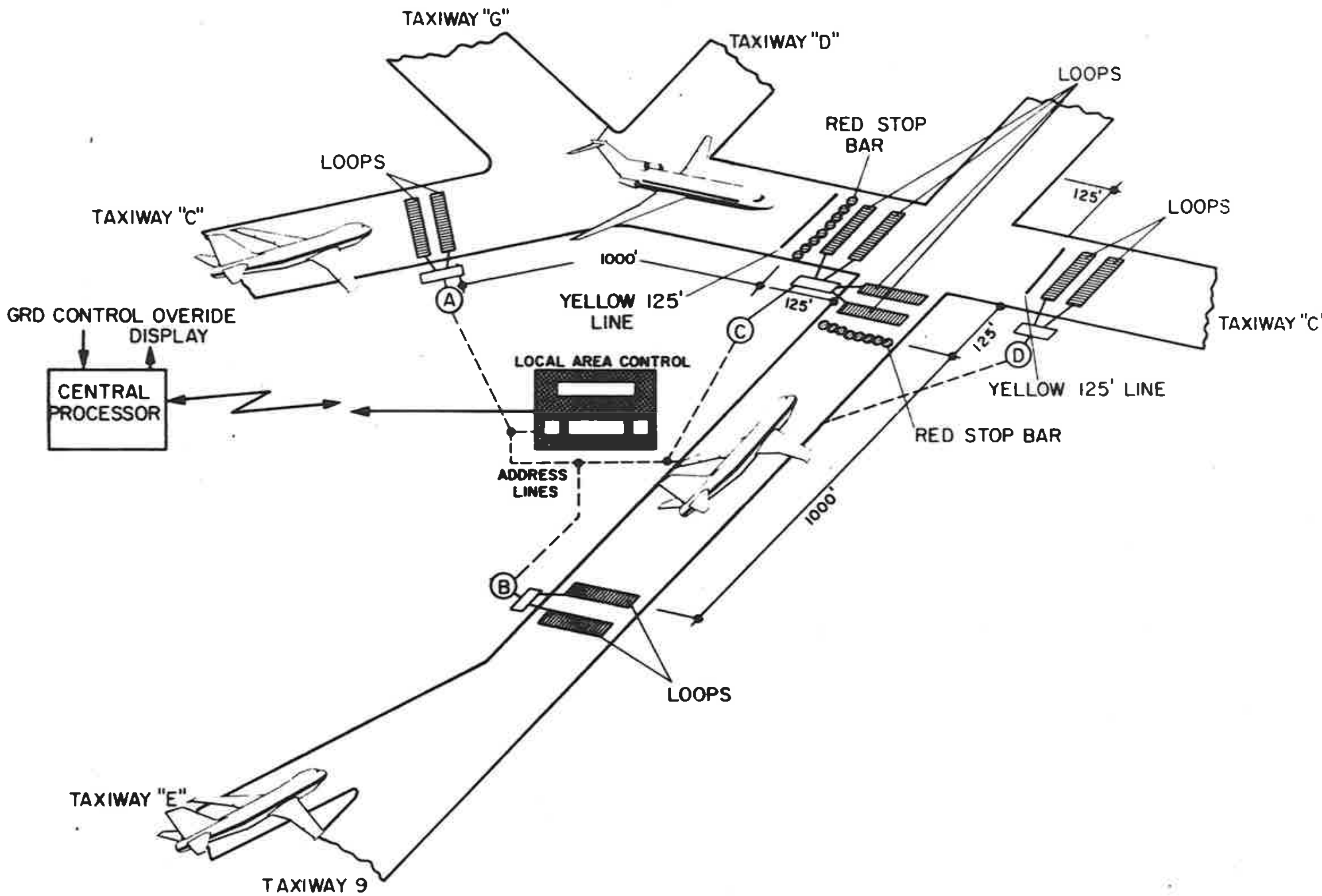


FIGURE 2-4
AUTOMATIC INTERSECTION CONTROL SYSTEM

environment as dictated by the needs of the airports. The mechanizations discussed in Section 2.1 and herein, therefore, represent the most promising alternatives which the program will pursue. Limited paper evaluations of new alternatives have been and will continue to be conducted.

2.2.1 Surveillance

The functional characteristics of an Advanced Surveillance Equipment were examined in Section 2.1.3. In mechanizing the module it can be divided into subsystems as shown in Figure 2-5. The Data Acquisition Subsystem (DAS) utilizes vehicle sensors to detect the position of the target on the airport surface. In some cases, target identity of some sort is included. This position information is then sent to the Processor Subsystem (PS). In general, the processor (1) filters the position information to minimize the effects of noise; (2) associates identity with each target and tracks the target; (3) controls the interface with equipments such as the ARTS computer from which aircraft identity/position correlation would be automatically obtained; (4) controls the operation of the DAS; (5) prepares data for display including background formats; and (6) controls the interface with the Display Subsystem (DS) including any keyboard input functions. The Display Subsystem provides the controller interface with the system.

The distinguishing factor between the two mechanization alternatives of the Advanced Surveillance Equipment is the DAS; the first relies upon the ATCRBS beacon transponder while the second is based upon ASDE.

2.2.1.1 ATCRBS Trilateration Mechanization

This system uses the ATCRBS beacon transponder located in vehicles on the airport surface to furnish position and beacon code data for each vehicle. The system would be designed so as to be compatible with the Discrete Address Beacon System (DABS) as that system replaces ATCRBS. The system operates during the dead time of the secondary radar so that there is no interference with ARTS III interrogations.

The DAS consists of the aircraft transponder, an interrogator, three or more receivers, and a small digital computer. The interrogator is synchronized with the secondary radar so that system operation occurs only in the dead time of a given PRF period; i.e., it would perform interrogations of ground transponders only after all "normal" transponder replies had been received

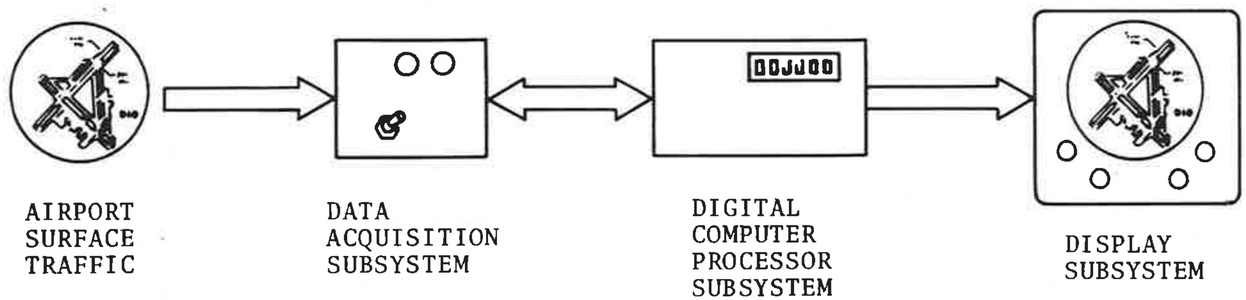


FIGURE 2-5
ADVANCED SURVEILLANCE SYSTEM DIAGRAM

by ARTS III. Interrogations of ground vehicles and aircraft on the airport surface would occur sequentially based on fixed areas of the airport surface such that each seccessive interrogation would apply to a specific area. Their transponder would reply and be picked up at three or more receivers. Time of arrival would be measured and sent to the computer. Beacon code would be determined and correlated with the time of arrival. The computer would compute the position by trilateration and send vehicle position and beacon code to the Processor Subsystem (PS).

2.2.1.2 Digitized ASDE Radar Mechanization

This system would use the ASDE (ASDE-2 or ASDE-3) to furnish target position. Since ASDE is not a cooperative system (i.e. it does not use an on-board beacon), it will not furnish beacon code. The system must then start with identity and position correlation from an external source (e.g. ARTS) and thereafter track each target to maintain this correlation. This initialization and tracking requirement makes this system less desirable than trilateration. However, it may be the more cost effective of the two systems and could be used at non-TCA airports.

The DAS is comprised of an ASDE radar and an Analog Radar Digitizer. The ASDE radar provides an analog video signal (which represents the return from the transmitted pulses), the antenna azimuth readout signal, and pulse timing information. The ASDE range will be approximately 2 miles. The video signal will contain all returns of the radar, targets and background clutter. There is extensive ground clutter on an ASDE. The digitizer will do background clutter suppression based upon airport geometry and target detection, possibly with the aid of velocity detection. It will convert the radar signals into a set of target coordinates to be furnished to the Processor Subsystems (PS).

3. PERFORMANCE MEASURES, DEPLOYMENT CRITERIA AND COSTS

This section summarizes the basic performance measures developed in the study, develops deployment criteria to be used in the subsequent airport-by-airport analysis (see Section 4.) and summarizes the general system costs.

3.1 Performance Measures

The controller performance values, P, used in this study for both the LC (Local Controller) and GC (Ground Controller) were estimated from analyses of communications tape recordings. Most of the tapes were for busy traffic periods and were taken during the 19 airport survey conducted during the study period (December 1971 - June 1973). The other data points were obtained from the Government. This subsection presents the expected LC and GC benefits for each of the alternative ASTC systems, in terms of quantitative estimates of performance and qualitative descriptions of their benefits. The quantitative values will be used in the deployment analysis presented in Section 4.

3.1.1 Local Controller Performance

For the LC, the values of P representing the maximum sustained hourly operations rates of the controller for the various runway configurations under the conditions/systems are presented in Table 3-1. These values were established in Reference 1. Each runway configuration was examined to determine the cycle time between successive arrival operations, assuming that a departure operation was inserted between each arrival pair. From the communications tapes, the necessary events in each cycle were defined and estimates were made of the time between each event, including conservative safety buffers. Therefore, assuming a departure for each arrival and an ideal spacing between arrivals, the values in the table under "Ideal OPH" were generated. The letter designators for each runway configuration (S, D, D', N, F and M) were created to provide a code for classifying configuration types in Table 4-1 in Section 4.

The P values, in operations per hour (OPH) however, assume that both the arrival and departure demands are equal and sufficiently constant and that the arrival spacings always are such that the local controller can release a departure between each arriving pair. However, the spacing between each arrival pair can have some variability based on the precision with which approach control can deliver aircraft to the outer marker. Means for

TABLE 3-1

LOCAL CONTROLLER OPERATIONAL PERFORMANCE ESTIMATES

RUNWAY CONFIGURATION	GOOD VISIBILITY			BAD VISIBILITY WITH NO ASDE			BAD VISIBILITY WITH ASDE			BAD OR GOOD VISIBILITY WITH ADVANCED SURVEILLANCE SYSTEM (2)		
	IDEAL (1) SPACING	IDEAL OPH	PRACTICAL OPH	IDEAL SPACING	IDEAL OPH	PRACTICAL OPH	IDEAL SPACING	IDEAL OPH	PRACTICAL OPH	IDEAL SPACING	IDEAL OPH	PRACTICAL OPH
SINGLE RUNWAY (S)	120 sec	60	54	165 sec	44	40	150 sec	48	43	120 sec	60	60
DUAL LANE (D) (3)	80 sec	90	81	110 sec	65	58	100 sec	72	65	80 sec	90	90
(D')	75 sec	96	86	-	-	-	-	-	-	75 sec	96	96
NEAR END CROSSING (N)	70 sec	103	93	100 sec	72	65	90 sec	80	72	70 sec	103	103
FAR END CROSSING (F)	100 sec	72	65	130 sec	55	50	120 sec	60	54	100 sec	72	72
CROSSING IN MIDDLE (M) (4)	85 sec	85	76	115 sec	63	56	105 sec	69	62	85 sec	85	85

(1) Spacing between successive arrivals

(2) Assuming ideal management of arrival spacing

(3) Values for D are for runway pairs so close that more than one aircraft cannot be parked between them
Values for D' are based on wide separation between runways

(4) Average between Near End Crossing and Far End Crossing

reducing the delivery error to the outer marker are under study for incorporation in the ATC system of the future (metering and spacing). However, the local controller still has the responsibility of determining whether or not the spacing interval on the final approach is adequate to release a departure. In today's system even in good visibility and with the means available to him for determining position and spacing on the final approach, the local controller requires arrival intervals which reduce P by 10% less than the ideal system as the results in Reference 1 indicate. Thus, the values in the table under "Practical OPH" are 10% less than the "Ideal" values.

It is important to note here that during over demand periods in which queues exist, it should be possible to attain the "Ideal" values of P with proper management of the arrival stream (for example through precise metering and spacing) and an improved surveillance capability (e.g., ASE). However, the operations rate for the given demand can be maximized by proper management of arrival spacings. Even if arrivals are generated at lower than peak demand rates, the spacing between arrivals must be controlled to permit the maximum number of departure slots when queues exist, i.e., arrivals should not be permitted to randomly enter the approach stream as they arrive in the terminal area. The achievement of the ideal rate is also contingent on surveillance improvements, including coverage of the final approach airspace, to enable the Local Controller to take advantage of these opportunities. Thus, the P values for the Advanced Surveillance System are the same as the "Ideal" values, although precise metering and spacing would also be required.

The values for the Bad Visibility Conditions in Table 3-1 were developed analogously to the good visibility values. In the case of the values for good visibility conditions, the "Ideal" values were based on a theoretical determination of the operational sequence of events. Data from the communications tape recordings verified the sequence of operations and that a 10% reduction in OPH occurred in practice. Since improved landing systems are not yet in the field and thus the IFR demand does not really exist yet, the theoretical estimates of IFR spacings between arrivals could not be verified by observations. Therefore, the good visibility operational sequence of events for each configuration were used as the theoretical base and additional times were added for the critical events in each sequence to account for spacing uncertainties due to the lack of surveillance. The Practical OPH values were determined similarly to the good visibility conditions as 10% less than the theoretical or ideal values. The times that were added to each operational sequence were estimates of the additional uncertainties in performing the following three critical events: determining when the arrival exits and clears the runway, determining whether a departure can be released depending on the position of the next arrival, and determining whether the next landing should be cleared subject to the constraint of runway clearance by a departing aircraft. These time estimates provide sufficient margins of safety to accommodate the uncertainties in the positioning information. In particular, for a single runway(s) and no ASDE, 15 seconds was considered to be a reasonable estimate of the additional uncertainties for each of the three events. With an ASDE the runway clearance detection was considered immediate, resulting in a total of 30 seconds uncertainty for the other two events. For the other configurations, the estimates were a total of 30 seconds without an ASDE and 20 seconds with an ASDE. The differences between no ASDE and ASDE reflects the requirement that without an ASDE, the controller must depend on pilot reports for runway position and clearance and with an ASDE he can observe the targets on the ASDE display. The values are higher for a single runway because the events are more critical since each operation depends directly on the completion of the previous operation.

For the Advanced Surveillance case, the same values of P were assumed for "Bad Visibility" as for "Good Visibility" and the "Practical" values are the same as the "Ideal" values. That of course assumes that the surveillance system will provide coverage of the approach and departure airspace. For all of the values in bad visibility, it is also assumed that runway occupancy time will be controlled so as not to restrict the spacings between operations. Runway guidance must be provided so that the pilot can control his speed on the runway to minimize the time to reach and clear the desired exit.

3.1.2 Ground Controller Performance

For the GC, the performance values, P, for good visibility conditions were estimated from the data presented in Table 3-2. VHF voice communications channel loading was found to be the constraining factor on performance. The four sets of channel loading data in Table 3-2 that show observed loadings and estimated loading estimates for "Surveillance", "Conflict Control", "No Conflict Control" and "Other" were taken from Reference 1. These four data points provided the basis for

TABLE 3-2
GROUND CONTROL–GOOD VISIBILITY PERFORMANCE CAPABILITIES

AIRPORT	DATE	TIME	# OF CONTROLLER	OPS RATE PER HOUR	OBSERVED COMMUNICATIONS CHANNEL LOADING DATA *					POTENTIAL SYSTEM IMPROVEMENTS		
					TOTAL COMMO. CHANNEL LOADING	OBSERVED LOADING / IMPROVED LOADING ESTIMATE [PER CENT IMPROVEMENT OF TOTAL]				(PER CENT CHANNEL LOAD REDUCTION)/ADJUSTED CHANNEL LOADING RESULTING FROM IMPROVEMENT		
						SURV.	CONTROL CONFLICT	CONTROL NO CONFLICT	OTHER	TAXIWAY IMPROVEMENTS	ADVANCED SURVEILLANCE	STRS AND AICS
PHL	12-17-71	0850-0950	1	45	29					(10)/26	(10+25)/19	(10+25+10+6)/14
PIT	12-17-71	1828-1928	1	53	34					(10)/31	(10+25)/22	(10+25+10+6)/17
CLE	12-15-71	0845-0945	1	56	40					(10)/36	(10+25)/26	(10+25+10+6)/20
LAX	1-11-72	1930-2000	1	64	47	$\frac{17.8}{3.7}$(30.0)	$\frac{10.4}{4.5}$(12.6)	$\frac{15.9}{6.1}$(20.8)	$\frac{2.9}{2.9}$(0.0)	(6.3)/44	(6.3+30)/30	(6.3+30+10.4+6.3)/22
PHL	12-16-71	1630-1930	1	68	35					(10)/32	(10+25)/23	(10+25+10+6)/18
EWR	6-23-65	1500-1700	1	68	46					(0)/46	(0+25)/34	(0+25+10+0)/30
BOS	12-1-71	1630-1700	1	74	49	$\frac{14.7}{5.0}$(19.8)	$\frac{9.7}{4.3}$(11.0)	$\frac{14.5}{5.8}$(17.8)	$\frac{10.2}{10.2}$(0.0)	(5.5)/46	(5.5+19.8)/37	(5.5+19.8+8.9+5.5)/30
LGA	6-23-65	1500-1700	1	96	70					(0)/70	(0+25)/52	(0+25+10+6)/41
LAX	1-11-72	1200-1230	1	104	58	$\frac{19.5}{7.1}$(21.4)	$\frac{19.1}{11.1}$(13.8)	$\frac{17.8}{7.6}$(17.5)	$\frac{1.6}{1.6}$(0.0)	(6.9)/54	(6.9+21.4)/42	(6.9+21.4+8.8+6.9)/32
JFK	6-23-65	1500-1700	1	111	71					(0)/71	(0+25)/53	(0+25+10+6)/42
ORD	6-23-65	1500-1700	1	120	66					(10)/59	(10+25)/43	(10+25+15+10)/26
ORD	2-12-73	2000-2030	2	122	121					(10)/109	(10+25)/79	(10+25+15+10)/48
ORD	1-14-72	0825-0925	2	130	79					(10)/71	(10+25)/51	(10+25+16+10)/32
ORD	1-13-72	1700-1730	2	140	165	$\frac{50.8}{0.0}$(30.8)	$\frac{40.3}{1.6}$(23.5)	$\frac{62.5}{13.9}$(29.5)	$\frac{11.2}{11.2}$(0.0)	(11.8)/146	(11.8+30.8)/95	(11.8+30.8+14.8+11.8)/51

* IN PERCENT

projecting the relationships between channel loading and operations rate as a function of system improvements. It is assumed in this study that the GC will reach a maximum sustained traffic handling capability when his communicating 70% of the time. This limit on channel loading is an estimate of the sustained level beyond which a controller should not be expected to operate over long periods of time (e.g., hours) on a daily basis. Channel loadings of 80% to 85% were observed over short periods of time (10-15 minutes) but they obviously could not have sustained that level for very long. Because of time wasted in keying microphones and accounting for delays between messages, there appears to be a physical limit on channel loading below 100%, at about the 85% to 90% level.

The four base data points are presented as they were in Reference 1, except that: the values listed under Surveillance, etc. are in actual channel loading instead of per cent of the total channel loading and the values for the ORD data point are for the arrival GC only, since, of the two GC's, he had the most limiting channel load. The departure GC through procedural improvements has already been relieved of some routine workload functions in the ramp, which resulted in a significantly lower communication workload than the arrival GC (measured at up to 20% reduction in loading). The values for the "Improved Loading Estimate," shown as the value below the line in Table 3-2, were defined in Reference 1 as the channel loading resulting from system improvements as follows:

1. Surveillance - The observed values included messages: from the pilot which provided the GC with information about the status of aircraft such as pushback and taxi requests; controller requests of the pilot for aircraft status information such as identity, position and destination; and pilot responses to the latter requests. The workload reductions assumed a surveillance system that provided the GC with a display showing the location, identity, destination, aircraft type and classification as to arrival or departure of each aircraft on the airport surface. An additional feature, which is not defined in Reference 1, but included in this study and reflected in the values in the table is that the proposed surveillance system would include an alert to the GC that an aircraft wanted to enter the taxiway system, thus desiring a taxi clearance.

2. Conflict Control - The observed values included messages that were conflict resolution or intersection control

oriented. They included conflicts on the ramp, at taxiway intersections and active runway crossings. The workload reductions assumed the deployment of a taxiway intersection control system, excluding conflicts on the ramp or at active runways.

3. No Conflict Control - The observed values included routine messages such as pushback and taxi clearances and routing instructions. The workload reductions were based on the development, in conjunction with improved surveillance, of one-way flow patterns (Standard Taxiway Routes) with clear guidance signs and the delivery of initial routing instructions other than by the GC.

4. Other - Message types not classified by any of the above three categories.

The last three columns in Table 3-2 present estimates of communications channel loading for each of the candidate system improvements during good visibility operations. The estimates are progressive assuming a logical time ordered implementation schedule. The first proposed improvements are Taxiway Improvements. Section 4 presents the specific improvements that were found necessary to create an adequate one-way flow pattern at each airport. A quantitative estimate of the channel load reduction and resulting total channel loading for each are presented in the table. For the four base data points the taxiway improvement estimates were taken to be one-half of the potential channel load reduction under Conflict Control. For the other airports, to be consistent with the base data points, an airport considered to have major taxiway configuration problems similar to O'Hare was given a 10% reduction, for minor problems similar to Boston-Logan and Los Angeles a 6% reduction and for an airport with no taxiway deficiencies 0% reduction was used.

For the Advanced Surveillance Equipment, the reductions in channel loading for the baseline data points, in addition to the taxiway improvements, were taken to be all of the potential reductions under the surveillance heading. An average of these four values of 25% was taken as the reduction for the other data points.

The last system improvement in the table is a combination of the Standard Taxiway Routing System and the Autonomous Intersection Controller System. The reduction for the STR system was estimated to be 50% of the initial routing portion of the No Conflict Control values for the four baseline points.

For the other data points, 15% was used for the ORD points and 10% for all the other points. The reduction for AICS was taken to be one-half of the potential reduction under the Conflict Control heading for the four baseline points. For the other points, 10% was used for the ORD points and 6% for the remainder of the points. An analysis made of the conflict rates for the improved taxiway systems at ORD, LAX and BOS indicated that the AICS would reduce the Conflict Control Workload by 50%. It was found that a large number of AIC units would be required to resolve all of the potential conflicts, i.e., 28, 27 and 23 units at the respective airports. However, it was also found that a relatively small number of AIC units could handle 50% of the potential conflicts, i.e., 4, 6 and 7 units at the respective airports. Considering the high cost of an AIC unit ($25,000 each), the more limited deployment was assumed to be sufficient. In estimating the cost for the AIC system at the other airports in Section 4, it will be assumed that an average of 6 units would be deployed for a total of $150,000, if AICS is needed.

The data points that provided estimates of GC performance in bad visibility conditions are presented in Table 3-3. As in good visibility the communications channel loading will be used as the measure of performance capability and the 70% level will also be used as the limiting value for each controller. In Reference 1, the number of aircraft handled simultaneously was used as the performance measure in bad visibility. However, channel loading appears to be just as valid for a measure of performance and it provides for a more consistent analysis in this study. Table 3-3 presents only estimates for present operations with and without ASDE and for taxiway improvements with ASDE.

There is a marked difference in performance with and without an ASDE because the basic operational concept is different. Without an ASDE, the controller must depend on pilot position reports and his memory in order to visualize the situation. As a result, only one GC can be used and he must be very cautious in granting taxi clearances to aircraft that may result in a potential taxiway conflict with each other. Even at ORD, when the ASDE is not in use, only one GC is used. Without an ASDE, the GC must exercise rigid control procedures at intersections where taxi routes are likely to cross. The pilots will generally be given routine instructions to hold short of such intersections and contact the controller for clearance to

TABLE 3-3

GROUND CONTROL - BAD VISIBILITY PERFORMANCE CAPABILITIES

AIRPORT	DATE	TIME	# OF CONTROLLERS	ASDE		OPS RATE PER HOUR	OBSERVED COMMUNICATIONS CHANNEL LOADING PERCENT	
				YES	NO		TOTAL COMMO. CHANNEL LOADING	ESTIMATED LOADING WITH TAXIWAY IMPROVEMENTS
DCA	10-28-71	0945-1015	1		NO	18	26	26
BOS	5-18-72	1730-1800	1		NO	30	27	27
LAX	1-10-72	1900-1930	1	YES		38	48	45
ORD	3-3-73	0633-0718	1	YES		48	49	44
LAX	1-10-72	1830-1900	1	YES		52	51	48
ORD	3-3-73	0845-0915	2	YES		62	128	115

cross the intersection. Two GC's could not maintain such control unless their control areas were separated geographically. With the use of an ASDE, a controller does have a significant increase in positive surveillance capability. Although his capability is not equal to that in good visibility conditions, the GC can operate similarly in that aircraft can be granted taxi clearances more freely than without an ASDE since the GC can observe the critical taxiway intersections on the ASDE display. With an ASDE, pilot position reports are still requested but they are to verify identity, intent, etc. to assure the controller of his decisions.

The expected reduction in channel loads in bad visibility due to taxiway improvements are also shown in Table 3-3. For DCA, LAX and ORD the same reduction (0%, 6% and 10%) was made as in Table 3-2 for good visibility conditions. For the BOS data point in Table 3-3, a zero per cent reduction was made since without an ASDE the traffic level would be low and the improvements to the minor deficiencies in the taxiway configuration did not appear to warrant any channel load reduction.

No further estimates of channel load reduction in bad visibility conditions due to the other system alternative were attempted. However, it is expected that the bad visibility performance with an ASE will be the same as for good visibility conditions.

The data from Tables 3-2 and 3-3 are presented in Figures 3-1 through 3-4 showing progressive system improvements. In each figure, an attempt was made to construct curves that represent the relationships between channel loading and operations rate. In Figure 3-1, for each visibility/surveillance condition, bounding curves were constructed through the outlying data points that also generally fit the trend of all of the data points. It is important to note that data points above about 120 operations per hour can only be obtained from ORD. For a particular value of channel loading, the range of values between the bounding curves should be interpreted as the range of operations rates that could be expected due to the difficulty incurred by the GC from random events occuring in the taxiway system. Some examples of events that create workload problems are: an arrival without an available gate, a large number of departures requesting pushbacks or taxiway clearances at about the same time, an aircraft stalled because of mechanical failures, an unfamiliar pilot, a heavy jet that can use only a limited portion of the taxiway system, etc.

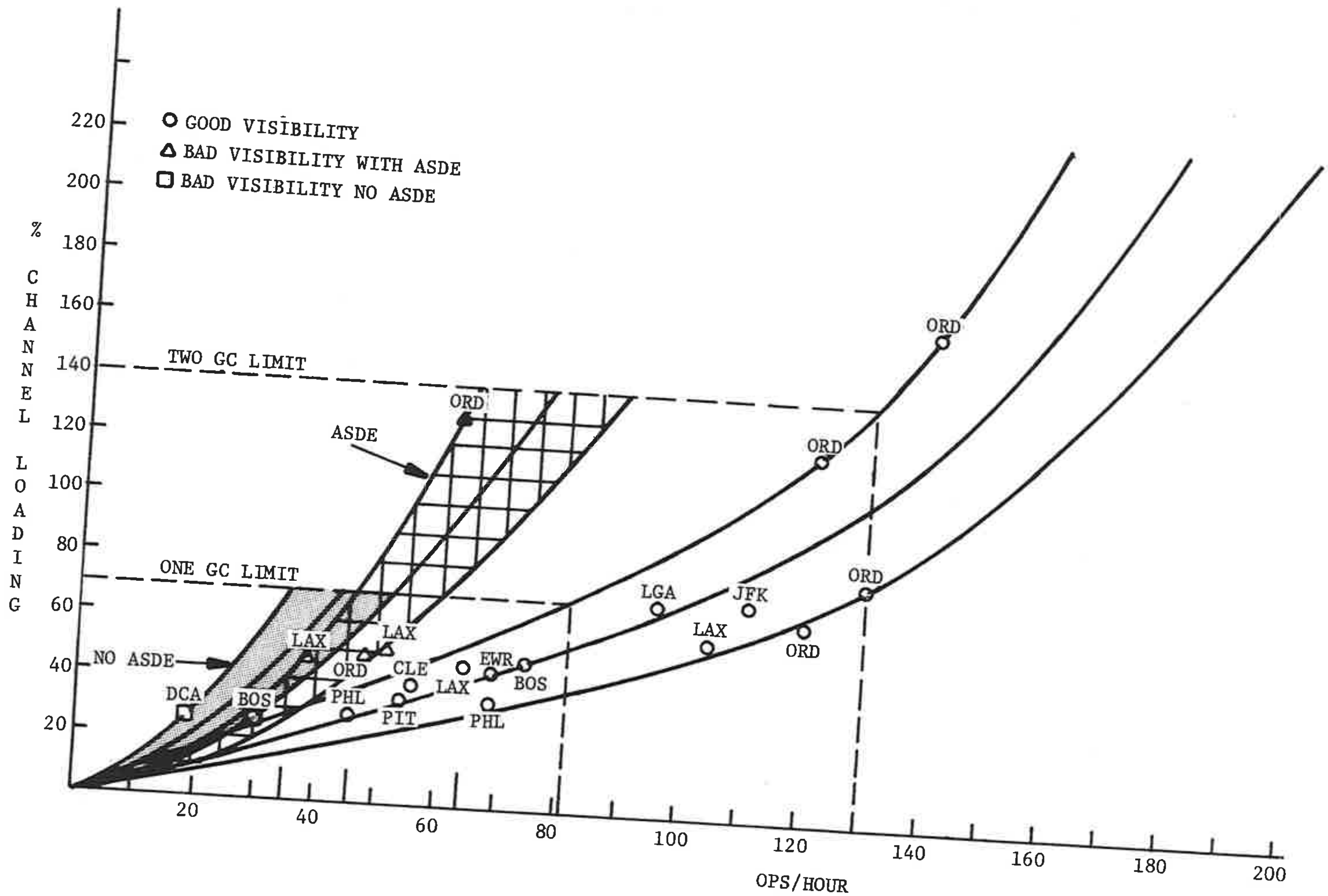


FIGURE 3-1
GROUND CONTROL COMMUNICATIONS CHANNEL SATURATION ESTIMATE FROM OBSERVED DATA

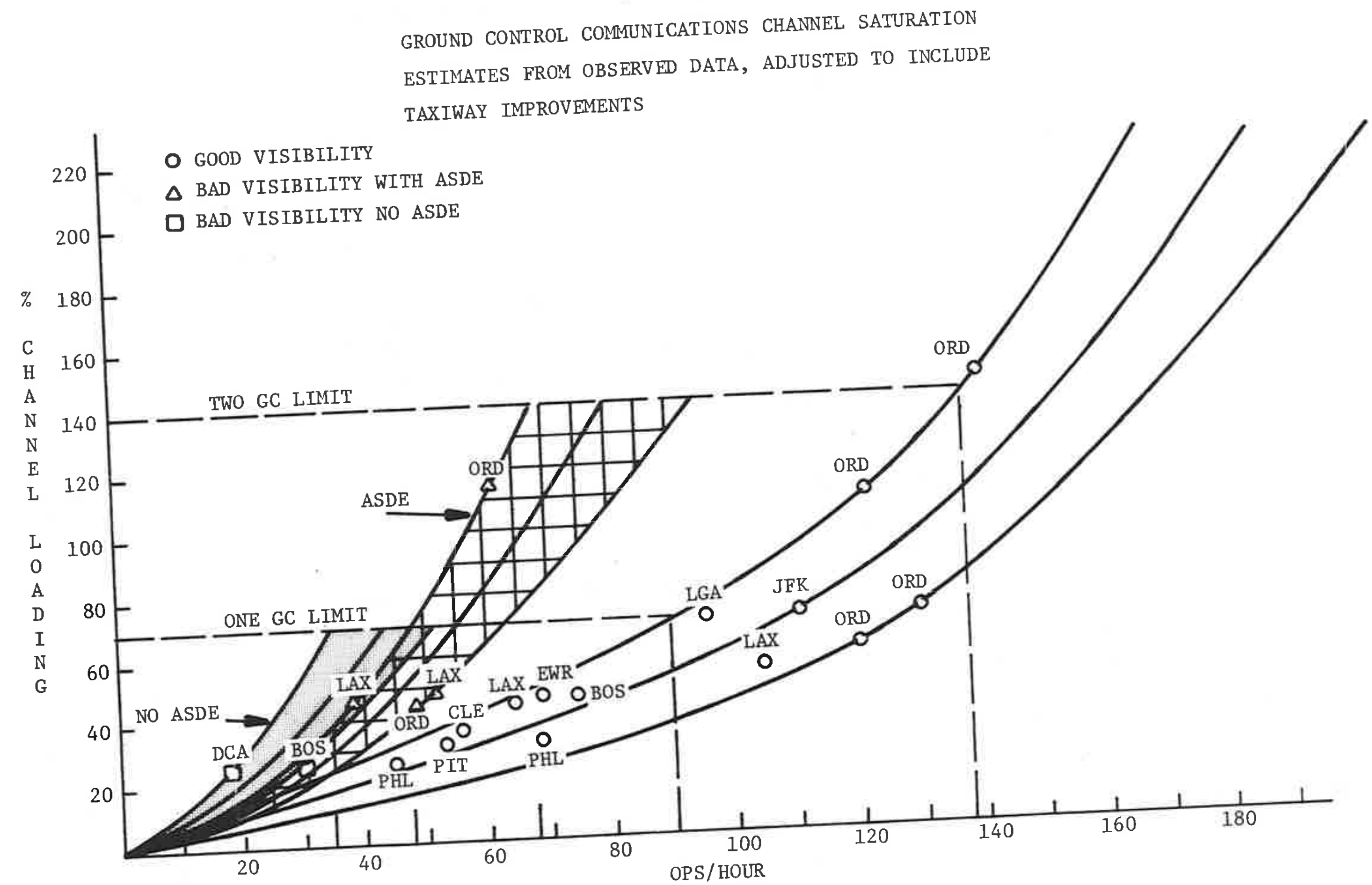


FIGURE 3-2
GROUND CONTROL COMMUNICATIONS CHANNEL SATURATION ESTIMATES FROM OBSERVED DATA, ADJUSTED TO INCLUDE TAXIWAY IMPROVEMENTS

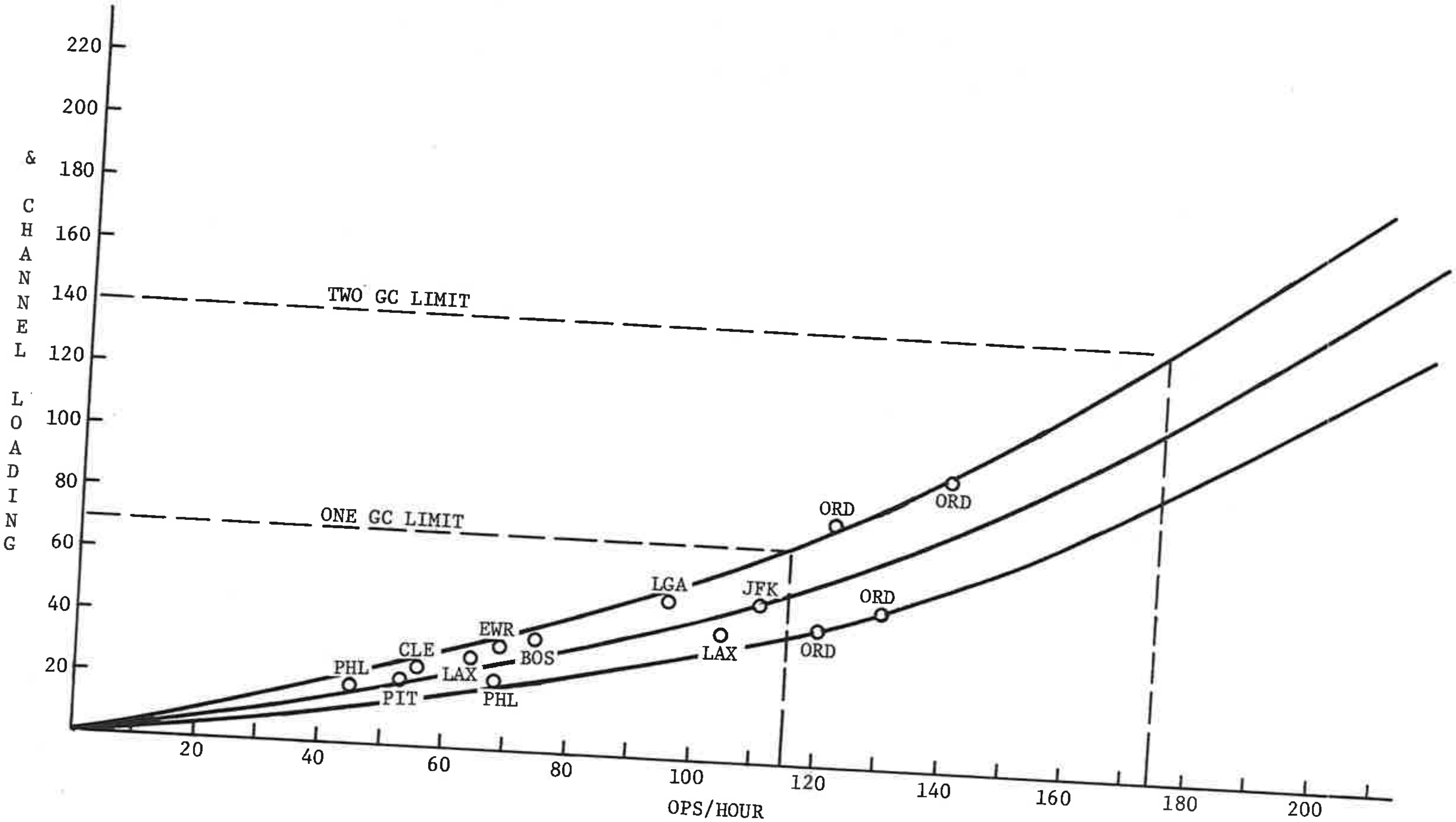


FIGURE 3-3
GROUND CONTROL COMMUNICATIONS CHANNEL SATURATION ESTIMATES FROM OBSERVED DATA, ADJUSTED TO INCLUDE TAXIWAY IMPROVEMENTS AND ADVANCED SURVEILLANCE SYSTEM

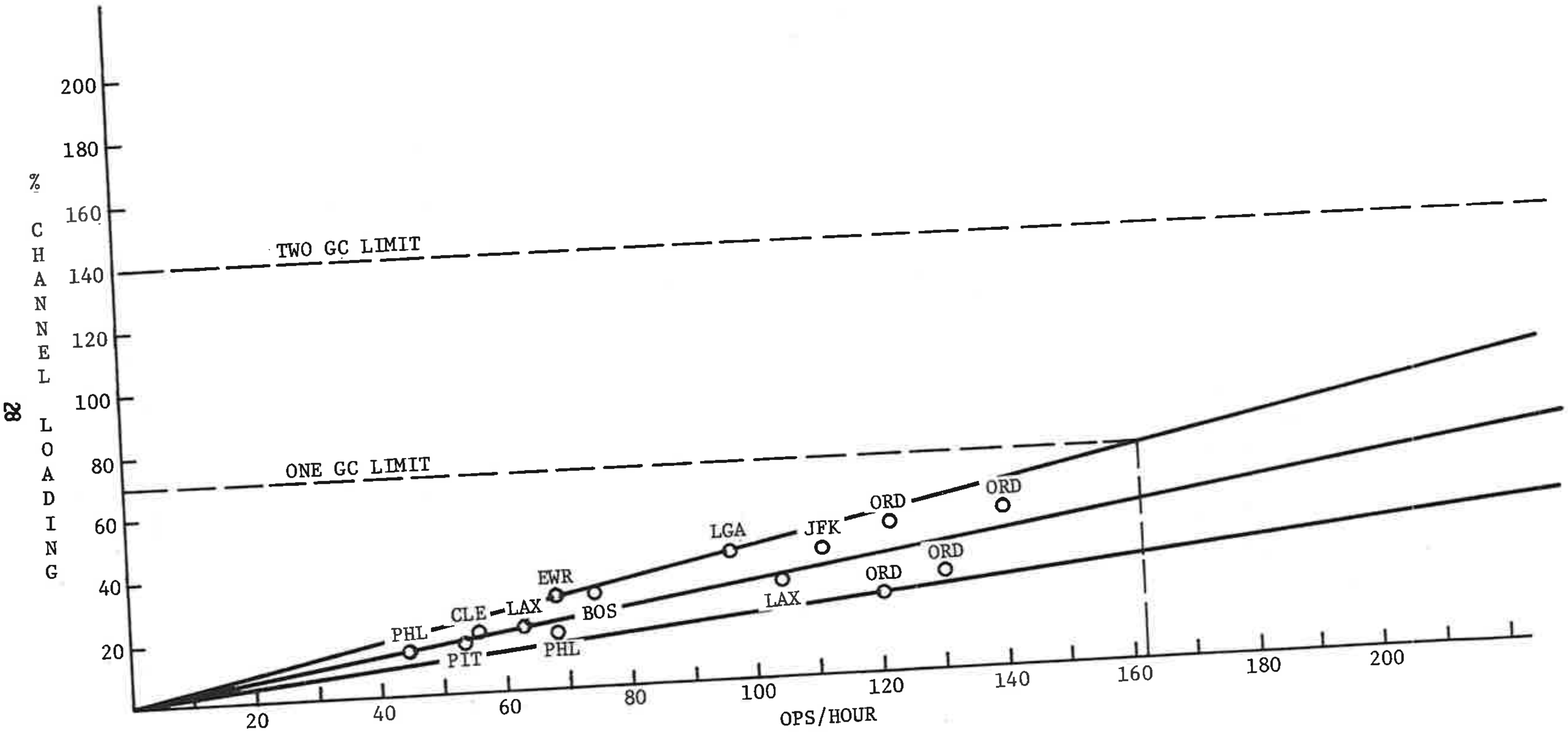


FIGURE 3-4
GROUND CONTROL COMMUNICATIONS CHANNEL SATURATION ESTIMATES FROM OBSERVED DATA, ADJUSTED TO INCLUDE: TAXIWAY IMPROVEMENTS; ADVANCED SURVEILLANCE SYSTEM; STANDARD TAXIWAY AND ROUTING SYSTEM; AND AUTONOMOUS INTERSECTION CONTROLLER

The upper curve in Figures 3-1 through 3-4 for all three sets of visibility conditions was used as the criteria for GC workload limits. Although, for a particular channel loading a higher operations rate can be attained sometimes, the value for the upper more restrictive curve is all that can be assured a high percentage of the time. A dashed line at 70% channel loading for the one controller limit and at 140% for the two controller limit has been drawn on all of the figures. Their intersections with each of the upper curves are indicated on the operations rate axis. A summary of these values are presented in Table 3-4.

The values in Table 3-4 are the performance values that are used in the deployment analysis in Section 4. It should be noted that a distinction is made in the table for airports that cannot establish smooth one-way traffic flows. It should also be pointed out that these values were developed for air carrier operations and should not be indiscriminately applied to general aviation traffic. The GC at an airport with predominantly or a large precentage of general aviation traffic may have much less workload per operations rate than at an air carrier airport.

3.2 Deployment Criteria

The deployment criteria are developed separately for good and bad visibility conditions, inasmuch as the bad visibility occur during busy hours only about 10-40 hours per year while problems associated with good visibility are a daily occurance. The generalized criteria developed in the following paragraphs are not dependent on the control position (ground and local).

3.2.1 Good Visibility Deployment Threshold

The deployment threshold for any of the alternative ASTC systems is taken as the point at which estimated yearly aircraft delay costs exceed the yearly cost of the system. The delays are estimated under the assumption that a controller cannot provide the required services to aircraft at a higher rate than some value P. If the demand exceeds this capacity, P, then a queue is created and aircraft are delayed until an under demand period occurs that is sufficient to service all of the aircraft at the rate P.

TABLE 3-4

ESTIMATED PERFORMANCE VALUES (OPH)
FOR GROUND CONTROLLER VERSUS
PROGRESSIVE SYSTEM IMPROVEMENTS

SYSTEM	GOOD VISIBILITY		BAD VISIBILITY	
	1GC	2GC	1GC	2GC
UNIMPROVED TAXIWAY SYSTEM				
NO ASDE	81	130	35	--
ASDE			46	64
IMPROVED TAXIWAY SYSTEM				
NO ASDE	90	138	35	--
ASDE			48	68
ADVANCED SURVEILLANCE SYSTEM	115	175	115	175
STRS AND AICS	162	≫200	162	≫200

The delay equation for good visibility operations can be written in terms of demand and capacity rates as;

$$D = 30t^2 \left[\frac{(N_1-P)(N_1-N_2)}{P-N_2}\right], \text{ where} \qquad (3\text{-}1)$$

t = Duration of the oversaturation period in hours

N_1 = Demand rate during oversaturation period in operations per hour

N_2 = Demand rate during the following period, when the waiting lines are absorbed, in operations per hour

P = Capacity of the system in operations per hour

D = Total aircraft delays in minutes

The derivation of equation (3-1) assumes that aircraft operations are generated at a uniform rate, N_1 per hour, during time t and that during the following under-demand period aircraft operations are generated at a uniform rate, N_2 per hour. However, it is well known that demand is not generated at uniform rates. Aircraft delays occur due to departure queues even when the hourly demand is much lower than the capacity. Reference 3 shows that, within a peak hour, demand is generated in spikes (primarily departures), generally on the hour, half-hour, quarter-hour, etc. Therefore, for this study, it has been assumed that during some portion of the hour, t, the demand peaks and during the remainder of the hour a trough exists at a lower demand level. This was necessary because demand data for projecting future demand did not exist other than by the hour. The particular value of t was chosen to be 20 minutes and the ratio of the peak 20 minutes to the 40 minute trough was 1.3 to 1.0. These values appear to be reasonable from examining the demand profiles of peak hours in Reference 3. At airports that are not yet approaching capacity, it appears that the peaking factor would be much greater than 1.3.

Since the deployment criteria is defined for airports operating at or near capacity, when the demand in many of the busy hours are at or approaching the peak hour demand, it was assumed a necessary requirement that aircraft delays be absorbed within the hour in good visibility conditions, to prevent excessive buidups of delays. Now using the peaking relationships discussed above:

$t = 1/3$ hour ,

$N_1 = 1.3N_2$,

$\frac{N_1 + 2N_2}{3} = d$, the average hourly demand,

$N_2 = \frac{d}{1.1}$,

$N_1 = \frac{1.3d}{1.1}$,

and equation (3-1) can be written in terms of P and d as follows:

$$D = \frac{d}{1.1} \left[\frac{1.3 - 1.1 \ (P/d)}{1.1 \ (P/d) - 1} \right], \qquad (3\text{-}2)$$

$$= d\ K, \text{ where} \qquad (3\text{-}2)$$

K = average delay per aircraft.

The delay coefficient (K) is plotted in Figure 3-5 as a function of the ratio between capacity and average demand, P/d. It should be noted from Figure 3-5 that the average delay per aircraft will be held within reasonable bounds if P/d is held above one and will begin rising rapidly if P/d falls below that value. This is obviously undesirable from the viewpoint of generating large delays. Moreover, operations below a P/d ratio of one will result in an overflow into the succeeding hour, or hours, and will generate progressively larger delays. On the basis of the examination of Figure 3-5 it appears that a good operating level, capable of absorbing capacity and demand perturbations, would be at about a P/d ratio of 1.1.

The above criterion checks fairly closely with ARO, Airport Reservation Office, ceilings, Reference 4, established at JFK, ORD, DCA and LGA as summarized in the tabulation below:

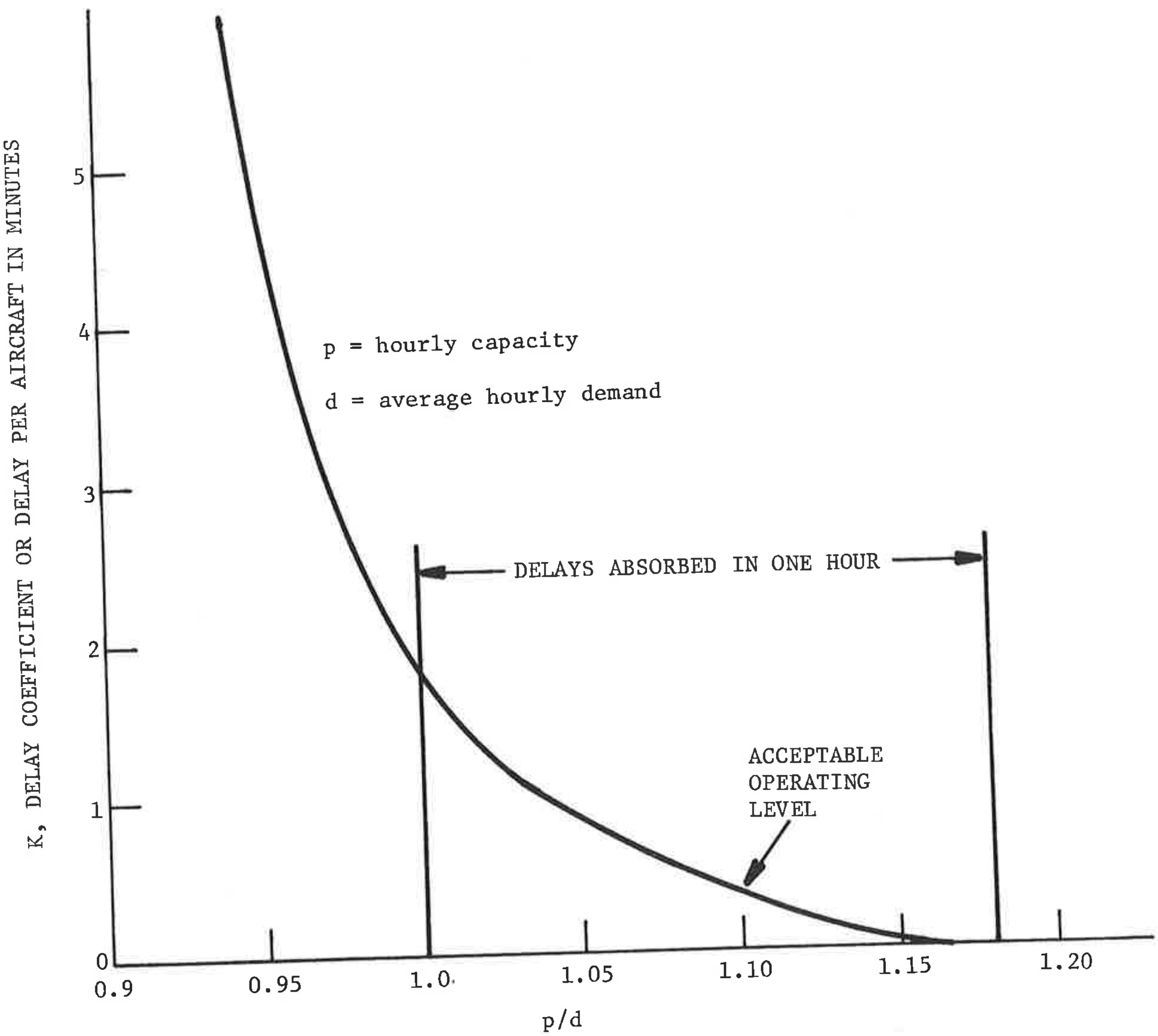


FIGURE 3-5
AIRCRAFT DELAY
VERSUS
HOURLY CAPACITY TO DEMAND RATIO

Airport	Ceiling	Estimated Capacity	P/d
JFK	80	86	1.07
ORD	135	158	1.17
LGA	60	93	1.55
DCA	60	81	1.35

The ratio's at JFK and ORD agree very closely with the 1.1 criteria.

Since the bulk of the traffic during peak hours at JFK and ORD are air carriers and the peak hours at LGA and DCA contain a larger percentage of general aviation, it appears that a P/d of 1.1 reflects the scheduling of air carrier operations.

Given the assumption of a capacity/demand ratio of 1.1 the average delay per aircraft delayed during a saturated hour (i.e. P/d = 1.1) would be nominally 0.4 minutes.

Considering that these delays occur 250 days out of 365 per year (i.e. on a daily basis), this would result in an approximate yearly cost of delay (C_D) of:

$$C_D = K\,d\,n\,C_m(250) = 0.4(250)\,d\,n\,C_m = 100\,d\,n\,C_m$$

where n is the number of peak hours per day and C_m is the aircraft operation cost per minute.

Equating the above to the yearly cost of a system (C_s) yields a deployment threshold for the given system in terms of delays due to saturation. Therefore, in addition to operational benefits such as a decrease in congestion, departure queues and arrival stacks, the deployment of the given system, which will increase capacity by at least 5% (that is reduce K to zero), is also financially justified when:

$$nd = \frac{nP}{1.1} \geq \frac{C_s}{100\,C_m} \qquad (3\text{-}3)$$

For example, assuming that the yearly cost of the most expensive system to be considered is $600,000 and that the delay cost per aircraft per minute is $10 (Reference 5) the deployment threshold is 600. Consequently, at an airport with a saturation rate of 60 operations per hour the deployment of the system would be justified financially if the saturation persisted for 10 hrs per day.

To summarize, the above deployment criterion will be used to determine whether an airport qualifies for a given system under the assumption that peak hour demand will be held to about 10% below capacity until a sufficient number of peak hours is generated, by demand redistribution over the day, to justify a deployment of an improved system. The growth of non-peak hours, after the demand peak reaches 10% below capacity, will be assumed to be linear between the year that one or more hours first reach saturation and the year that all of the busy hours reach the saturation level.

Busy hours, as used herein, occur usually between 0700 and 2200, and include the peak hours. See Appendix C for specifics.

The demand data for this analysis were obtained from References 6 and 7. Reference 6 presents for a typical busy day the hourly demand profile for AC (Air Carrier) operations for each airport. This profile was then adjusted to include the GA (General Aviation) operations by assuming that the same relationship be applied to the hourly counts as the relationship between the yearly number of Total Operations versus AC operations. This latter relationship was taken from Reference 7 which presents present and projected yearly operations for AC and GA operations. The unconstrained demand lines presented in Section 4 for good visibility conditions for each airport are based on a linear projection of the demand profiles discussed above using the 1973 and 1983 yearly operations to determine the growth rate. The unconstrained demand lines for bad visibility conditions were generated in the same manner except that only 20% of the GA operations were included. In 1971 at ORD, LAX, ATL, JFK, and SFO the percent of GA itinerant arrivals that were instrument approaches were 15%, 20%, 15%, 10% and 10% respectively (Reference 8). It is reasonable to expect that when improved landing systems are available, these percentages should increase. Therefore, for this analysis, the percent of GA that will also operate in bad visibility conditions was nominally assumed to be 20% of the GA good visibility operations.

The unconstrained demand lines described above were used in the analysis except where the combined capacity of the LC/runway system constrained the peak hour growth in good visibility conditions, i.e., when the largest good visibility peak hour demand reaches P/1.1, the peak hour is constrained at that level. However, the total demand was assumed to continue to grow at the same rate as the unconstrained demand growth until all of the busy hours for that airport reach the saturation level. It did not seem reasonable to allow bad visibility capacities to limit demand since it occurs infrequently; also, since the capacities described previously for the GC are not hard limits, it did not seem reasonable to allow GC capabilities to limit demand growth.

In order to project the number of non-peak hours in good visibility conditions that grow to saturation level, to satisfy equation (3-3), it was necessary to project the growth of the busy hour demand profile after the first peak hour reaches the saturation level. Assuming that an airport has a nominal number of busy hours, Z, (from Reference 6 it was found that about 90% of the daily traffic occurs in the busy hours) then the number of peak hours will reach a maximum of Z when 90% of the yearly demand reaches 365Z P/1.1, or

$$.9(a_2 + a_1 T_s) = \frac{365Z\ P}{1.1} , \qquad (3\text{-}4)$$

where

a_1 = yearly growth rate in operations from Reference 7,

a_2 = yearly operations in the year, Y_1, in which the first peak hour reaches saturation,

Z = number of busy hours for the airport,

T_s = number of years from Y_1 until all Z hours are saturated,

P = Performance capacity in operations per hour, OPH, of the LC in good visibility.

Therefore, the number of years from Y_1, when the first peak hour reaches saturation, when all of the busy hours will be saturated, can be estimated by solving equation (3-4) for T_s, or,

$$T_s = \frac{365Z\ P - .99a_2}{.99a_1} . \qquad (3\text{-}5)$$

Now, assuming that the number of busy hours that reach saturation, n, grow linearly, n can be defined as

$$n = n_o + \frac{(Z-n_o)}{T_s} T_1 \qquad (3\text{-}6)$$

where

n_o = the number, usually one, of peak hours that initially reach the saturation level

T_1 = Time in years after Y_1 to reach n peak hours.

The determination of Z is made by inspection of the daily demand per hour profile of Reference 6. The determination is usually very obvious, typically over the hours from 0700 to 2300. The actual values for the airports studied ranged from 14 to 19 hours.

The methods presented thus far are based on the present capacity of the ASTC and assumes that the alternative system being considered will eliminate all of the delays. Because of the logical deployment sequence of alternative systems in good visibility, i.e., ASE before any others, the assumption is valid. Also it must be pointed out that the methods were developed for LC operations. Since, as explained before, the GC capacity limits are not hard limits, the threshold for deployment has been based on a one-to-one ratio between peak hour capacity and demand instead of the 1.1 ratio developed for the LC. Otherwise, the methods are the same for the LC and GC.

3.2.2 Bad Visibility Deployment Threshold

The methods presented in the previous subsection for good visibility conditions are based on the fact that peak hour saturations occur daily. Bad visibility conditions during busy hours are infrequent occurences and, therefore, are not a factor in constraining demand peaks and accumulate much fewer yearly delays than daily good visibility saturation. The methods presented for justifying the cost of alternate ASTC systems in bad visibility conditions are based on the demand levels determined by good visibility conditions LC capacities. The basic equation, which was developed analogously to the GC model, for estimating delay costs of a bad visibility system is:

$$C_D = 30\ (\$10)t^2\ f\ \frac{x}{Z}\ (N_1-P_1)\ \frac{(N_1-P_1+P_2-N_2)}{(P_2-N_2)}\ , \qquad (3\text{-}7)$$

where

Z = number of busy hours for that airport,

f = yearly frequency of bad visibility (CAT II AND III A) periods each of which exceed a predetermined time,

t = average duration in hours of those bad visibility (CAT II and III A) periods which exceed a predetermined period of time,

P_1 = value of P for the bad visibility system,

P_2 = value of P for the good visibility system,

x = number of busy hours in which the demand exceeds P_1,

N_1 = average demand of the x hours, and

N_2 = average good visibility demand following the bad visibility period.

The model is based on the assumption that f times a year a BV period will occur of duration t hours during which delays/ queues will be created because the demand N_1 is greater than the capacity P_1 and the queues will be extinguished in the good visibility period following the bad weather in which the good visibility demand N_2 is less than the good visibility capacity P_2. The x/Z term is used as a measure of the probability that the bad visibility period will overlap a bad visibility peak demand period. It is expected that when the delays begin accelerating because of growing demand, equation (3-7) will give a conservative estimate of the delays.

The values of f and t were estimated from Reference 9 and are based on CAT II and III A visibility conditions. Values for x, Z, N_1 and N_2 were derived from References 6 and 7; the basic data being the per hour demand profile for a typical busy day for air carrier and general aviation traffic projected as described in subsection 3.2.1. The daily profile is then rank ordered and a straight line is drawn between the peak hour OPH, h_1, and the least demand hour OPH, h_2, of the Z busy hours.

This approximation appeared to fit the rank ordered profiles very well. The number of hours in which the bad visibility demand exceeded the bad visibility capacity P_1 could then be defined as

$$x = \frac{(h_1-P_1)Z}{(h_1-h_2)} \tag{3-8}$$

Values for the demand, N_1 and N_2, were estimated assuming that the bad visibility demand, N_1, was the average of the peak hours that exceed P_1, or, $(h_1+P_1)/2$, and the good visibility demand, N_2, was the average of the good visibility hourly demands, or, $(h_1+h_2)/2$. This latter estimate was then adjusted to include all of the GA demand instead of only 20% of it.

The rationale, then, for deciding for a given year, whether or not an alternative ASTC could be justified was to compute the yearly delay costs for the existing system and the alternative system using equation (3-7) and comparing the difference in those delay costs to the yearly cost of the alternative system.

3.3 System Costs

The estimated cost of the alternative ASTC systems are presented in Table 3-5. The costs are based on cost estimates from References 10 and 11. The installation costs in the table were assumed to be 60% (Reference 12) of the hardware investment cost, which would include installation, certification, etc.

The AIC and STR systems were not included in Table 3-5 because, as will be shown in Section 4, neither system had a potential for deployment at any of the airports. The reason is that neither of the systems affect the LC/runway operations, and all of the airports become runway limited at a demand level that is lower than the GC capacity. Since the ASE improves the capacity of both the LC and GC, it was the only alternative for good visibility operations, and with an ASE, the GC capacity is well above the demand levels constrained by the runway capacity.

The System/Module entries in Table 3-5 are based on maximum interchangeability of modules between systems. The radar for

TABLE 3-5

SYSTEM COST ESTIMATES

SYSTEM/MODULE	COST (1000)
ANALOG RADAR SYSTEM (NEW ASDE)	
Radar	$ 180
Installation	100
Display (5 Bright)	45
Installation	30
Total Cost	$ 355
DIGITIZED RADAR SYSTEM	
Radar	180
Installation	100
Displays (5)	45
Installation	25
Digitizer	60
Installation	35
Computer	80
Installation	50
Total Cost	$ 575
TRILATERATION SYSTEM	
Two Interrogators	90
Installation	55
Three Receivers (Minimum)	65
Installation	40
Displays (5)	45
Installation	25
Computer	80
Installation	50
Total Cost	$ 450

the Analog Radar System is the same as for the Digitized Radar System, and the display and computer in the Digitized Radar System are the same as in the Trilateration System. As shown in Figure 3-6 upgrading from one system to another may require less cost than buying a new system because of unit interchangeability. In upgrading from an ASDE to a Digitized Radar System, the cost of the radar and its installation is not incurred again so the incremental cost is only $295,000. Since the analog bright displays with the ASDE cannot be used with the digitized radar system, they can be relocated to another airport that has a requirement for an ASDE or additional displays. Upgrading from a digitized radar to a trilateration system would require only the addition of interrogators and receivers ($35,000 per Receiver) since the computer and displays should be interchangeable. The minimum incremental cost would be $250,000 for an airport requiring only 2 interrogators and 3 receivers and as high as $675,000 for an airport requiring 2 interrogators and 15 receivers. As before, the radar and the digitizer could be relocated to another airport with part of the upgrading cost recoverable by this means.

The cost of the analog radar system is based on a new ASDE. The $45,000 for ASDE display includes 5 Bright Displays. Airports with less than two LC's and two GC's will not require as many. The cost of slave displays are $4,000 each.

As stated before, the radar in the digitized radar system is the same as the ASDE but the display is different. The cost of the total system is based on one radar.

The minimum trilateration system cost is based on three receivers, and two interrogators. The number of receivers required at a particular airport will depend on the geography of the individual airport in order to insure complete coverage. The estimate of how many were required at a particular airport was made by inspection of the airport map with the general criteria that sets of three receivers should not have obstructions between them.

Although an orderly implementation of ASTC systems is desired with maximum interchangeability, since the exact order of implementation and condition of the equipment in the system to be replaced cannot be assured, it was decided to use the total system costs in the analysis. This may overestimate the system costs which would yield a conservative estimate of the potential deployment year in that the system may be justified earlier.

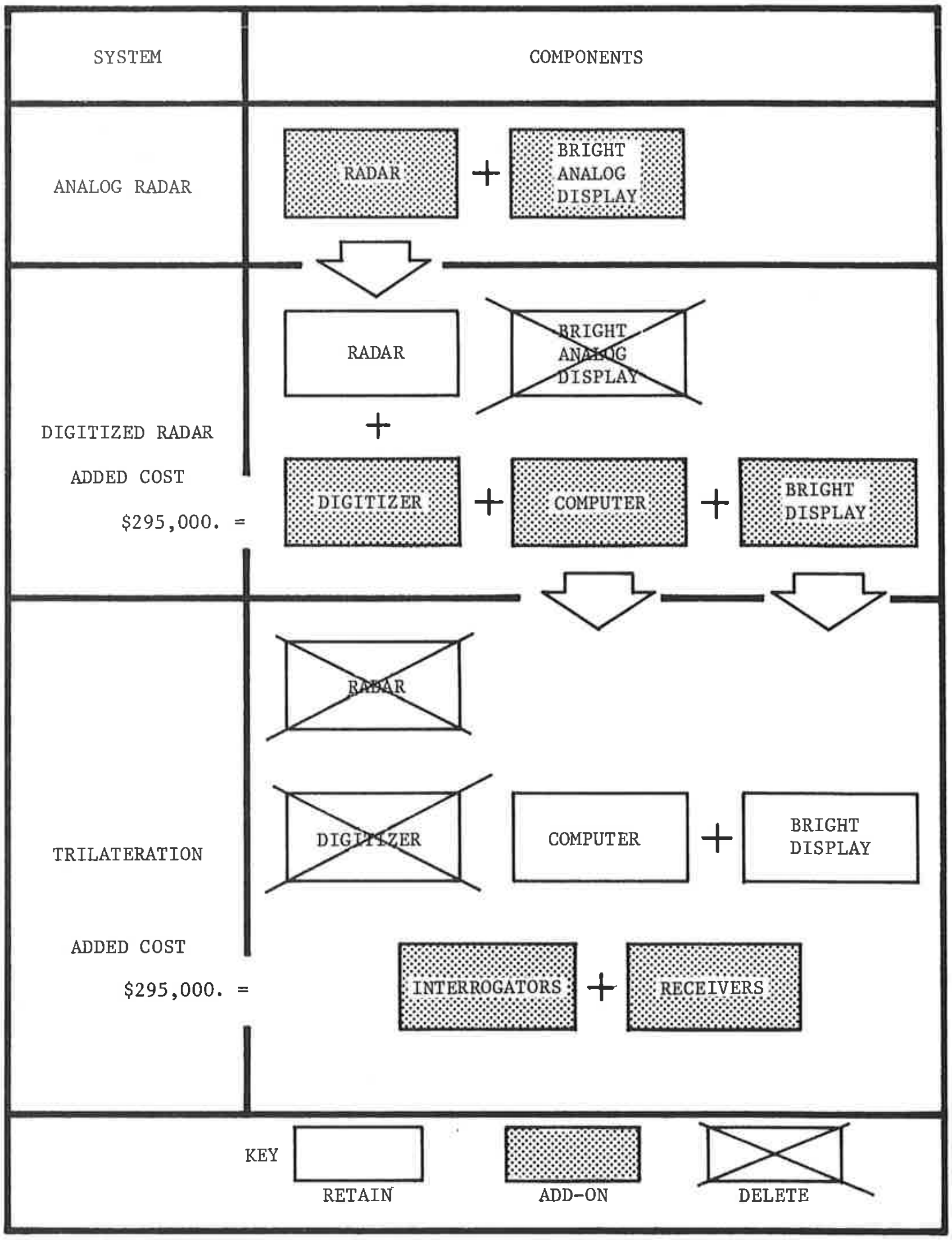


FIGURE 3-6
MODULAR SYSTEM EVOLUTION

To be compatible with the delay models presented earlier, the system costs in Table 3-5 have been converted to yearly costs. This was accomplished by amortizing the system costs over a ten year period, which is the expected useful life of the equipment, and adding an estimate of the yearly operating and maintenance costs.

Also, since it is expected that at least one additional controller will be required for either ASE system, $75,000 per year was added to those yearly costs. An interest rate of 6% was used to yield a yearly amortized cost of 13.6% of the combined investment and installation costs. The yearly operating and maintenance costs are expected to be 15% of the investment costs (Reference 11). Therefore, the yearly costs of the ASDE is $82,000, the digitized radar is $208,000 and the trilateration system ranges from $185,000 to $240,000. At a particular airport the yearly cost of the ASE system was taken as the average between the digitized radar and trilateration system.

3.4 Deployment Analysis Procedure

The approach taken for the deployment analysis of each airport is identical, and they were all based on the capacities, models and costs presented in the previous subsections. The general approach is presented here and a complete example is presented in Appendix C. The steps of the analysis were as follows:

1. Plot the projected unconstrained demand for the LC in good visibility versus the present capacity of the LC/runways. Determine when the demand grows to within 10% of the capacity. If runway expansion plans exist for the airport, assume that they would be instituted at that time to accommodate the demand. After all expansions have been included, again determine when the demand grows to within 10% of the capacity. Calculate from equations (3-3) and (3-6) when the ASE will be justified. Since the ASE will not be available until 1980, if this date occurs before 1980, the peak hour demand growth is constrained until 1980 when it is again permitted to grow due to the installation of ASE until it reaches 10% less than the ASE capacity level.

   If the date is 1980 or beyond, the ASE is deployed and the peak hour demand is permitted to grow until it reaches 10% below the ASE capacity level. This constrained demand after runway improvements and installation of the ASE is plotted for the other three cases: GC in good visibility and bad visibility, and LC in bad visibility. The deployment analysis is conducted independently for each of the other three combinations. No deployment dates beyond the ASE, LC in good visibility deployment are considered because that combination is the limiter on demand.

2. The present capacity of the GC in good visibility is compared to the constrained demand to determine if the ASE could have been justified earlier than the LC in good visibility/ASE deployment date.

3. Determine if an ASDE can be justified at present for either the LC or GC in bad visibility conditions or in a year previous to the ASE deployment date from the good visibility cases above.

4. If an ASDE is justified, determine if an ASE can also be justified for either controller before the good visibility deployment dates for ASE. In comparing delay costs with an ASDE versus an ASE, it is assumed that even if there is only one GC for good visibility conditions, a second GC can be added when an ASDE is in use for the brief period of the bad visibility condition.

The determination in steps (3) and (4) of the year for deployment is accomplished by interpolation between the differences in system delay costs for two selected years. The selected years are generally 1973 and the ASE deployment date in good visibility. The interpolation of system differences in delay costs were assumed to be linear between the two years, which appeared reasonable since both points occur before the demand becomes constrained, hence the delays would not yet have begun to accelerate rapidly.

4. AIRPORT SYSTEM DEPLOYMENT SCHEDULES

This section presents the estimated deployment schedules for each of the airports on the basis of the methodology presented in Section 3. For each airport, both runway and taxiway operations are discussed, a representative runway/taxiway configuration is selected and the years for potential deployment of alternative systems are selected. An overview of the basic inputs used in the deployment analyses of all airports is shown in Table 4-1. The table is presented in two parts. Part A presents estimates of Weather Conditions and Demand and Part B presents estimates of airport system Capacities as follows:

1. Weather Conditions - The data presented were taken from Reference 9. Estimates were made of the frequency and average duration of bad visibility conditions (Category II and IIIA) that persisted for more than 90 minutes during busy hours.

2. Demand - The present yearly demand values and future projected yearly demand values were taken from Reference 7. The 1973 Peak Scheduled Air Carrier operations per hour were taken from Reference 6. The Bad Visibility demand values are based on the assumption that only 20% of the general aviation traffic will operate during bad visibility conditions.

3. Capacities - The runway configurations were selected as the representative peak hour configuration in good visibility. The same configuration is also assumed for bad visibility operations. The resulting capacity values were taken from Section 3. The data on gates are presented although gates are not used as a constraint on demand in the analysis. The capacities are based on an average of 45 minutes service time in the gate and an average gate utilization factor of 60% unless otherwise noted in the text. At ORD, LAX and BOS some observations on gate occupancy times were taken.

In the following subsections, these inputs are used to construct a graphical representation for each airport showing years when demand saturates capacity and the visibility condition and control position causing the saturation. Also presented are runway/taxiway flow patterns, a discussion of the airport operations and potential problem areas with respect to the layout. A complete example of the analysis computations for ATL is presented in Appendix C.

TABLE 4-1
DEPLOYMENT ANALYSIS INPUTS
PART A:
WEATHER CONDITIONS AND DEMAND

AIRPORT	BAD VISIBILITY (CAT II & IIIA): YEARLY FREQUENCY > THAN 90 MIN. DURATION	BAD VISIBILITY (CAT II & IIIA): AVERAGE DURATION (HRS)	BUSY HOURS TIME OF DAY, DURATION	1973 PEAK SCHEDULED AIR CARRIER OPH	DEMAND ANNUAL OPERATIONS (1000): 1973 AIR CARRIER	DEMAND ANNUAL OPERATIONS (1000): 1973 TOTAL	DEMAND ANNUAL OPERATIONS (1000): 1983 AIR CARRIER	DEMAND ANNUAL OPERATIONS (1000): 1983 TOTAL	DAILY PEAK OPERATIONS PER HOUR: 1973 GV	DAILY PEAK OPERATIONS PER HOUR: 1973 BV	DAILY PEAK OPERATIONS PER HOUR: 1983 GV	DAILY PEAK OPERATIONS PER HOUR: 1983 BV
ORD	4.9	2.8	0700 to 2200, 15 HOURS	133	532	620	711	835	155	137	209	184
LAX	8.3	2.7	0700 to 2200, 15 HOURS	80	381	507	454	627	106	85	132	103
ATL	11.3	3.0	0500 to 2400, 19 HOURS	84	369	438	580	739	100	87	168	139
JFK	13.4	2.6	0700 to 0200, 19 HOURS	66	318	369	380	455	66,(77)	66,(68)	79,(94)	79,(82) *
SFO	3.7	2.8	0700 to 2300, 16 HOURS	55	267	353	389	473	73	59	97	84
LGA	5.2	2.7	0700 to 2200, 15 HOURS	53	264	340	324	425	68	56	86	69
MIA	0.5	1.8	0700 to 2400, 17 HOURS	65	241	367	350	521	99	72	141	104
DCA	2.6	3.9	0700 to 2200, 15 HOURS	49	223	326	240	343	72	54	75	57
BOS	10.9	2.2	0700 to 2200, 15 HOURS	54	201	321	268	398	86	60	107	79
DTW	7.3	3.3	0700 to 2200, 15 HOURS	46	180	277	220	353	71	51	90	63
EWR	6.1	2.8	0700 to 2400, 17 HOURS	37	179	244	312	406	50	40	84	68
PHL	6.2	3.1	0700 to 2300, 16 HOURS	50	175	276	255	386	79	56	110	80
PIT	4.6	2.9	0700 to 2200, 15 HOURS	54	162	266	192	362	89	61	121	75
CLE	3.2	3.3	0700 to 2200, 15 HOURS	48	113	254	143	274	108	60	116	72
BAL	9.5	3.4	0700 to 2300, 16 HOURS	26	107	233	154	339	57	32	82	46
SEA	9.7	4.2	0700 to 2200, 15 HOURS	31	99	150	183	274	47	34	86	63
PHX	NO DATA AVAILABLE, USE MIAMI DATA		0800 to 2200, 14 HOURS	22	75	380	122	483	22,(111)	22,(40)	36,(142)	36,(57) *
OAK	2.8	3.6	0700 to 2400, 17 HOURS	11	65	409	118	506	11,(69)	11,(23)	20,(86)	20,(33)*
BDL	8.2	2.9	0700 to 2300, 16 HOURS	17	56	141	76	210	43	22	64	31

* AIR CARRIER,(TOTAL)

TABLE 4-1
DEPLOYMENT ANALYSIS INPUTS
PART B:
SYSTEM CAPACITIES

AIRPORT	PERIOD	REPRESENTATIVE (1) PEAK HOUR RUNWAY CONFIGURATION		CONTROLLER CAPACITY				GATES		REMARKS
				RWY/LC CAPACITY (OPH)		GC CAPACITY (OPH)				
				GV	BV	GV	BV			
		AC	GA (2)	PRESENT ASE	NO ASDE ASDE ASE	PRESENT ASE	NO ASDE ASDE ASE	NUMBER	CAPACITY (OPH)	
ORD	1973	N(27R,32R) F(27L,32L)	F(36,22R)	158 175	115 126 175	138 175	--- 68 175	69	125	COULD EVENTUALLY DROP TO 1 GC WITH STRS & AICS.
	FUTURE	SAME AS ABOVE						105	189	
LAX	1973	D(25L,R) D(24L,R)		162 180	116 130 180	138 175	--- 68 115,175	67	107	GA USES R24L,R MIXED WITH AC. GC CAPACITY MAY BE LOW SINCE GA NEEDS LESS CONTROL THAN AC.
	FUTURE	SAME AS ABOVE						112	179	
ATL	1973	D(9C,R) S(9L)		124 * 133 *	90 * 99 * 138 *	130* 158*	35* 64* 158*	70	112	*CAPACITY OF R9L REDUCED BY 20% DUE TO TAXIING AC CROSSING RWY. *TAXIWAY PROBLEMS ON PERIPHERAL REDUCE GC CAPACITY BY 10%.
	FUTURE	D(9L,R) D(8L,R)		162 180	116 130 180	138 175	--- 68 175	133 to 170	212 to 272	
JFK	1973	D'(22L,R)	S(13,31)	86 96	58 65 90	90 115	--- 68 115	124	198	GA HANDLED ON OFF RWYS,- NOT INCLUDED IN RWY/LC CAPACITY SINCE ARO QUOTA EXCLUDES THEM DURING PEAK AC OPERATIONS.
	FUTURE	SAME AS ABOVE						152	243	
SFO	1973	DF(1,28)		93 103	58 65 90	90 115	--- 48,68 115	60	96	
	FUTURE	SAME AS ABOVE						90 to 96	144 to 153	
LGA	1973	N(13,22)		93 103	65 72 103	90 115	35 68 115	76	121	
	FUTURE	SAME AS ABOVE						90	144	
MIA	1973	2S(9L,R)	S(12)	108 120	80 86 120	90,138 115	35 48,68 115	80	128	
	FUTURE	SAME AS ABOVE						100	160	
DCA	1973	S(36)	S(15 or 33)	81 90	40 43 60	90 115	35 68 115	36	57	SINGLE RUNWAY IN BAD VISIBILITY.
	FUTURE	SAME AS ABOVE						36	57	
BOS	1973	N(4R,9)	S(4L)	120 133	65 72 103	138 175	35 68 115	62	100	DUALS WILL GIVE BETTER WIND-ROSE COVERAGE.
	FUTURE	SAME AS ABOVE						94	150	
DTW	1973	P(3 or 21L,R)	S(15)	108 120	58 65 90	90 115	35 68 115	49	78	
	FUTURE	S(3L) M(3R,9L)		130 145	96 105 145	138 115,175	35 68 115,175	117	187	
EWR	1973	S(22R)	S(11)	81 90	40 43 60	90,138 115	35 68 115	32	51	R22L NOT COMPLETED AT TIME OF SURVEY.
	FUTURE	D(22L,R)	S(11)	108 120	58 65 90	90,138 115	35 68 115	83	133	
PHL	1973	S(9)	S(17)	81 90	40 43 60	90,138 115	35 68 115	45	72	PARALLEL TO RWY 9 GOING IN AT TIME OF SURVEY.
	FUTURE	D(9)	S(17)	108 120	58 65 90	90,138 115	35 68 115	88	140	
PIT	1973	P(28L,R)	S(23 or 32)	108 120	80 86 120	90,138 115	35 68 115	38	61	
	FUTURE	SAME AS ABOVE						108	168	
CLE	1973	F(5R,36)	S(5L or 36R)	92 102	50 54 72	90 115	35 48,68 115	40	64	
	FUTURE	D(5L,R)	S(36L)	108 120	58 65 90	90,138 115	35 48,68 115	65	104	
BAL	1973	S(33)	S(22)	81 90	40 43 60	90 115	35 48,68 115	20	32	
	FUTURE	P(15L,R)		108 120	80 86 120	90,138 115	35 48,68 115	60	96	
SEA	1973	D(34L,R)		81 90	58 65 90	90 115	--- 48,68 115	32	51	
	FUTURE	SAME AS ABOVE						62	99	
PHX	1973	S(8R)		54 60	40 43 60	90 115	35 48 115	37	59	AC USE ½ OF AIRPORT, S(8R)
	FUTURE	D(8R,C)		81 90	58 65 90	90 115	35 48 115	84	134	
OAK	1973	S(29)		54 60	40 43 60	90 115	35 48 115	10	16	AC USE ½ OF AIRPORT.
	FUTURE	D(29L,R)		81 90	58 65 90	90 115	35 48 115	30	48	
BDL	1973	S(6)	S(15)	81 90	40 43 60	90 115	35 48 115	13	21	
	FUTURE	P(6L,R)		108 120	80 86 120	90 115	35 48 115	50	80	

(1) RUNWAY CONFIGURATION:
S - SINGLE.
P - PARALLEL.
D - DUAL LANE.
D' - DUAL LANE SPACED SO EXITING ARRIVALS DO NOT AFFECT OTHER RUNWAY.
F - FAR-END CROSSING.
N - NEAR-END CROSSING.
M - MID CROSSING.

(2) GA RWY/S NOT INDEPENDENT OPERATION FROM AC RWY/S.

4.1 Chicago O'Hare International Airport

The following summarizes the results of the ASTC deployment analysis at the Chicago O'Hare airport.

4.1.1 Present Facilities and Operations

The present runway/taxiway complex and the gate complex are shown in Figure 4-1 which also includes visual and radar surveillance blindspots. From the viewpoint of traffic control, the only potentially critical blindspot in the runway/taxiway system is at the bridge route. However, this blind spot does not involve any intersecting traffic and its effect on the control system should be minor. At worst it may cause some confusion on the sequencing of aircraft lined up for takeoff on 32R when it is in use. The remaining blind spots are in the gate finger and hangar areas and may cause a control problem when, and if, the tower assumes responsibility for ramp control. At the present the gate complex consists of 69 gates. This may provide at most a steady state capacity of 125 commercial passenger aircraft operations assuming equal arrival and departure rates and a 60% gate utilization with an average gate occupancy time of about 40 minutes. Gate occupancy times of about 40 minutes were observed at ORD and the observed frequent use of the penalty box somewhat verified the seemingly low gate utilization of 60%. Additionally, the cargo and general aviation facilities can absorb some level of traffic not determined by surveys. The general taxiway flow pattern on the outer and inner circulars is in opposing directions. The direction of flow on the outer is assumed to be counterclockwise for the purpose of this analysis. Landings are assumed to take place on 27R and 32L with departures on 27L and 32R. This configuration is used in excess of 70% of the time. Heavy aircraft use the outer in a clockwise direction on some segments due to: the weight limitations on segments of the inner; heavy departures on 32L; and weight limits over the bridge route. This introduces control problems due to bidirectional traffic flows.

4.1.2 Future Facilities and Operations

The Chicago O'Hare runway/taxiway expansion plans are shown in Figure 4-2. These plans include addition of runways parallel to 22R and 27R and construction of a taxiway link extending from 22R to the Present Penalty Box area. The addition of the new runways is unlikely to provide an increase in good weather operational rates with the exception of a possible increase

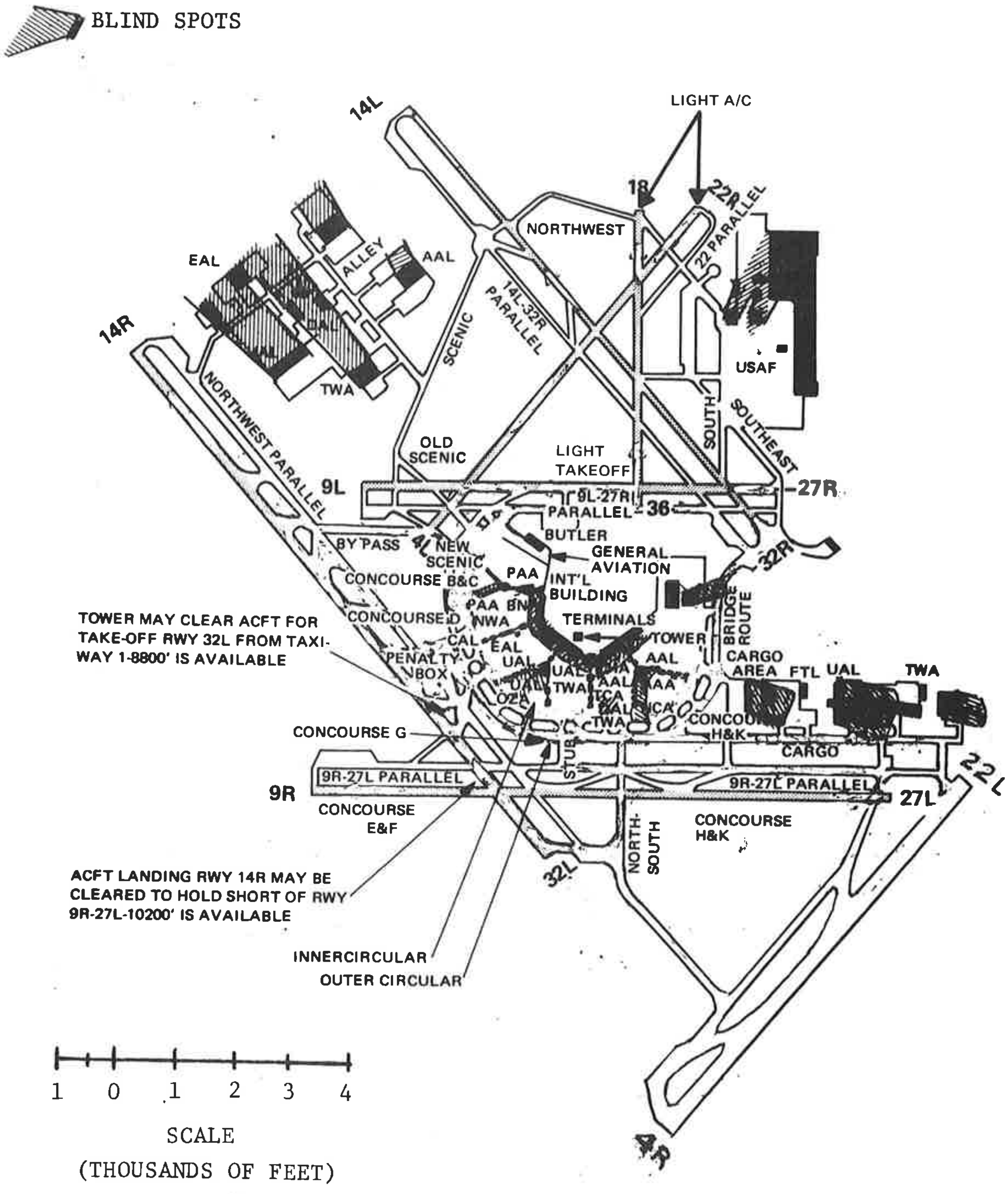


FIGURE 4-1
CHICAGO O'HARE INTERNATIONAL AIRPORT (ORD)

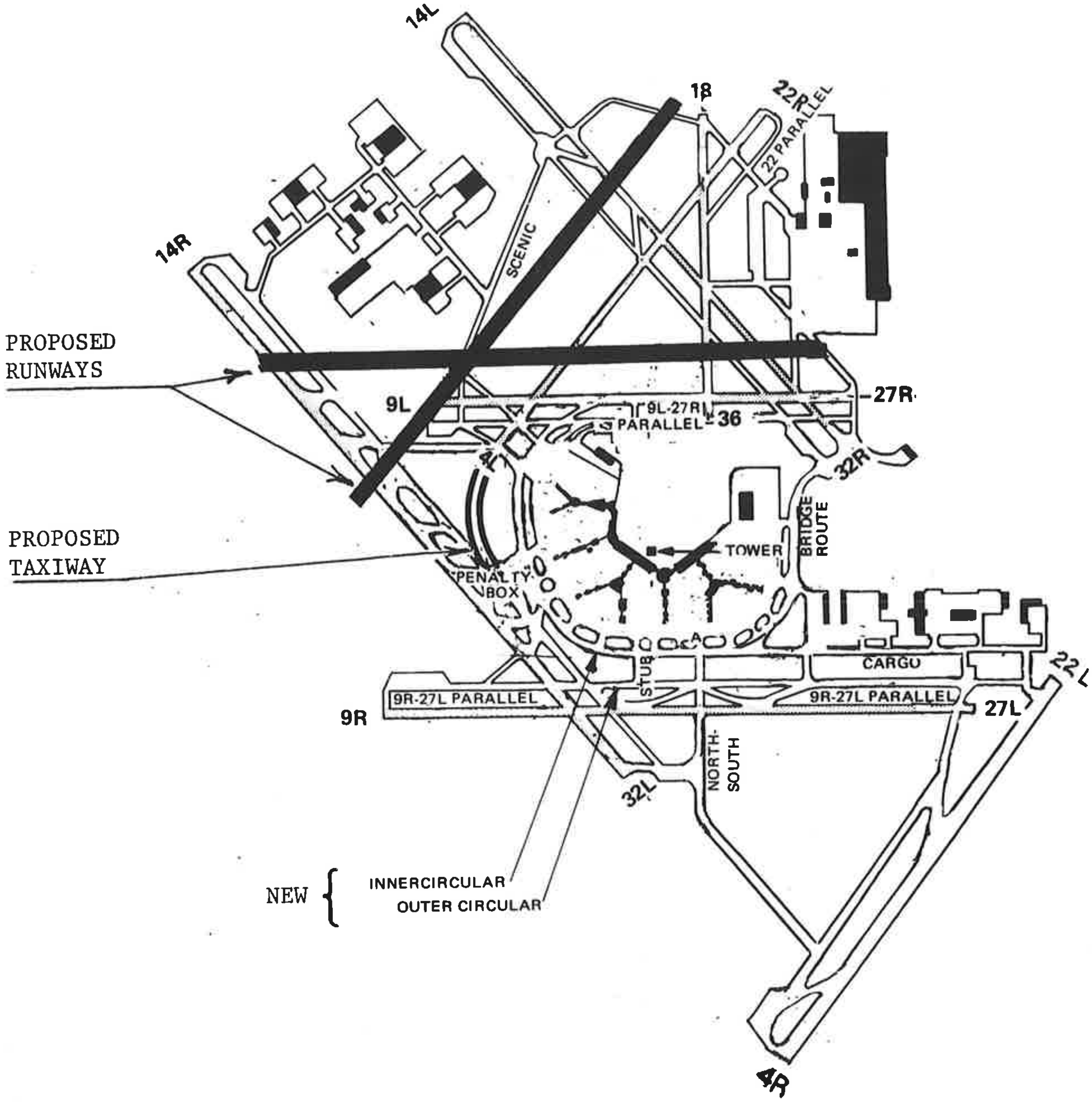


FIGURE 4-2
CHICAGO O'HARE INTERNATIONAL AIRPORT
POSSIBLE RUNWAY-TAXIWAY EXPANSION SCHEME

in the flexibility of runway selection for heavy aircraft and the improvement of landing surfaces. These runways may, however, fill the gaps in capacity mentioned in the previous sections (maintenance, snow removal and unfavorable wind conditions) to provide a fairly uniform runway system capacity under nearly all weather conditions. The addition of a parallel to the 32-14 runway would, if considered, cover all conceivable contingencies. The addition of the new taxiway link would provide a new outer taxiway thereby (hopefully) removing the constraint on routing of B747's (provided the Bridge Route is improved) and would also provide a possibility of gate expansion.

The gate system improvements are apparently indefinite at this time but consideration is being given to conversion of the fingers to satellites and the addition of a new International Terminal with 22 gates. This expansion is shown in Figure 4-3.

The conversion of a satellite configuration in conjunction with development of the new outer taxiway would appear to offer the possibility of gate system expansion by perhaps 12-14 gates, provided that the Jumbo Jet operations are removed to the new terminal. This could increase the gate system capacity by approximately 20%. The addition of the 22 new international gates would provide a proportionally lesser improvement in airport capacity due to their longer gate occupancies. Optimistically the overall gate system capacity potential due to these improvements, including shifting of international operations to the new terminals, may increase the gate system capacity by up to 40%. This would provide a total of up to 190 commercial passenger operations per hour with gate delays similar to those existing at the present time. The runway capacity improvement needed to sustain this level of activity would be primarily to provide an operations rate level provided now under best operating conditions. This would appear possible with the projected improvement in ATC including Cat II and III operational capability and improved approach control delivery with reduced aircraft spacing. The above balanced runway/taxiway/gate capacity would provide a sufficient capability to absorb the projected operations growth of about 30% by 1983 (Reference 7).

The airport authority, the tower and the airlines are also in agreement on the addition of improved gate holding penalty boxes and improved holding and bypass areas for holding departure

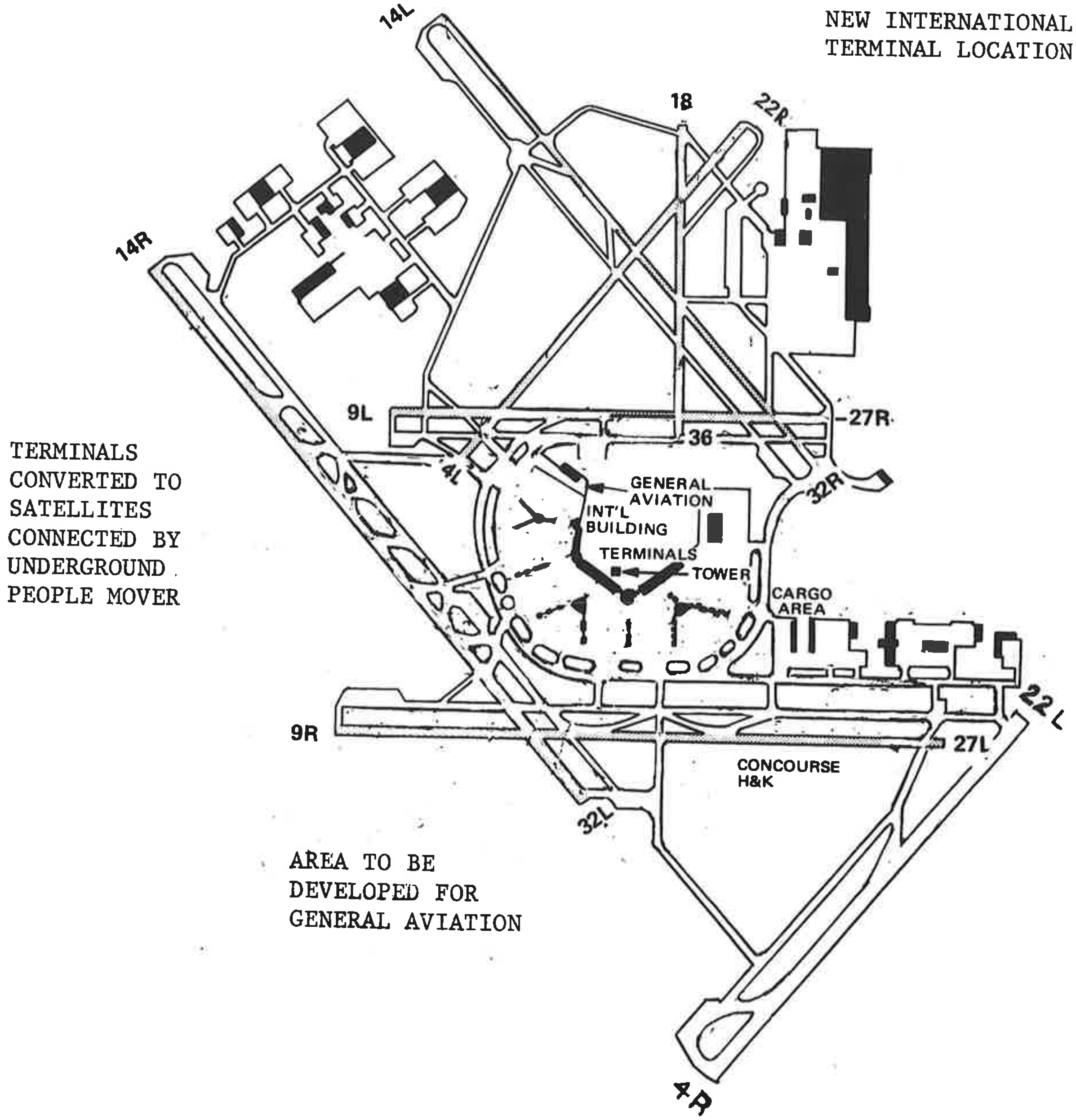


FIGURE 4-3
CHICAGO O'HARE INTERNATIONAL AIRPORT
POSSIBLE TERMINAL EXPANSION SCHEME

traffic due to destination or departure route constraints. These improvements should greatly simplify the ground and local control workload and provide an improved flow pattern during transient saturation periods.

The ASTC improvement planning for the Chicago O'Hare airport should, therefore, aim at providing for a peak good visibility operations rate of 175 aircraft/hour including 15% of general aviation aircraft. The bad visibility planning figure should also aim for 175 operations per hour.

4.1.3 Deployment Time Phasing

The ASTC system(s) deployment time phasing as a function of control position and visibility conditions is summarized in Figure 4-4.

In good visibility conditions the deployment of an ASE system is justified at present by both the ground and local control positions. In fact the peak hour demand growth rate should be limited to at most 142 operations per hour immediately with the potential growth possibly absorbed in the daily demand troughs, until ASE is deployed.

In bad visibility conditions an ASDE system is immediately justifiable on the basis of ground control operational deficiency of 33 operations per hour. At the date of availability of the ASE system, a deficiency relative to the yearly system breakeven cost of 55 operations per hour will exist for the ground position. The bad weather delays will consequently be very large and ASE deployment could be justified on the basis of bad visibility conditions alone at that time.

In summary, continued operation and improvement of the available ASDE system is fully justifiable at O'Hare and the deployment of an ASE system at the 1980 availability date is economically justifiable primarily by the ground position in bad visibility conditions and by both positions in good visibility.

4.2 Los Angeles International Airport

The following summarizes the general operational environment of LAX and presents an ASTC deployment plan.

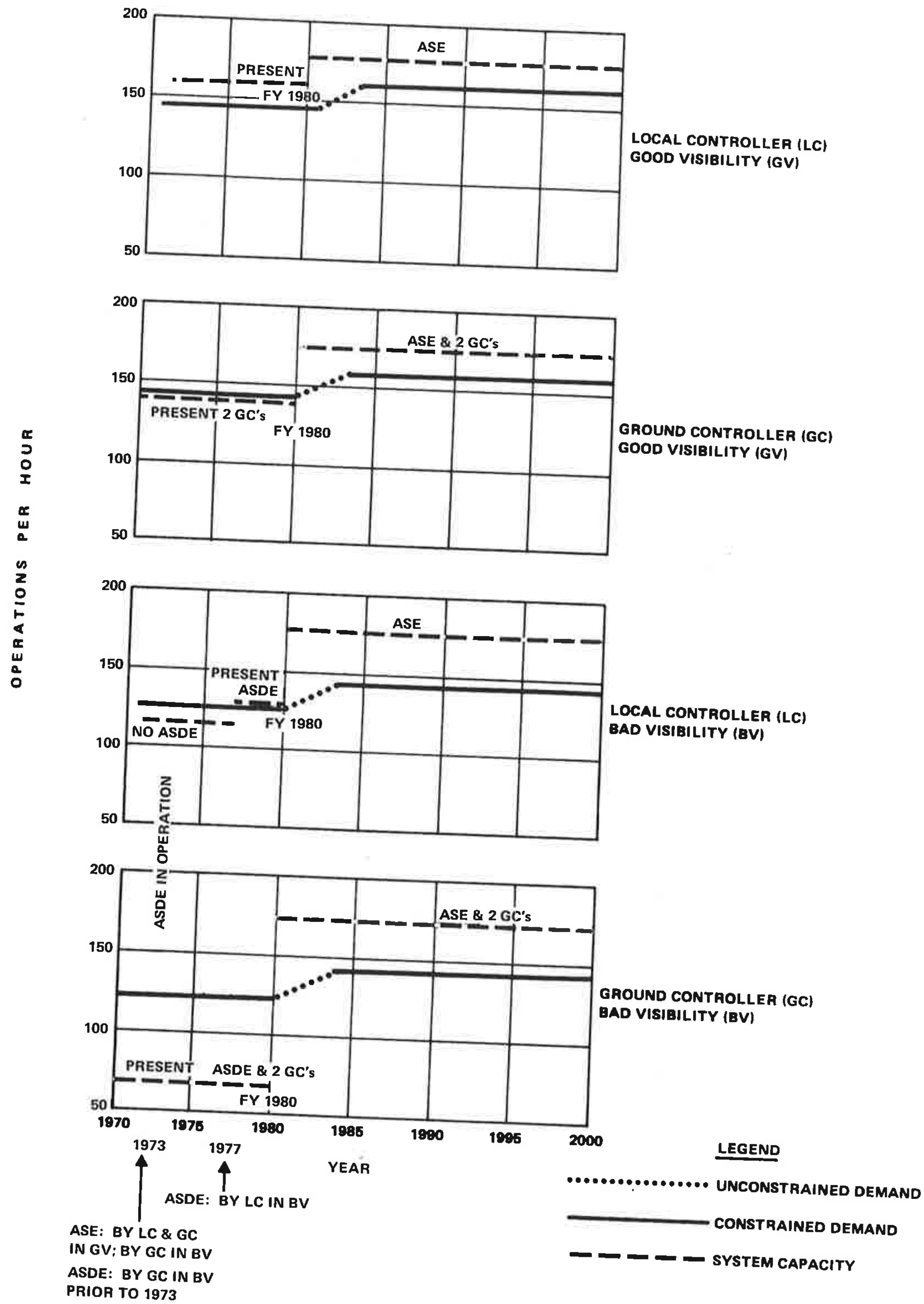


FIGURE 4-4
CHICAGO O'HARE INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

4.2.1 Present Facilities and Operations

The present runway/taxiway and gate facilities are shown in Figure 4-5, including areas of restricted visibility and ASDE blind spots. The visual constraints are generally minor in their effect on control capability. The most critical points appear to be in the departure lineup area on runway 25R and at the southwest corner of the south satellites. In the departure area the lack of visibility may cause some confusion on sequence of departures in line. The aircraft become visible again at the approach to the runway end and the element of confusion, if any, can be resolved at that time. The area southwest of the south terminals is a heavily used area and some problems on conflict resolution may arise there especially when there is opposing traffic on taxiway 47.

The ASDE blindspot areas may cause some delay in detection of the time at which arriving aircraft exit from runways 24R and 24L. The taxiway complex appears to be very efficiently laid out with the exception of north-south taxiways, and unidirectional flow patterns appear to be feasible. The north-south traffic utilizes mainly taxiway 47 with a resulting delay of 3-4 minutes in cases of conflict between north and south traffic. Taxiway 49 is not easily accessible from either the north or south terminals and the taxi time along this route may approach the taxi time along 47 including the inherent delay. Traffic in the ramp area is impeded by Jumbo Jet parking positions with a resultant constraint on unidirectional flow patterns around terminals. The control task is complicated by these factors. However, on the basis of available data, no strong case can be made that taxiway times become excessive.

The runway system consists essentially of two independent complexes of close-spaced parallel runways. The north complex handles primarily 747 arrival and departure traffic (since the south runway complex overpasses cannot support these aircraft), general aviation traffic, and departures through north outbound fixes. Arrivals other than the above are restricted by noise abatement procedures. The south complex carries the major portion of the commercial traffic. Operations rates equivalent to 93 operations per hour were observed and verified by examination of communication tapes. These rates were sustained over short time intervals only. Additionally, these rates were achieved with significantly fewer arrivals than departures. It is estimated that with an improved local control system, with feedback to approach control, 80-90 operations/hour could be handled with balanced arrival departure demand.

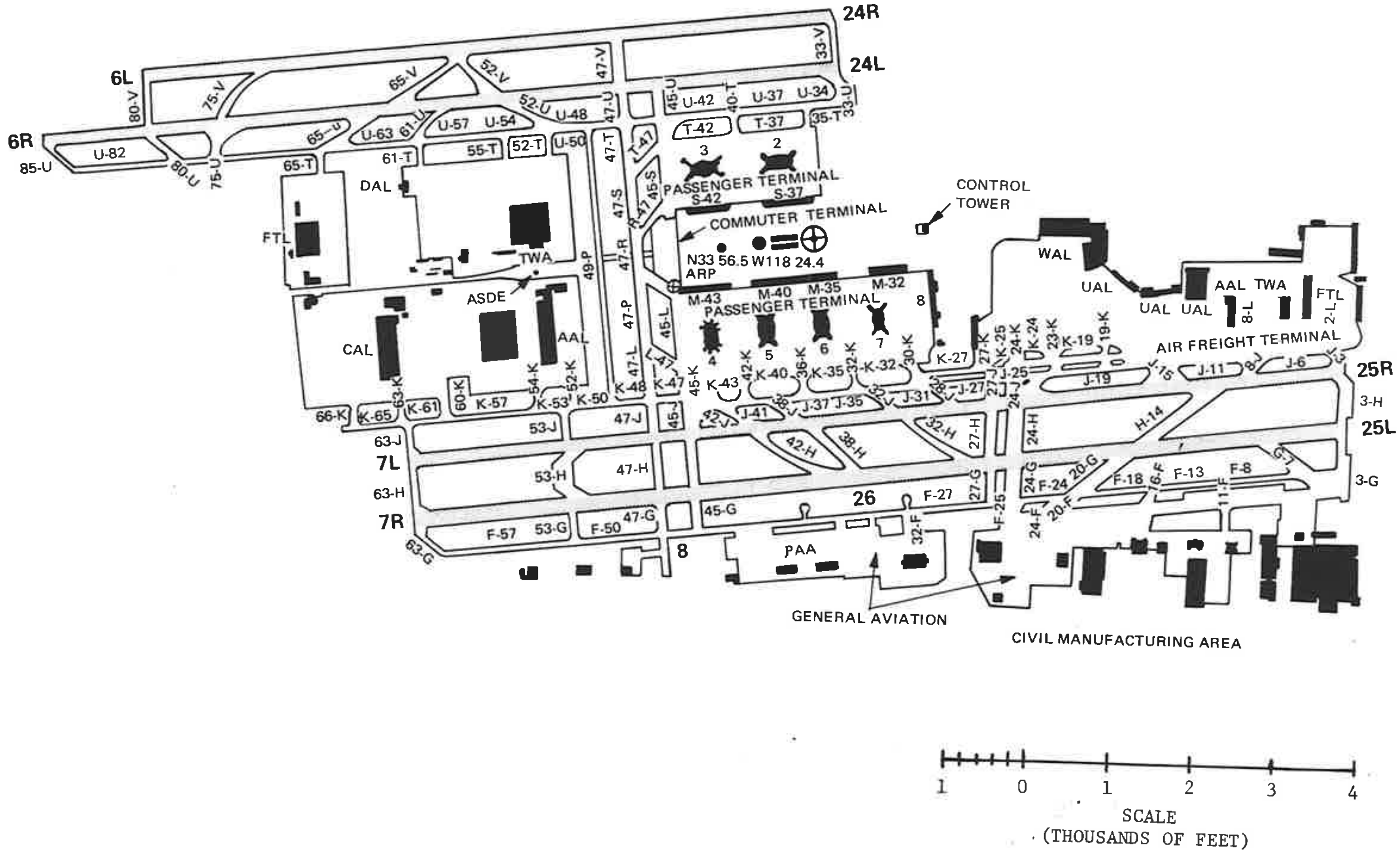


FIGURE 4-5
LOS ANGELES INTERNATIONAL AIRPORT (LAX)

Even though the north complex is not operating at full efficiency due to noise constraints, on the basis of the above it appears that the combined operations rate of the two runway complexes could saturate the present capacity of the gate system, without major ATC or ASTC improvements in good visibility conditions. In reduced visibility conditions, the maximum and average operations rates decrease by 44% and 20% respectively even though the ASDE is used. The major problems with the ASDE when operational, are that the display is just fair in the dark and requires an under-the-hood assistant in daylight. The assistant's duties include telling the local controller when arrivals come over the runway threshold and when arriving aircraft clear runways. Additionally, he appears to provide assistance to the local controller on active crossings and assistance to the ground controller in taxiway traffic surveillance. An improvement of at least the display system appears to be the minimum prerequisite for improvement of operations rates in bad visibility.

At the present time the terminal facility includes 67 gates. The average gate occupancy time was observed to be about 45 minutes. On this basis and a normal 60% gate utilization rate, it is estimated that the present gate complex may have the capability of handling an average of 107 operations per hour for an equal arrival/departure mix.

4.2.2 Future Facilities and Operations

The Los Angeles International Airport does not have any major runway/taxiway expansion plans. There does not appear to be much need for such an expansion inasmuch as the capacity of the runway system can exceed both present and projected gate facility capacities. The capacity of the runway system, subject to the resolution of the restrictions due to noise, is estimated by the Airport Authority at 205 per hour. This report estimates the capacity at a maximum of 180 operations per hour subject to moderate improvements in ATC and ASTC. The primary problem facing ASTC development is to provide a 20-30% improvement in operation rates under reduced visibility conditions.

The taxiway improvment plans include an addition of a north-south taxiway at the west end of the runways and some additions at the northwest portion of the taxiway system. It is not clear whether these plans will include improvements of the north-south taxiways 49 and 47 to provide a one-way traffic flow capability along these taxiways. This would greatly simplify the ground control function and would reduce delays to aircraft due to either having to wait when opposing traffic is using the north-south taxiway or having to maneuver in roundabout ways to use taxiway 49.

The plans for the improvement of the gate system may result, at most, in a total of 112 gates. Using the same assumption as before for gate utilization, and about 45 minute average gate turnaround time, this number of gates translates into a potential capacity of approximately 180 commercial operations per hour.

4.2.3 Deployment Time Phasing

The ASTC system deployment time phasing at LAX for each control position under bad and good visibility conditions is shown in Figure 4-6.

In good visibility conditions the local control positions can justify an ASE system by 1990. Under the same conditions the ground position can justify two GC's now and will justify ASE deployment by 1987.

Under bad visibility conditions ASDE is justified at the present time on both local and ground control requirements and an ASE system could be justified in 1976 on the basis of ground control requirements.

4.3 Atlanta International Airport

The following summarizes the results of the ASTC system deployment analysis at the Atlanta airport.

4.3.1 Present Facilities and Operations

The present runway layout, shown in Figure 4-7, consists of a dual lane runway set (9R-27L, 9-27C) and a parallel 9L-27R. The terminals are located north of the parallels. The 9 and 27 directions are utilized about the same proportion of the time for a total of 98% yearly. The capacity of the runway system is estimated at 124 operations per hour. This may be somewhat lower due to the problems associated with operations on the dual lane pair having to cross 9L-27R.

The taxiway system presents congestion problems in the ramp area with departure waiting lines forming to cross 9L-27R on runways 8 and 33. Similarly, arrival lines form on the 8 and 33

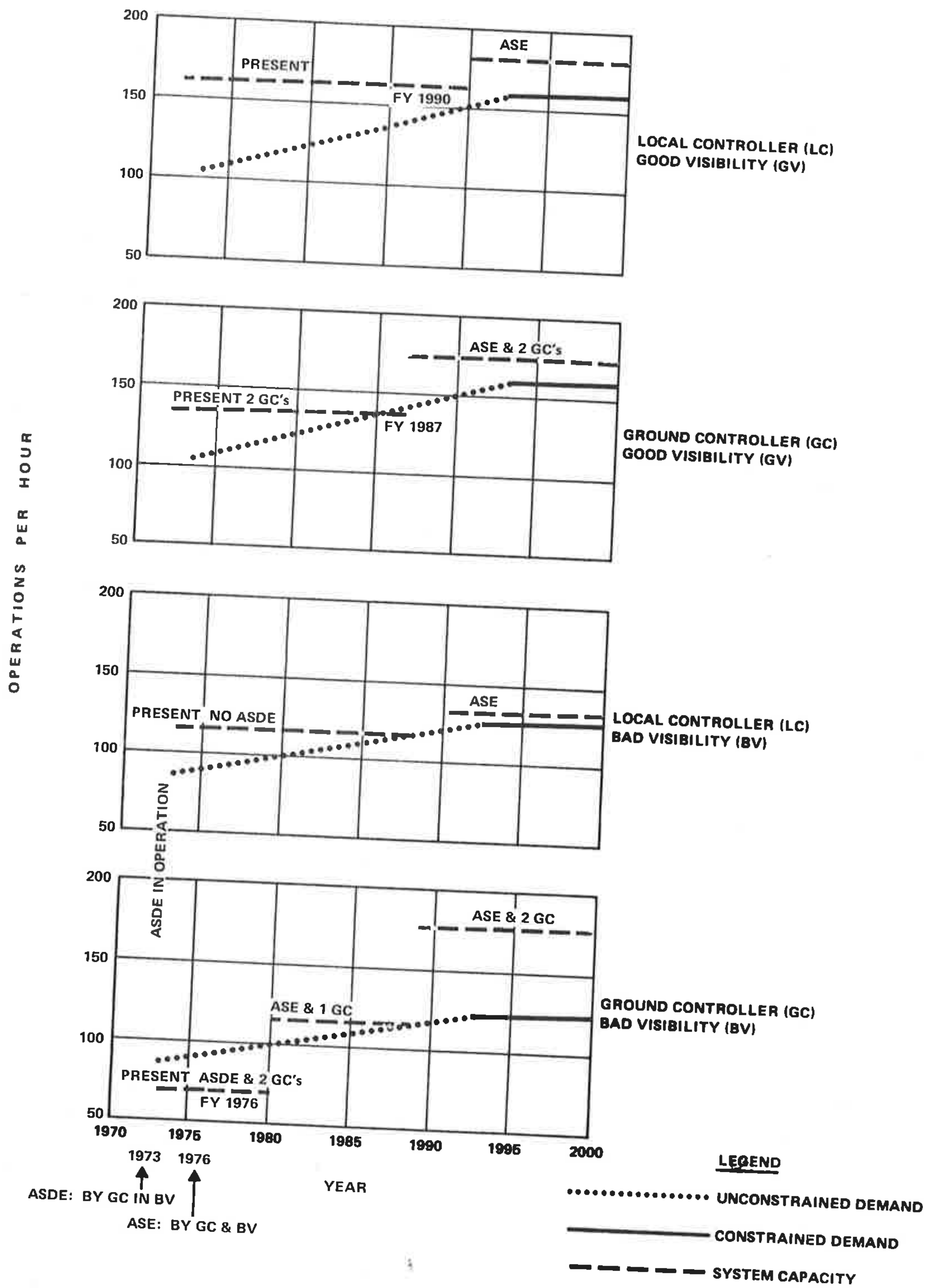


FIGURE 4-6
LOS ANGELES INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

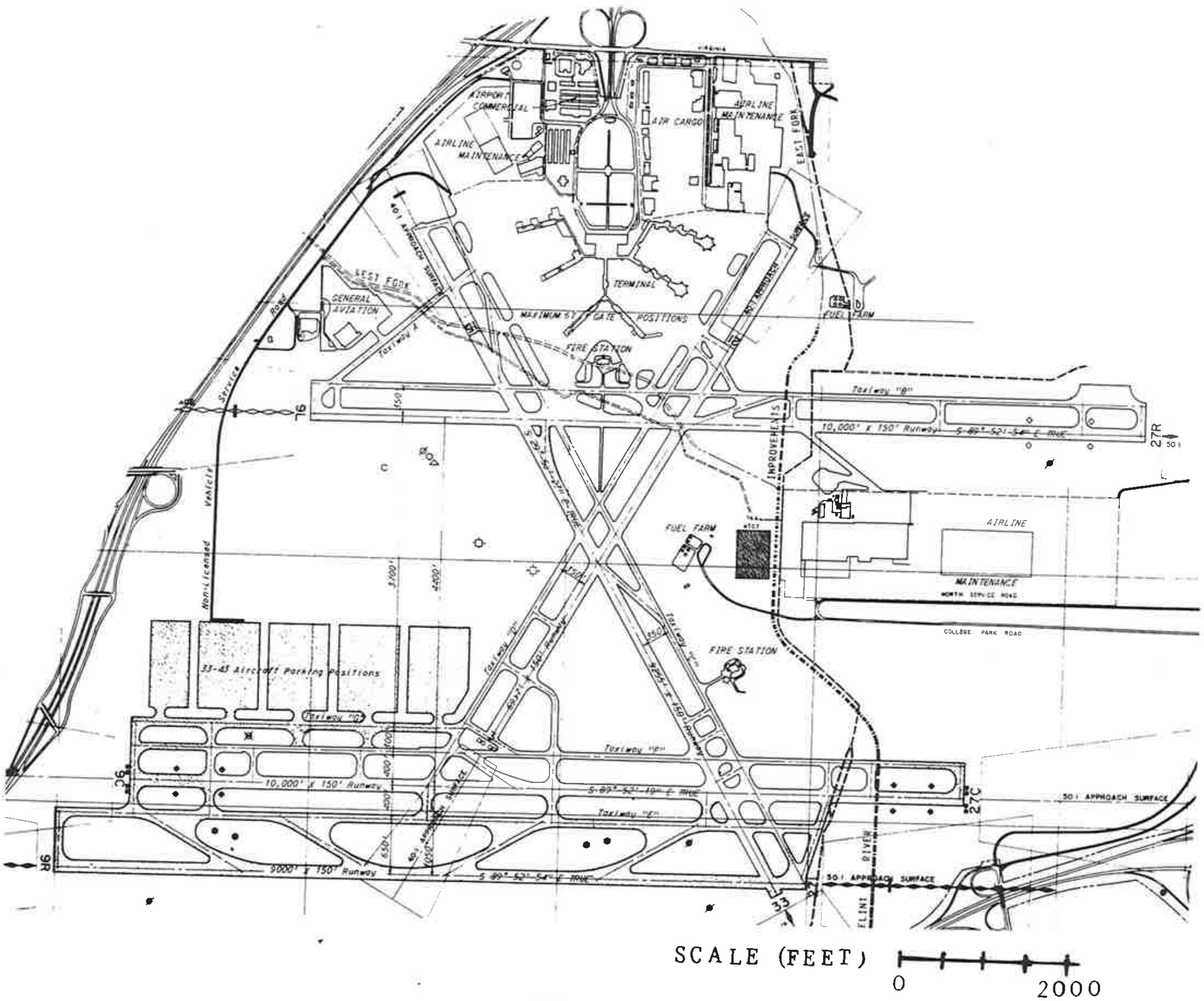


FIGURE 4-7
ATLANTA INTERNATIONAL AIRPORT (ATL): 1972 LAYOUT

parallel taxiways to cross 9L-27R inbound. Additionally, a problem exists at the crossing of 8, 33 and their parallel taxiways. The control workloads in the taxiway system are, as a result of the above, higher than at any of the airports where a detailed analysis was performed.

At the present time, Atlanta has two local and two ground positions. An additional position is being considered to handle the traffic between runways.

The gate system, 70 conventional commercial gates, including the hardstands served by planemates, appears to be adequate to serve the present needs of the airport.

4.3.2 Future Facilities and Operations

The future airport configuration, shown in Figure 4-8, will be generally equivalent to the LAX configuration. The estimates summarized for LAX will be assumed to be applicable for the purposes of deployment estimates. The future gate system of 170 aircraft gates should be sufficient to accommodate the runway operations rate.

4.3.3 Deployment Time Phasing

The runway expansion plans will provide sufficient capacity (runway/local control) until 1980, if deployed by 1975 as shown in Figure 4-9, under good visibility conditions.

At that time deployment of ASE will be justified by both the ground and local control positions under good visibility conditions.

In bad visibility conditions ASDE is justified at the present time in relation to local control positions by 1975. The slight increase in the GC performance in 1975 reflects the increase due to the change in taxiway configuration since the fourth runway was added and the terminal was placed in the center of the configuration. Deployment of ASE under good visibility conditions would be fully justifiable on the basis of ground control requirements at 1980 availability date. Additional benefits would accrue starting in 1980-1981 due to improved local control performance but could be justified for this position alone.

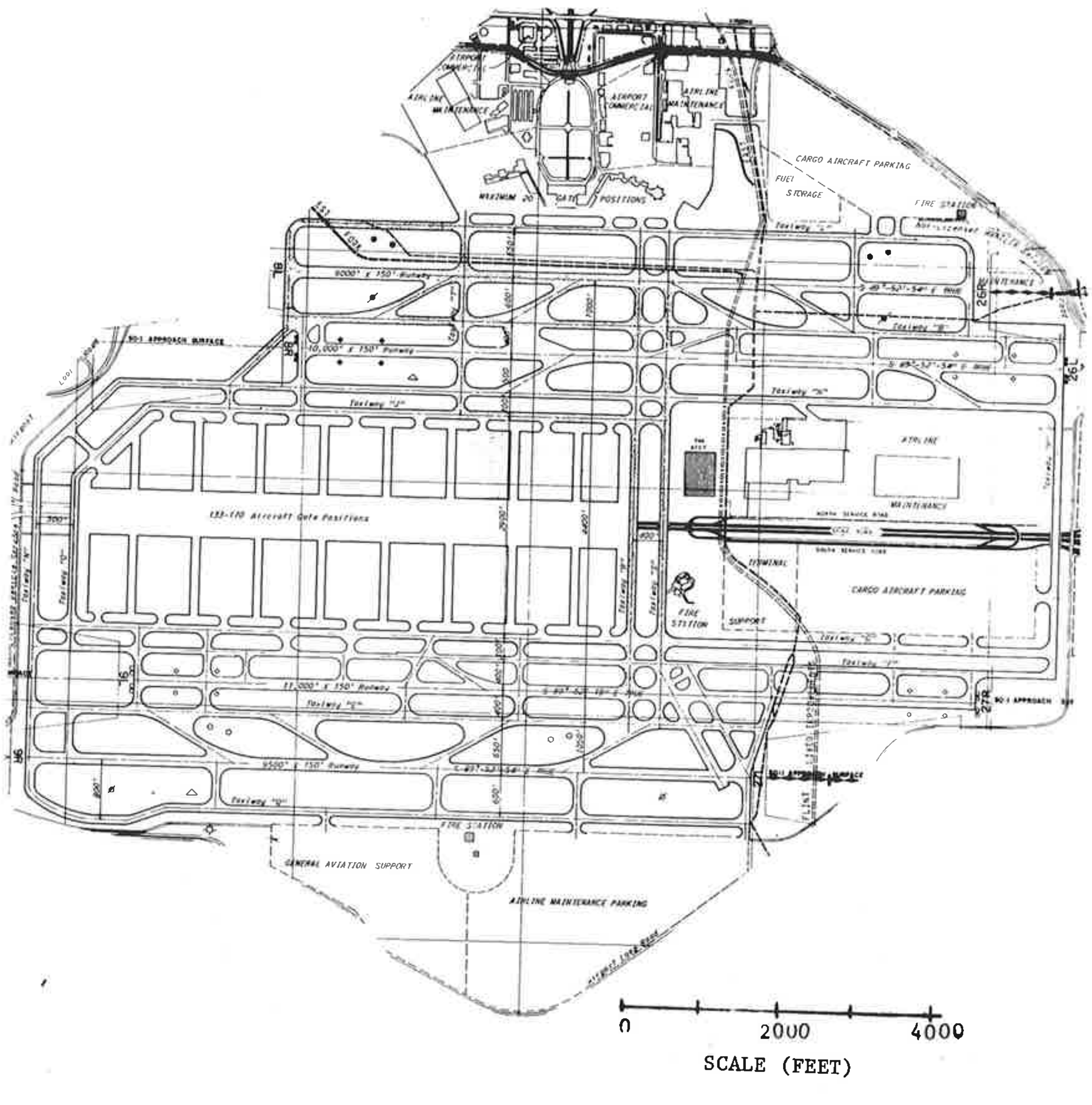


FIGURE 4-8
ATLANTA INTERNATIONAL AIRPORT (ATL): FUTURE LAYOUT

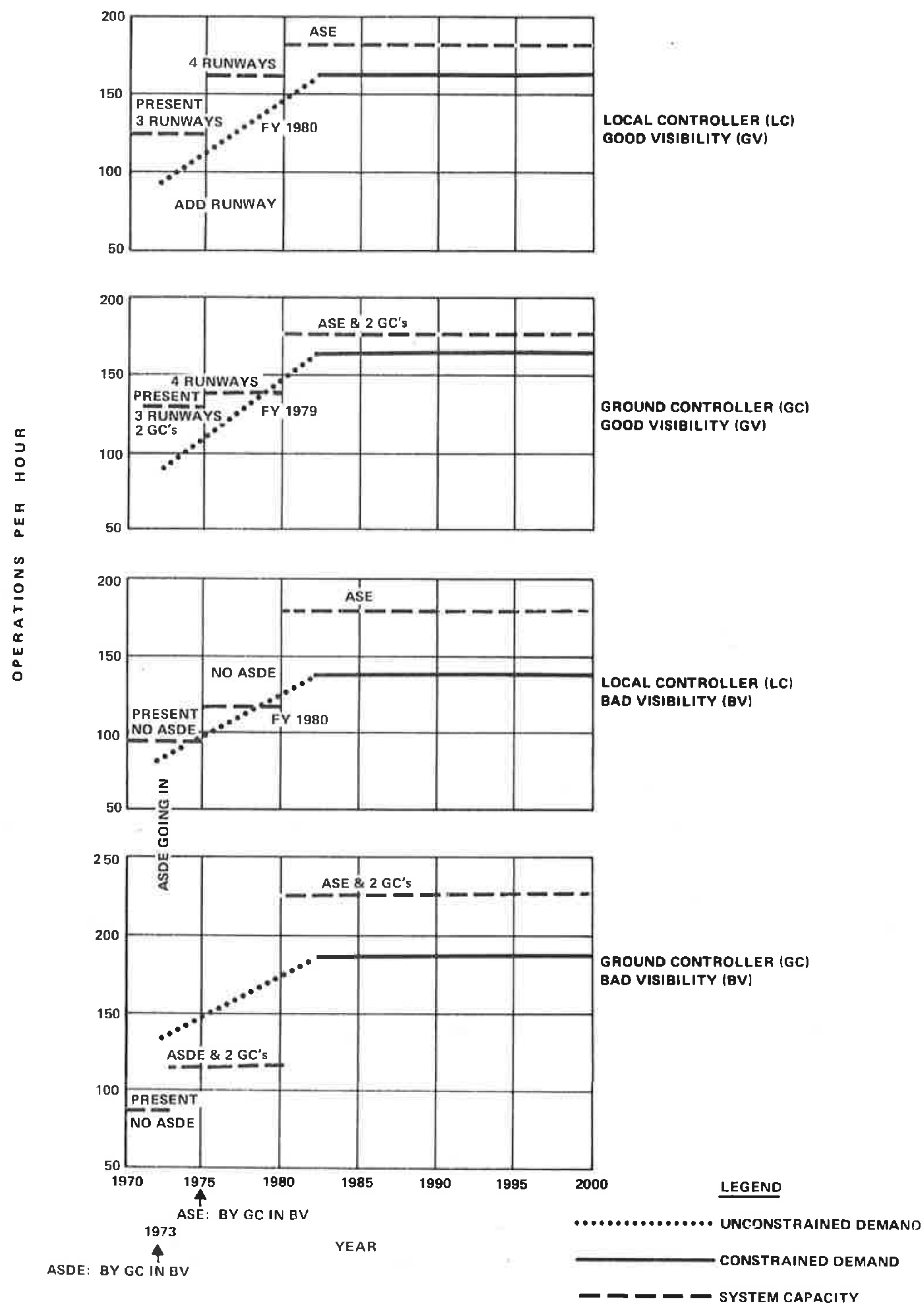


FIGURE 4-9
ATLANTA INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

4.4 JFK International Airport

The following summarizes briefly the general operational environment of JFK and presents an ASTC deployment plan.

4.4.1 Present Facilities and Operations

The airport layout for JFK is presented in Figure 4-10. This is generally similar to the Chicago O'Hare layout with the exceptions that tower visibility of portions of the taxiway system is obstructed and that a problem of runway crossing exists when 4R or 22L are used for landing with 4L or 22R used for departures. Both of these problems lead to increased workloads and potential reduction of capacity. Improved surveillance is obviously the only possible answer to this problem short of construction and relocation of the tower to achieve better out of the window visibility.

The runway system is most constrained with operations on the 4-22 pair. This appears to be the runway pair most often used during the afternoon peaks due to noise abatement procedures. The capacity of this runway pair at the present time is 86 oph. The two runways are operated as dual lanes but they are separated by enough distance so that storage of arrival aircraft between them is not a problem. General Aviation is restricted during peak hours and the additional capacity achievable with GA takeoffs/landings on another dependent runway (e.g., 14) is within the error budget of the above capacity estimate.

The taxiway system should be able to support the traffic demand easily, by analogy with the O'Hare taxiway system, except for the special problems mentioned previously and an apparently much greater frequency of taxiway segment closures resulting in two way traffic and one way links than at O'Hare. Control workloads may, therefore, be higher at JFK than at O'Hare. However, this increased workload should to a large extent be compensated for by the much smaller amount of traffic handled than at O'Hare.

The control tower operations are analogous to O'Hare with two ground and two local positions and the departure controller workload offloaded by the Clearance Delivery position.

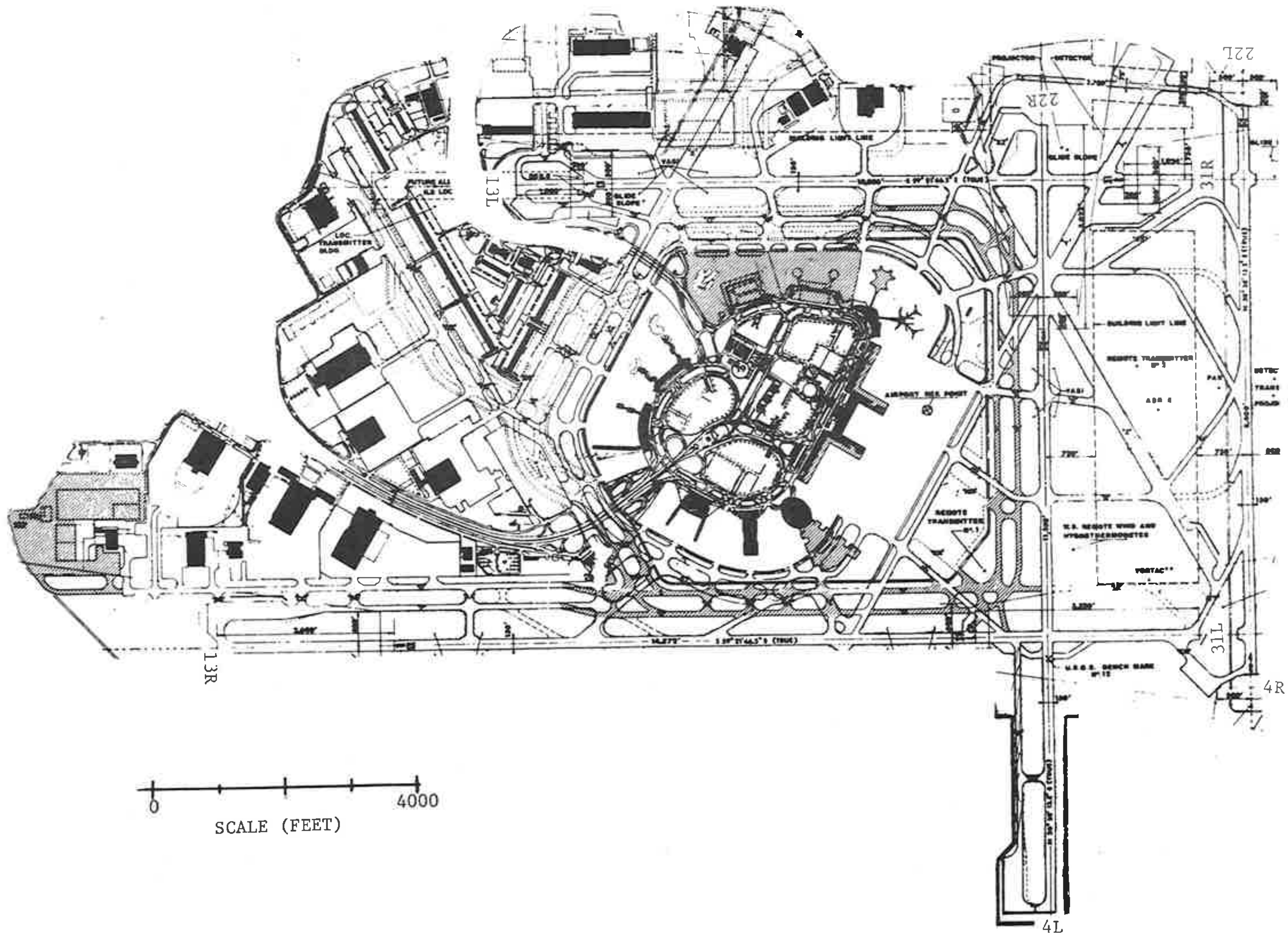


FIGURE 4-10
JOHN F. KENNEDY INTERNATIONAL AIRPORT (JFK)

The gate complex consists of 124 gates. However, because of the high percent of international and wide body jet flights, the gate occupancy time is much higher than at other airports. Data were not collected during the survey, but even if the time is twice as long, or 90 minutes, the gate capacity would be about 100 oph. This capacity would easily satisfy the runway capacity of 86 oph.

4.4.2 Future Facilities and Operations

The major improvements planned for JFK are in the gate areas with a planned complement of 152 gates of which 75 will be capable of accommodating 747's in contrast to today's gate complex which is designed primarily to handle aircraft up to the 707-DC8 size. ATC improvements, primarily a reduced separation rule for independent arrival operations, may increase the 4-22 pair capacity to 120 operations per hour when such a rule is implemented.

4.4.3 Deployment Time Phasing

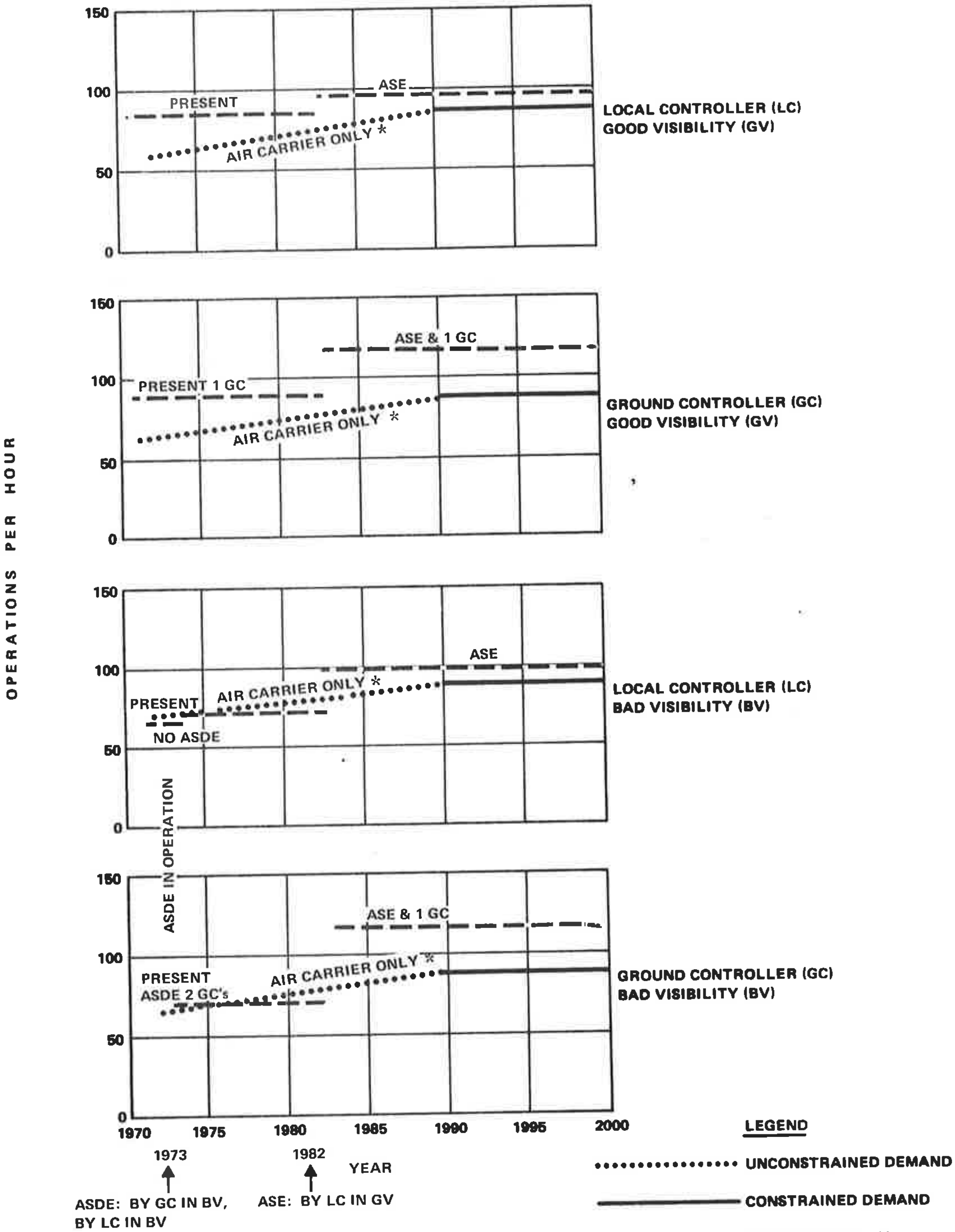
The ASTC system deployment time phasing is shown in Figure 4-11. In good weather operations the deployment of an ASE system could be quantitatively justified by the local position by 1982. It should, however, be noted that the tower visibility problems may justify deployment of an ASE system as soon as it becomes available purely on the grounds of operations safety associated blind spots to the ground control positions. Specific data in this respect should be collected as soon as possible to resolve this question. In bad visibility an ASDE is justified immediately because a single controller (implied by a no ASDE operation) will not be able to handle the present traffic loads.

4.5 San Francisco International Airport

The following summarizes briefly the general operational environment of SFO and presents an ASTC deployment plan.

4.5.1 Present Facilities and Operations

The airport layout for SFO is presented in Figure 4-12. In VFR conditions, all four runways are used. There are two sets of dual lane runways, each about 700 feet apart, that cross perpendicular to each other near the middle of the two pairs. The normal VFR operation is to land two aircraft abreast on runways 28L and R followed by two departures abreast on runways 1L and R.



* GA RESTRICTED DURING PEAK HOURS .

FIGURE 4-11
J. F. KENNEDY INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

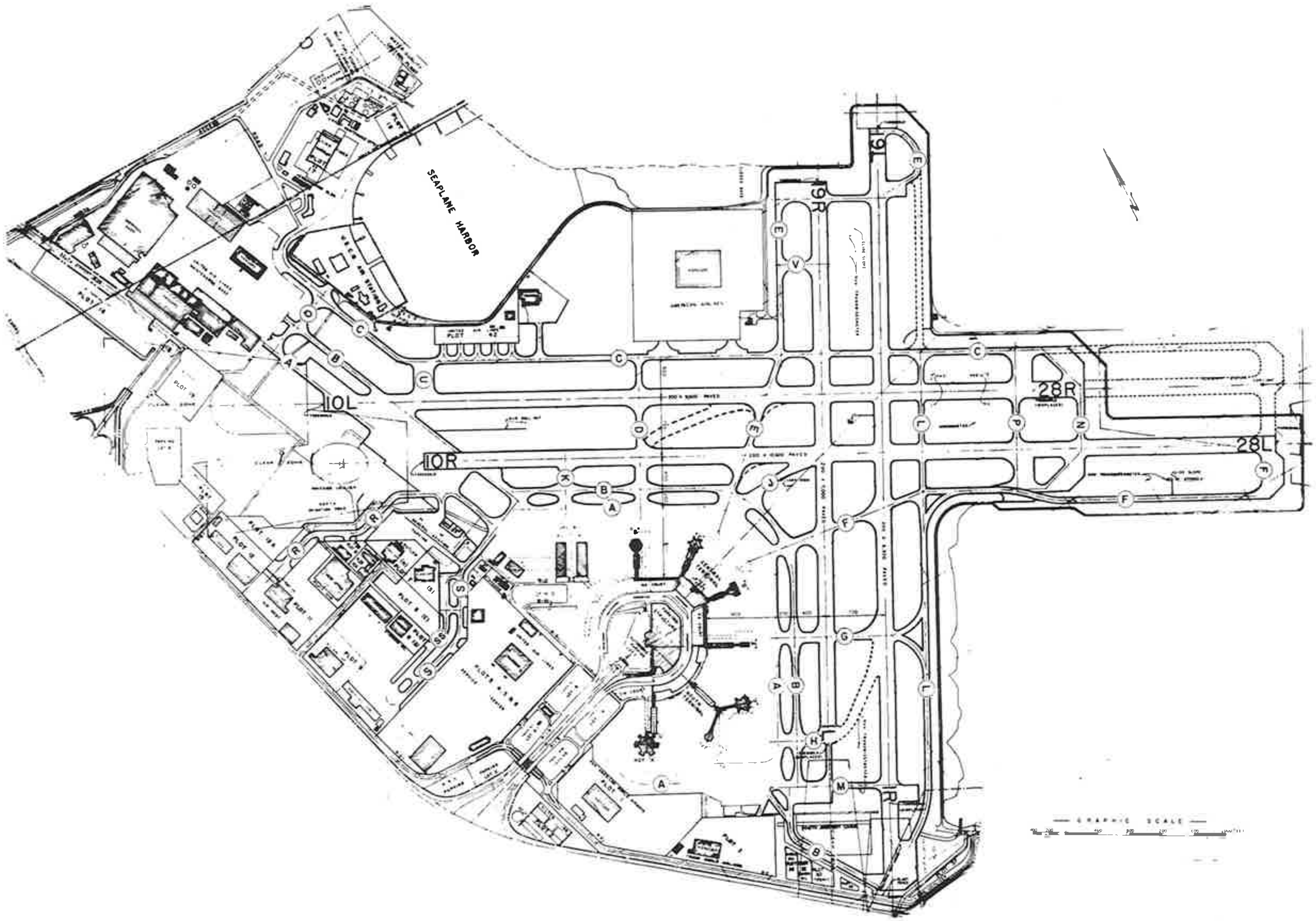


FIGURE 4-12
SAN FRANCISCO INTERNATIONAL AIRPORT (SFO)

They have the operations timed very well, resulting in a high operations rate over short periods of time when the air carrier demand exists for both arrivals and departures. A conservative estimate was made of the ideal interval between successive arrival pairs to be about 140 seconds (40 seconds for the arrivals from over the threshold to rolling past the intersecting pair of runways, 40 seconds for the departures to clear the arrival runways, 30 seconds buffer for the variation between simultaneous arrivals crossing the departure runways, and 30 seconds buffer for the uncertainties of aircraft mix, display errors, etc.). This would yield an ideal capacity of 103 oph and, as before (10% less), a practical estimate of capacity of 93 oph. The SFO tower uses a nominal value of 90 oph for planning purposes.

In IFR conditions, the runway configuration reduces to a conventional single set of dual lane runways with the nominal capacity values from Table 3-1.

The taxiway configuration is much like LGA. All three airports have a shortage of taxiway space between the ramp and the departure runways. Because of the lack of space at SFO, gate hold procedures have become necessary when departure delays are anticipated. A departing pilot is assigned a gate hold group (usually five aircraft to a group) and he is not permitted to start his engines until directed by the Clearance Delivery Controller that the entire group can "start engines."

There are two GC's, with the workload subdivided by geography. One GC handles the north side and the other handles the east side. They do not attempt to establish fixed taxiway traffic patterns.

The present gate complex at SFO consists of 60 air carrier gates, which converts to a capacity estimate of 96 oph; sufficient to handle the peak hour runway capacity of 93 oph.

4.5.2 Future Facilities and Operations

Presently, there are no plans to expand the runway system at SFO. However, the gate complex is to be expanded to 90 to 96 gates, which would yield a gate capacity of about 144 to 153 oph, which again will exceed the runway capacity.

4.5.3 Deployment Time Phasing

The ASTC system deployment time phasing is shown in Figure 4-13. In good visibility conditions, the deployment of an ASE system

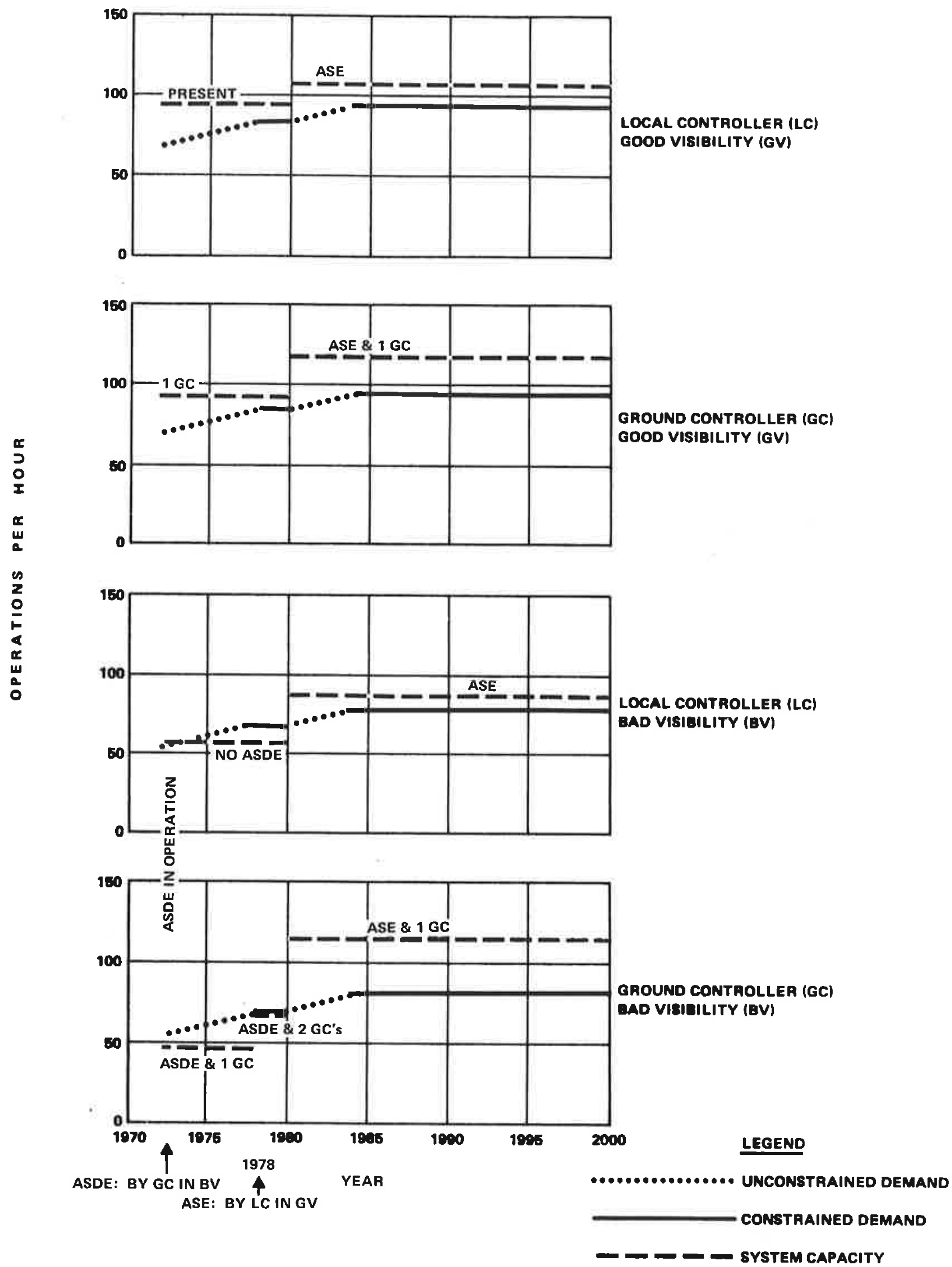


FIGURE 4-13
SAN FRANCISCO INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

can be justified by 1978 for the LC. The GC could be reduced to one GC at the deployment date of ASE.

In bad visibility conditions, the ASDE is justified at present for the GC. One GC could be used without significant delays, but since two are already used in good visibility operations, the other GC can reduce delays in bad visibility until the deployment of ASE, when the GC capacity will easily exceed the demand.

4.6 La Guardia Airport

The following summarizes briefly the general operational environment of LGA and presents an ASTC deployment plan.

4.6.1 Present Facilities and Operations

The airport layout for LGA is presented in Figure 4-14. There is a single set of crossing runways. The preferred runway configuration is arrivals on R22 and departures on R13. Another frequently used configuration is arrivals on R31 and departures on R4. Because of noise abatement restrictions, arrivals on R4 must have a gross weight of less than 12,500 lbs.

The ASR antenna at JFK is also used for LGA. They can see arrivals in to about 1/4 mile from the runway threshold. They generally use one runway for arrivals and one for departures but during a peak they sometimes mix operations on the same runway. There are two LC's, one for each runway, which requires close coordination. A coordinator position monitors the crossing runway problem. When it is required for a taxiing aircraft to cross an active runway, the ground controller is given the responsibility and the coordinator monitors it. Two ground controllers have been authorized. However, they have decided that the second position is of more benefit to them if they use it as a TCA controller.

Using the preferred runway configuration (arrivals on R22 and departures on R13), the peak hour capacity should be about 93 oph in good visibility conditions and 65 oph in bad visibility conditions without an ASDE.

The gate complex consists of 76 gates to yield about 120 oph, which is sufficient to handle the peak hour traffic.

4.6.2 Future Facilities and Operations

There are no plans to expand the runway system at LGA. The gate complex is to be expanded to 90 gates which will comfortably handle the demand.

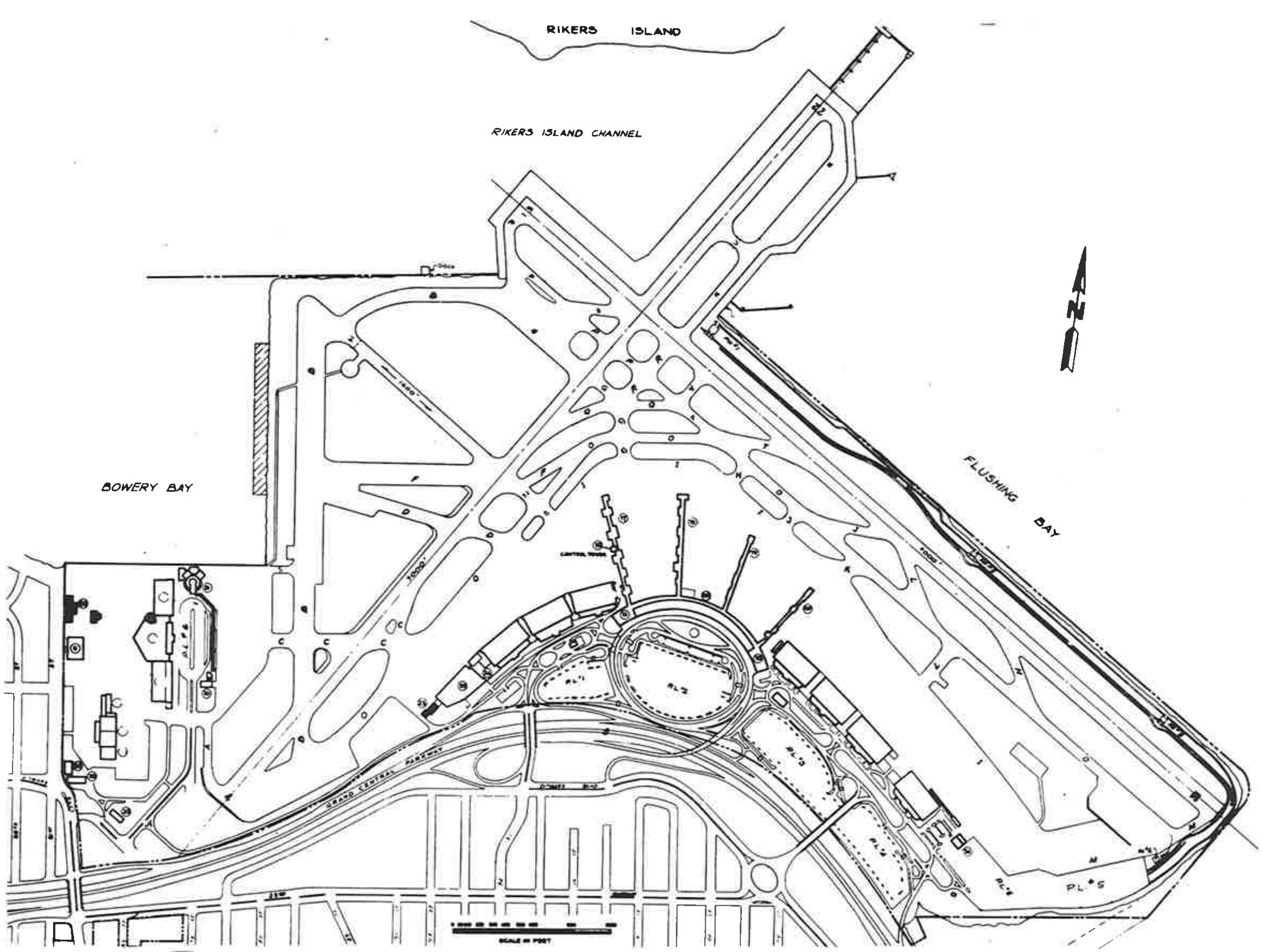


FIGURE 4-14
LA GUARDIA AIRPORT (LGA)

4.6.3 Deployment Time Phasing

The ASTC system deployment time phasing is shown in Figure 4-15. In good visibility conditions, the deployment of an ASE will be justified by 1982 for the LC. This deployment will prevent the need for a second GC for good visibility conditions.

In bad visibility conditions, an ASDE could be justified now for the GC and when the ASE is deployed, the second GC need not be added during bad visibility periods. However, it must be pointed out that the tower is very close to the runways, and the deployment of an ASDE may be questionable since the controllers can see the runways/taxiways during bad visibility periods when the runways are operating.

4.7 Miami International Airport

The following summarizes briefly the general operational environment of MIA and presents an ASTC deployment plan.

4.7.1 Present Facilities and Operations

The airport layout for MIA is presented in Figure 4-16. The runway configuration consists of a pair of independent parallels with a crossing runway between them. The crossing runway is used primarily when there is an over demand of departures. Using only the set of parallels would yield a runway capacity of about 108 oph.

Presently, there are two LC's and two GC's. The main GC problem at MIA was stated to be moving aircraft to and from the terminal and cargo ramp areas, and the maintenance hangars and quarantine area. Since MIA serves a large number of terminating flights, the towing of aircraft across and around the R9L,27R runway is a frequent event. None of the taxiways are numbered or lettered. The arrival and departing aircraft are usually permitted to use the runway which will provide them the shortest taxi route. The sorting out of traffic is done in the air and not on the ground.

Currently there are 80 gates at MIA. The capacity of 128 oph given in Table 4-1 may be high because of the large number of terminating flights. As at JFK the international flights spend more time in the gate than domestic, shorter range flights.

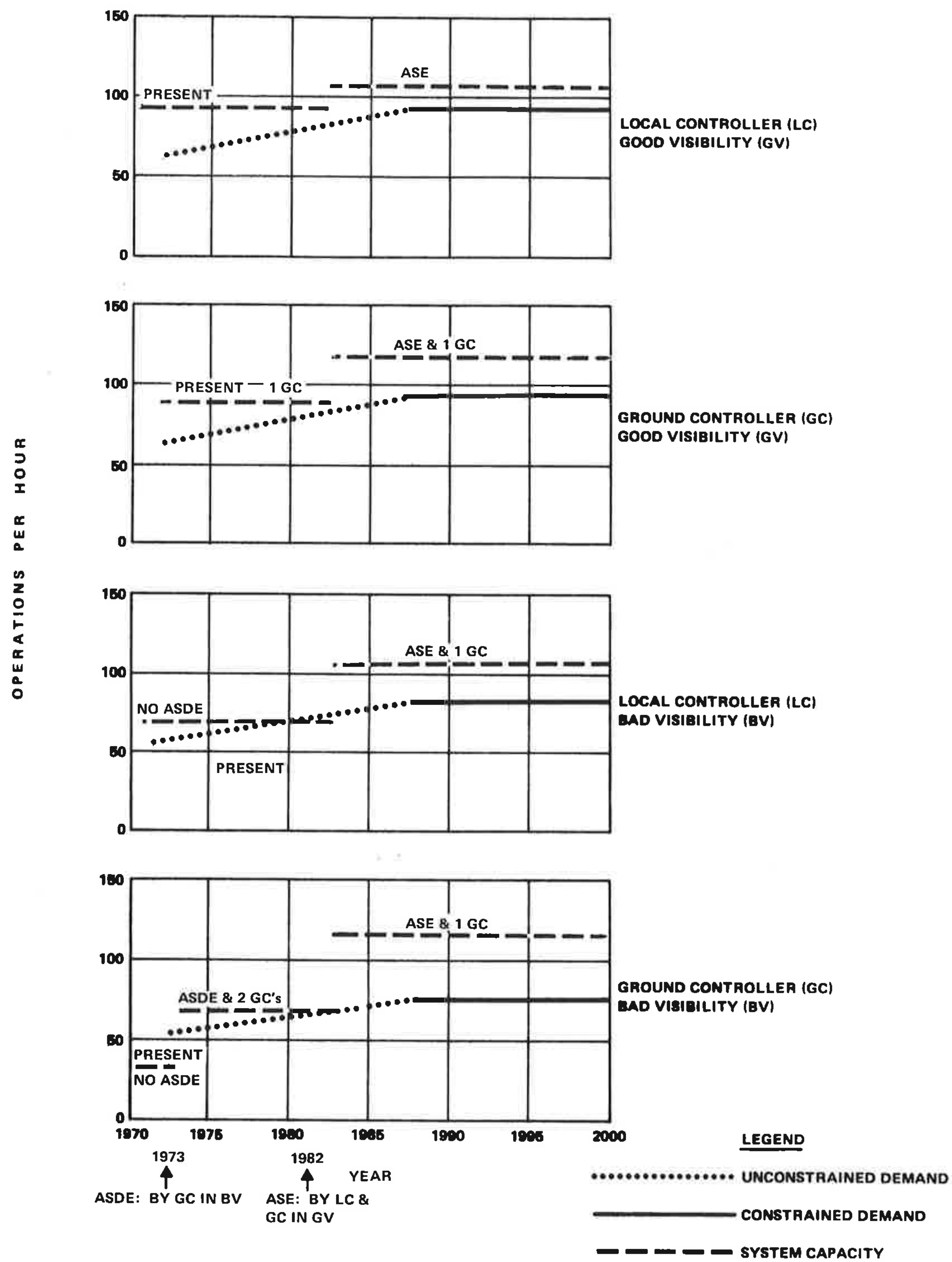


FIGURE 4-15
LA GUARDIA: ASTC SYSTEMS DEPLOYMENT

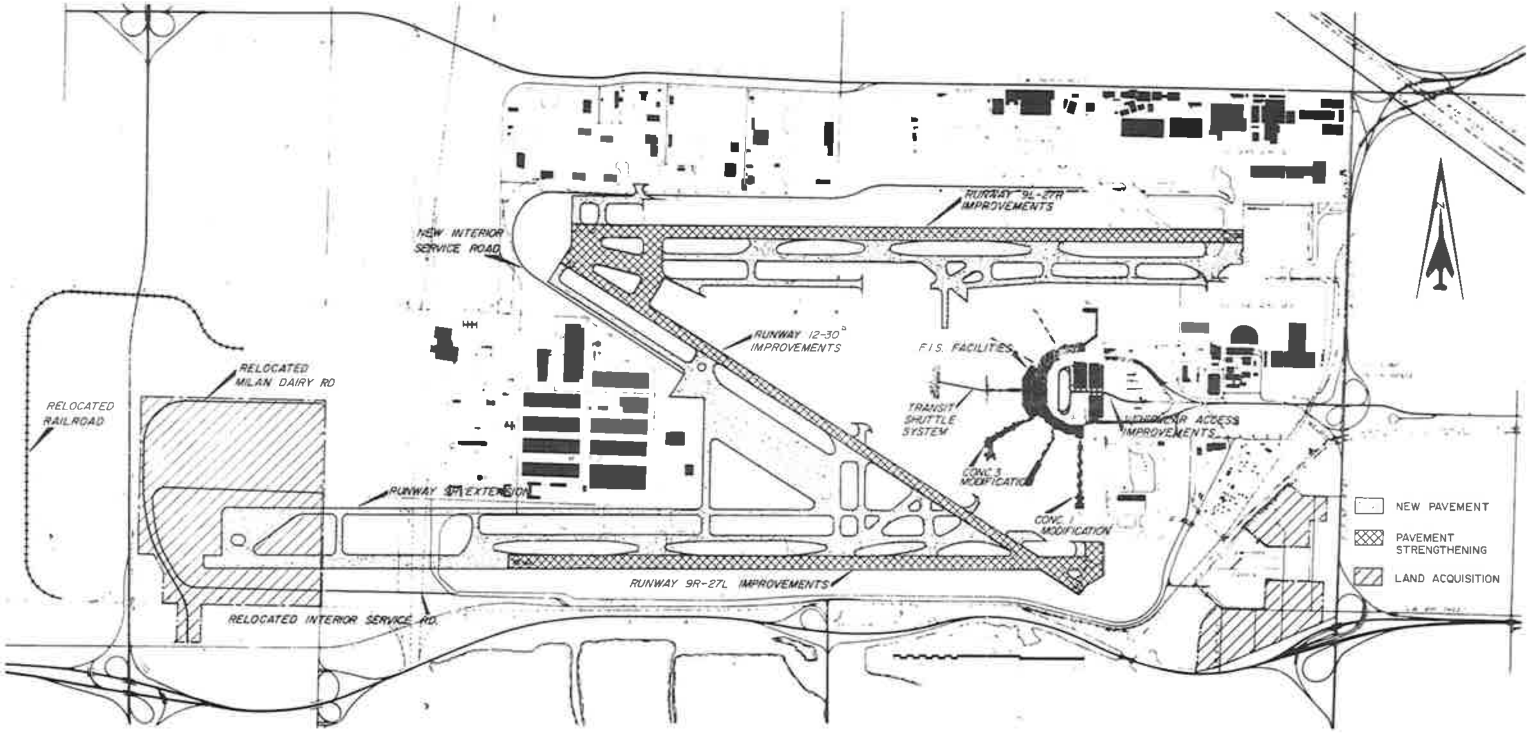


FIGURE 4-16
MIAMI INTERNATIONAL AIRPORT (MIA)

4.7.2 Future Facilities and Operations

The runway expansion plans consist only of extending the present runways and improving the runway exits and taxiway configuration to permit a smoother ground traffic flow. Also, peripheral taxiways are to be installed to permit tows to circumvent the ends of runway 9L,27R.

The current plan for gate management is to have the gates managed by the Port Authority and made available on a preferential system. The airlines would be assigned to certain concourses and if they require more gates, they would be assigned from those close by and available. The three strong air carrier competitors will be buffered from each other by not assigning them to adjacent concourses. The airlines will be charged only on the basis of gate usage. This procedure should increase gate utilization upward from 60%, thereby increasing the overall gate capacity.

The present 80 gates are to be increased to 100 gates by 1975. The gate capacity then should be about 160 oph, and even if it is slightly lower, it should exceed the projected runway capacity.

4.7.3 Deployment Time Phasing

The ASTC system deployment time phasing is shown in Figure 4-17. Because of the rapid growth of demand and the present capacity of the runways, an ASE could be justified for the LC in good visibility by 1974. The GC will benefit from the deployment of an ASE by reducing to one GC in good visibility.

Although the GC is saturated during bad visibility, the frequency of bad visibility periods is too low to justify an ASDE. The deployment of ASE would, however, be of obvious benefit to both the LC and GC when bad visibility conditions do occur.

4.8 Washington National Airport

The following summarizes the general operational environment of DCA and presents an ASTC deployment plan.

4.8.1 Present Facilities and Operations

The airport layout for DCA is presented in Figure 4-18. The runway systems consists of three crossing runways. Generally, the main runway, 18/36, is used for air carriers, and GA

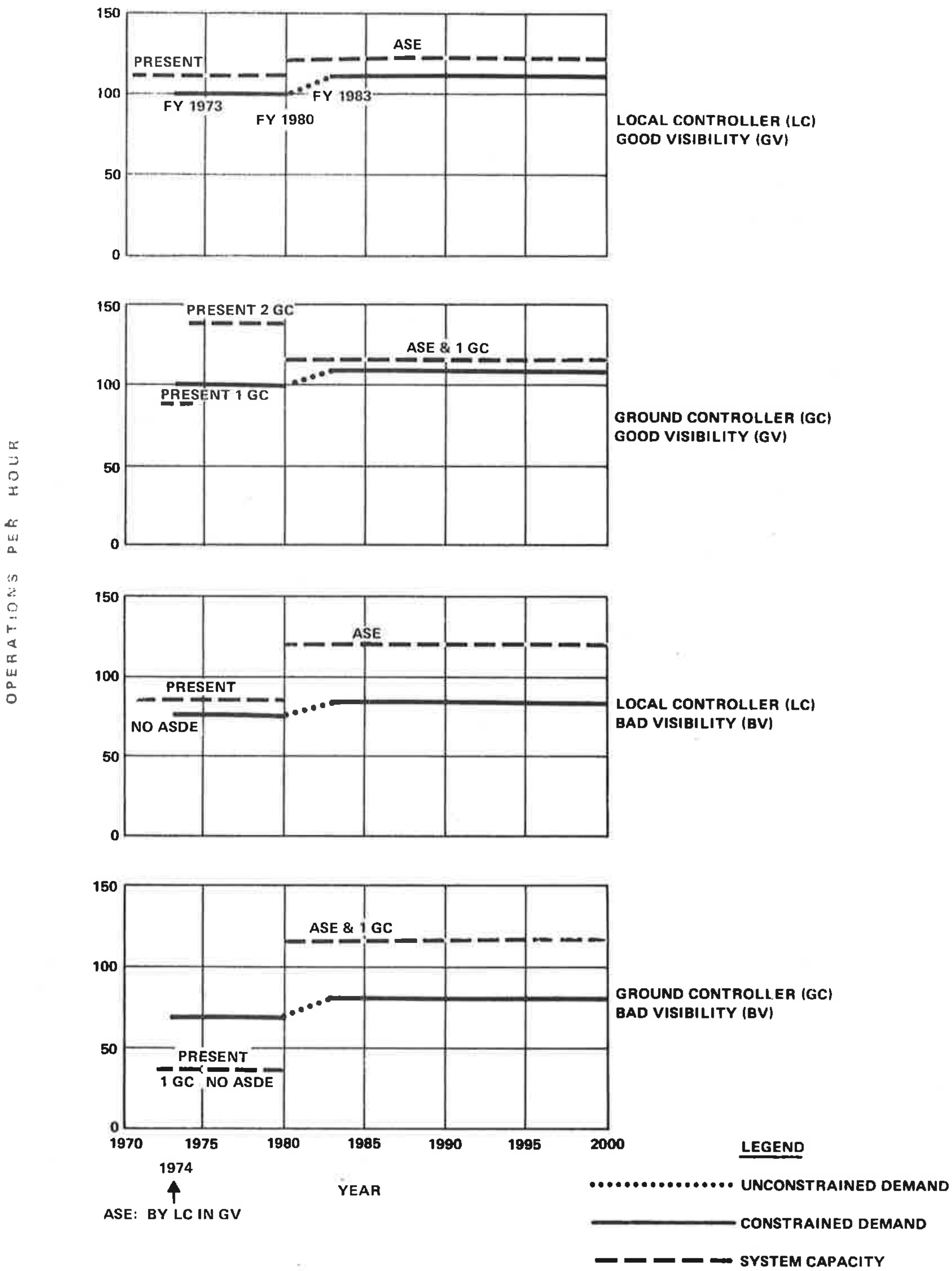


FIGURE 4-17
MIAMI INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

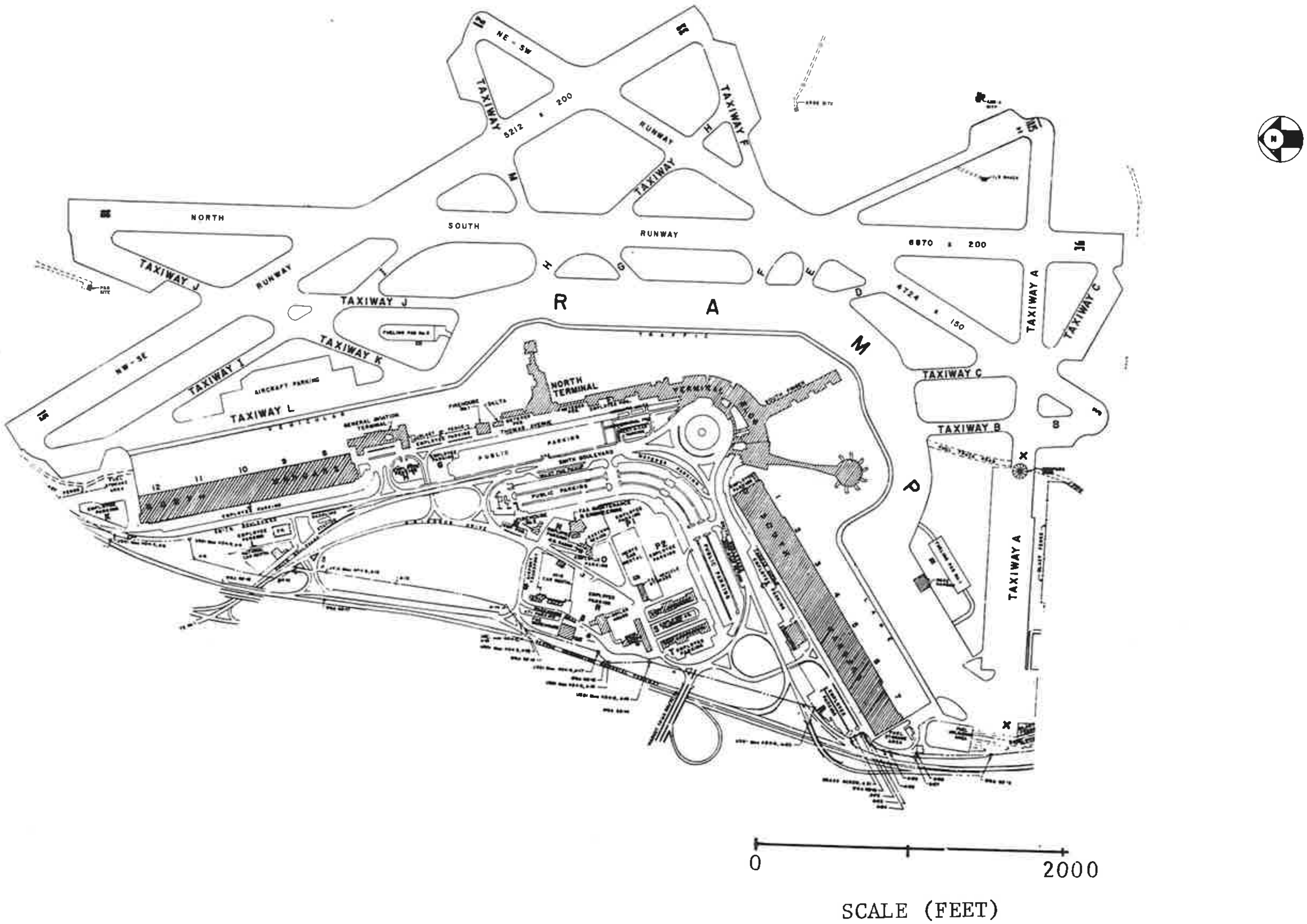


FIGURE 4-18
WASHINGTON NATIONAL AIRPORT (DCA)

operations are handled mostly on the two crossing runways, 3/21 and 15/33. The runway capacity was estimated at about 81 oph for good visibility conditions, and since the configuration reduces to a single runway for bad visibility conditions, the bad visibility capacity should be about 40 oph.

There are only one LC and one GC at DCA. The taxiway system is mostly the outer portion of the ramp and no major problems are reported to exist. The only problems appear to be in the ramp/gate area. As at LGA, the tower is close to the runways and visibility during bad visibility conditions is not as significant a problem as at other airports. However, a bad visibility communications tape was analyzed in which it was obvious that neither the GC nor the LC could see beyond the immediate vicinity of the tower.

There are currently about 36 gates at DCA for an estimated capacity of 57 oph. This should be sufficient to accommodate the peak air carrier hourly demand of 49 oph.

4.8.2 Future Facilities and Operations

At the present, it appears that no significant improvements are to be made in the near future.

4.8.3 Deployment Time Phasing

The ASTC system deployment time phasing is shown in Figure 4-19. For bad visibility operations, an ASE system could presently be justified for the LC and the GC can justify an ASDE, also in 1973. The ASDE would not be sufficient for the LC in bad visibility operations.

4.9 Boston-Logan International Airport

The following summarizes the general operational environment of BOS and presents an ASTC deployment plan.

4.9.1 Present Facilities and Operations

The airport layout for BOS is presented in Figure 4-20. The tower blind spots and most of the proposed runway/taxiway and gate complex improvements are superimposed on this figure. The major blind spot area, which is also a significant traffic bottleneck, is behind the Eastern Terminal area in the southwest part of the terminals. A two-way single width passage exists in this area and becomes closed by pushbacks from the Eastern Terminal. Traffic is relatively heavy in the area due to general aviation to and from the Butler general aviation area

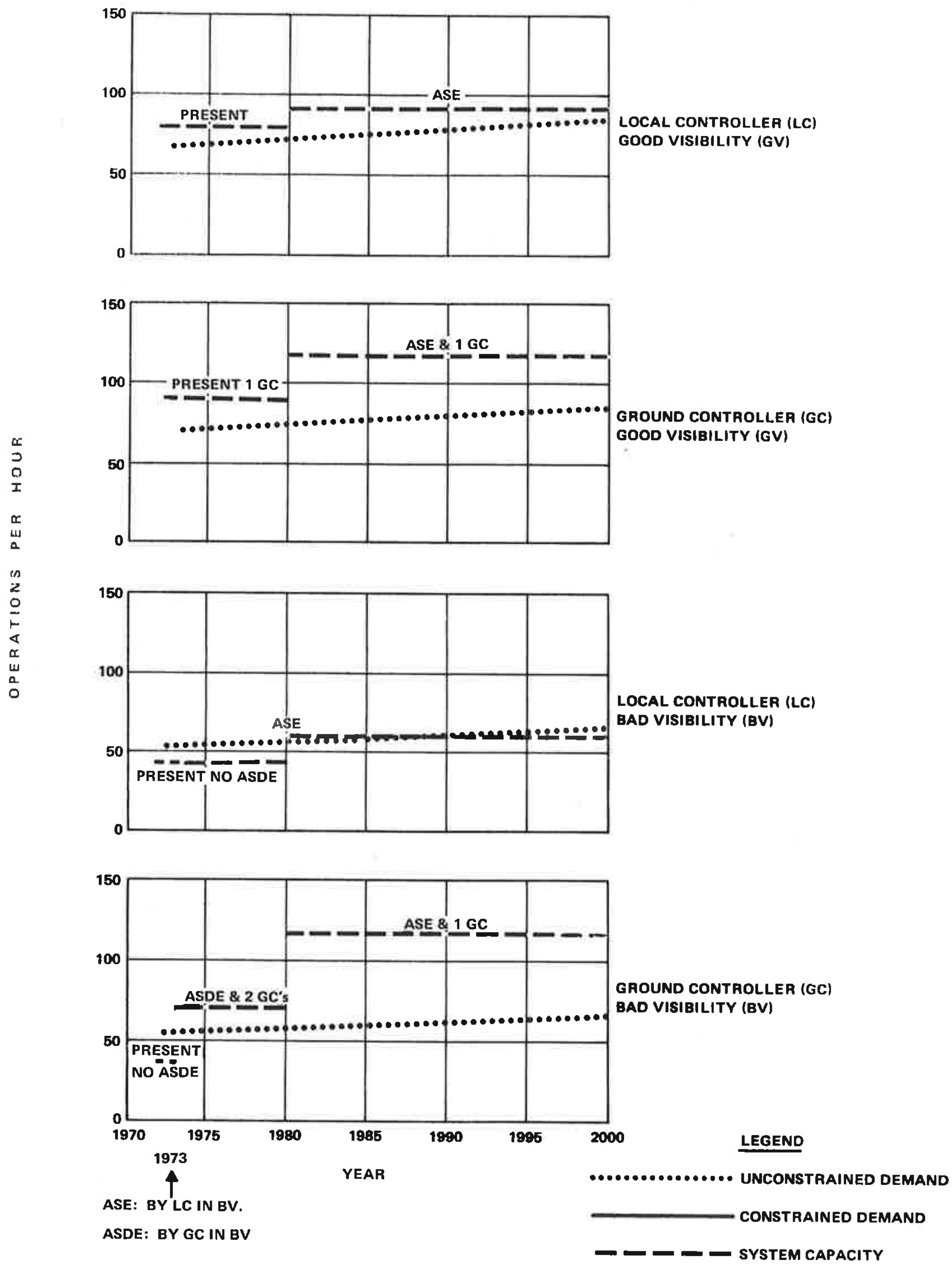


FIGURE 4-19
WASHINGTON NATIONAL: ASTC SYSTEMS DEPLOYMENT

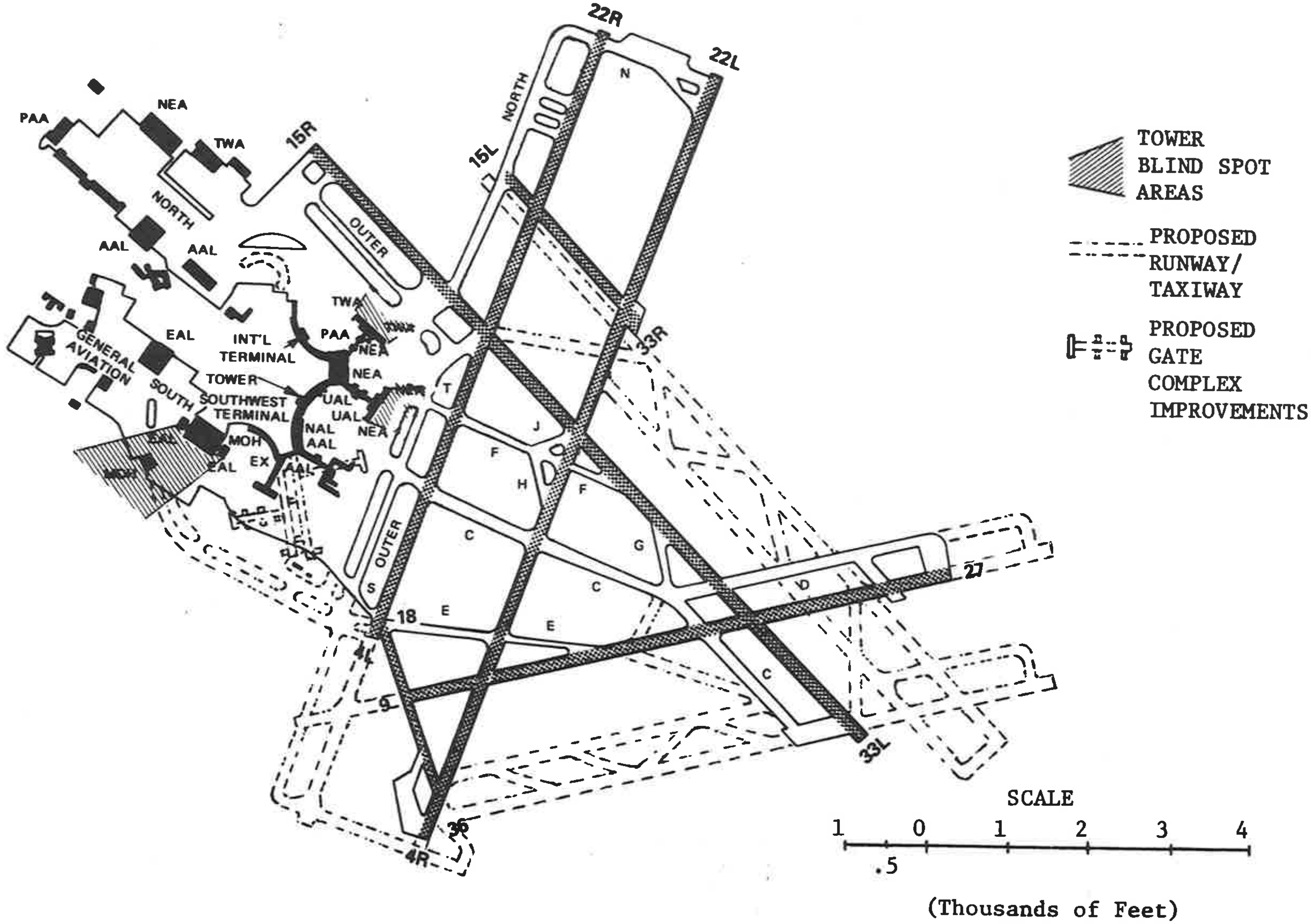


FIGURE 4-20
BOSTON-LOGAN INTERNATIONAL AIRPORT (BOS)

west of the Eastern Terminal and traffic gets held up significantly. The tower is not responsible for traffic control in this area. The other major traffic areas where tower visibility is obstructed is at Piers B (TWA) and C (NEA) with the view of the inner taxiway obstructed by Pier B. This is not a major problem area. The hangar area in the northwest does not involve heavy traffic and is not controlled by the tower. With the exception of the blind spot problems and the two-way single-width access areas in the southwest and northwest of the airport the taxiway layout and flow patterns appear to be quite reasonable.

The gate system at Logan consists of 62 commercial carrier gates. This would indicate a potential capacity of the gate system of 90-100 operations per hour by comparison to the gate complexes with 69 and 67 at O'Hare and Los Angeles International respectively. It appears that the gate complex should not be a constraint on airport capacity in the near future since Logan is now operating at an annual rate of 321,000 operations, of which about 37% are general aviation, and the ten year forecast demand is 400,000 operations with about 33% general aviation (Reference 7). Since both O'Hare and Los Angeles, with only about 10% larger gate complexes, now operate at a much lower general aviation fraction and a higher, 25% to 50%, operations rate than the projected Logan demand for 1983, it would appear that the Logan gate complex can meet the ten year demand requirements. Additional investigation of special circumstances, if any, is needed to verify the above estimate.

The runway complex could provide a capacity roughly balanced with the estimated gate capacity for the following runway configurations; 4L and 4R, 22L and 22R, 4R and 9, 27 and 33, 15 and 22R. Capacities greater than the gate system capacity would be provided by using the combination of runways 4L, 4R and 9, i.e., about 120 oph. The above does not account for constraints due to approach/departure airspace, constraints due to route layout, constraints due to noise abatement procedures, and wind extremes which may limit the complex to a single runway operation on 9, 27, 15 or 33. The wind extreme limitation is estimated on the basis of wind rose examination and runway utilization percentages to be below 5% of the operating time. The addition of parallels to runways 9 and 15 would resolve the residual capacity limitation problems and would provide a runway capacity in excess of the present gate capacity.

During the periods of low visibility the capacity of the airport decreases drastically to about 65 oph. The airport does not have an operational ASDE and control operations are carried out with position feedback from pilots.

4.9.2 Future Facilities and Operations

The projected facility improvements are shown in Figure 4-20 as dashed outlines. These improvements include: a full circumferential (semi-circle) inner and outer taxiway system; extension of runways 4L-22R and 9-27 at the south end of 4L; addition of a general aviation runway at the downwind end of 4L-4R; addition of a landing parallel runway to 15-33 (33R); expansion of the gate facilities of up to 94 gates, depending on aircraft mix and construction of a new tower. Additionally considered is a potential addition of a parallel to 9-27 (9R). The addition of the new inner and outer taxiways at the south end of the airport would resolve the problem of moving two-way traffic through a single lane taxiway. The relocation of these inner and outer taxiways towards the bay and the construction of the new high tower should provide tower visibility and control capability in the area assuming that the construction of the new gate complex in the southeast area is limited with respect to its height. The tower relocation and height increase should also resolve the problem of view obstruction at piers B and C and provide better visibility into the northwest and southwest portions of the terminal. The runway extensions should provide a more balanced and flexible commercial jet takeoff capability. The addition of the parallel to 15-33, and possibly the parallel to 9-27, would provide a balanced capacity of up to 120 commercial jet operations in all wind directions. This would perhaps add 20-30% operations per hour capacity for general aviation aircraft utilizing a third runway. The gate complex, with a capacity of about 150 operations per hour, should not be a constraint.

4.9.3 Deployment Time Phasing

The ASTC system deployment time phasing is shown in Figure 4-21. In GV conditions the LC operations can justify an ASE system in 1984 to meet the demand growth. In BV conditions the ASDE is justified at present for the GC and the LC will also benefit from its use by 1980. The deployment of the ASE will make the GC capacity in BV comfortably above the constrained demand.

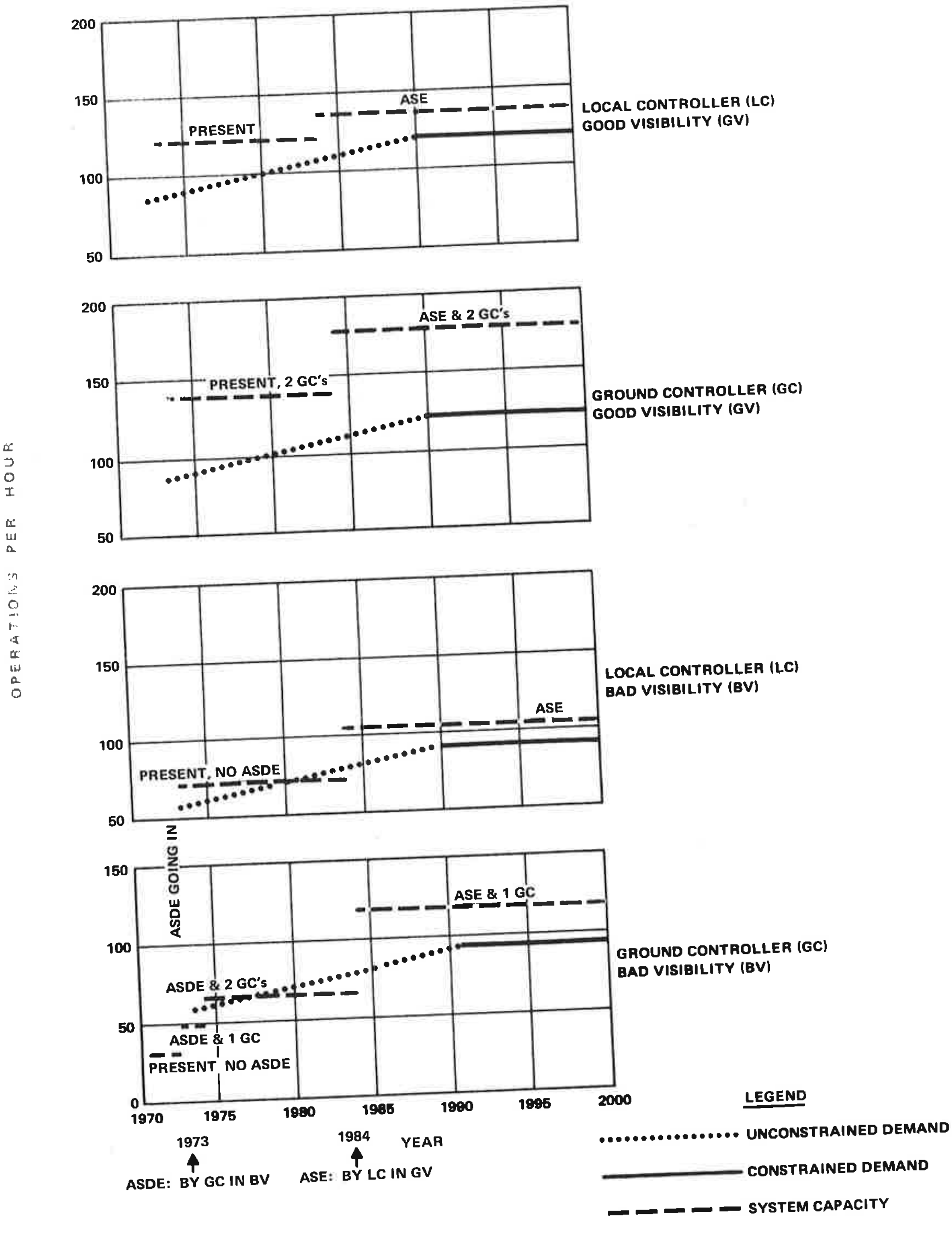


FIGURE 4-21
BOSTON-LOGAN: ASTC SYSTEMS DEPLOYMENT

4.10 Detroit-Metropolitan Wayne County Airport

The following summarizes the general operational environment of DTW and presents an ASTC deployment plan.

4.10.1 Present Facilities and Operations

The layout of DTW is shown in Figure 4-22 which also includes blind spot areas. The blind spots are a result of a poor tower location with insufficient height relative to the height of the surrounding buildings. The most serious blind spot is the approach path blankout to runway 21R which is currently being monitored by CCTV (closed circuit television). The taxiway/runway system is generally visible from the tower with the exception of the blind spots on the inner taxiway. Plans for relocation of the tower exist and may resolve the tower blind spot problem under VFR conditions. The taxiway system appears to be adequate to provide one way flow patterns in all directions with the exception of connecting the general aviation area when a dual taxiway. The main runway pair, covering 93% of operations is a dependent pair from the viewpoint of IFR arrival operations handling, but independent with respect to depatures. The capacity of this pair (3-21) should be 108 oph under good visibility conditions and 58 oph in bad visibility conditions without an ASDE.

Currently there are 49 gates at DTW, to yield a gate capacity of about 75 oph, which is sufficient for today's demand.

4.10.2 Future Facilities and Operations

The proposed runway expansion, shown on Figure 4-22, will significantly increase the good visibility and bad visibility capacities, i.e., from 108 oph to 130 oph in good visibility conditions and from 58 oph to 96 oph in bad visibility conditions. The expansion is to put in runways 3R and 9R which would permit independent IFR approaches in either configuration. The terminal area may be moved to the center of the four runways as shown on the figure.

The gates are to be expanded to 117 to provide a gate capacity of about 187 oph; well above the runway capacities.

4.10.3 Deployment Time Phasing

The ASTC system deployment time phasing is shown in Figure 4-23. In good visibility conditions, an ASE system may not be required until 1998. For the LC/runway system, the runway expansions will be needed by about 1987, which will provide sufficient capacity

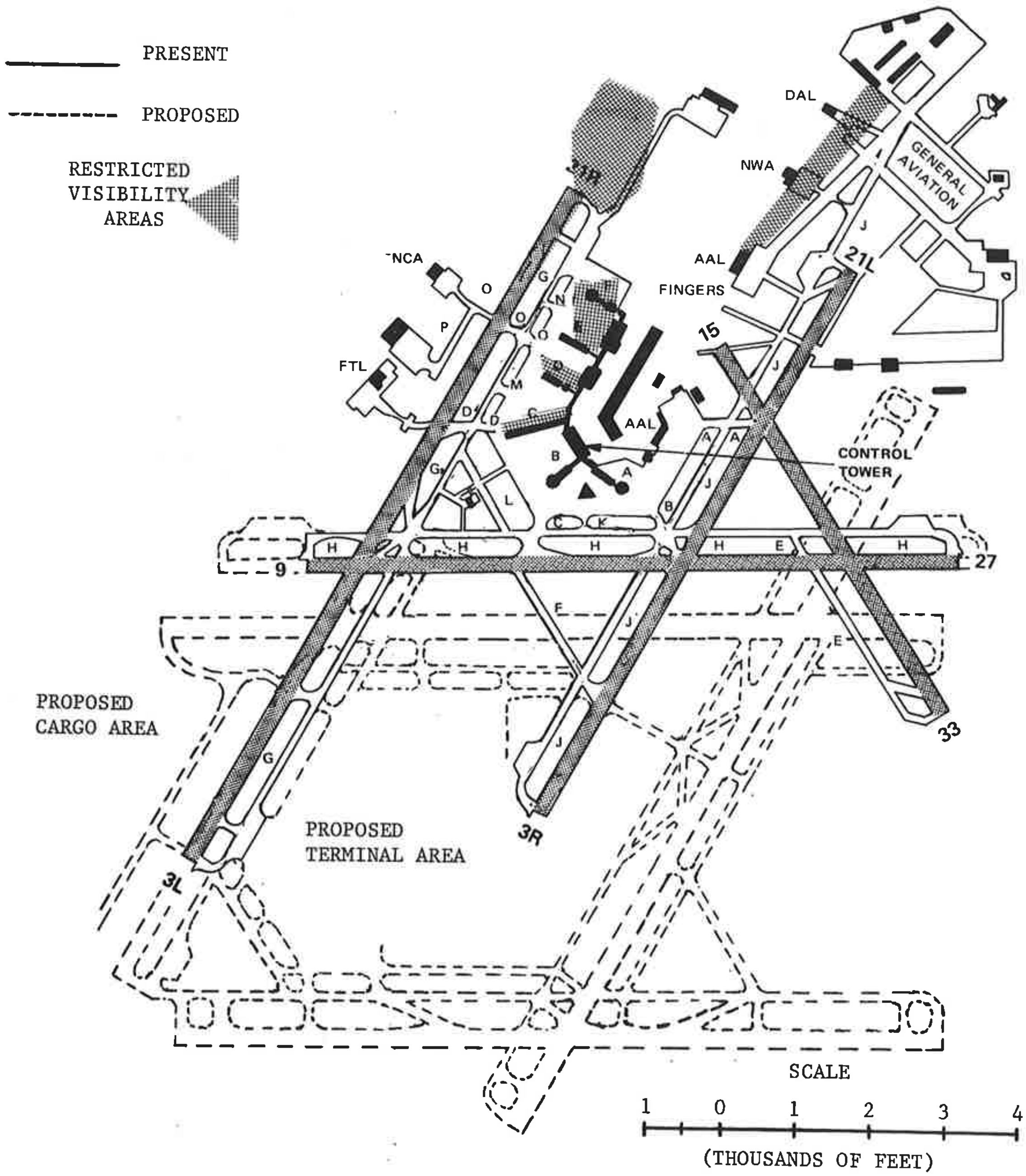


FIGURE 4-22
DETROIT METROPOLITAN WAYNE COUNTY AIRPORT (DTW)

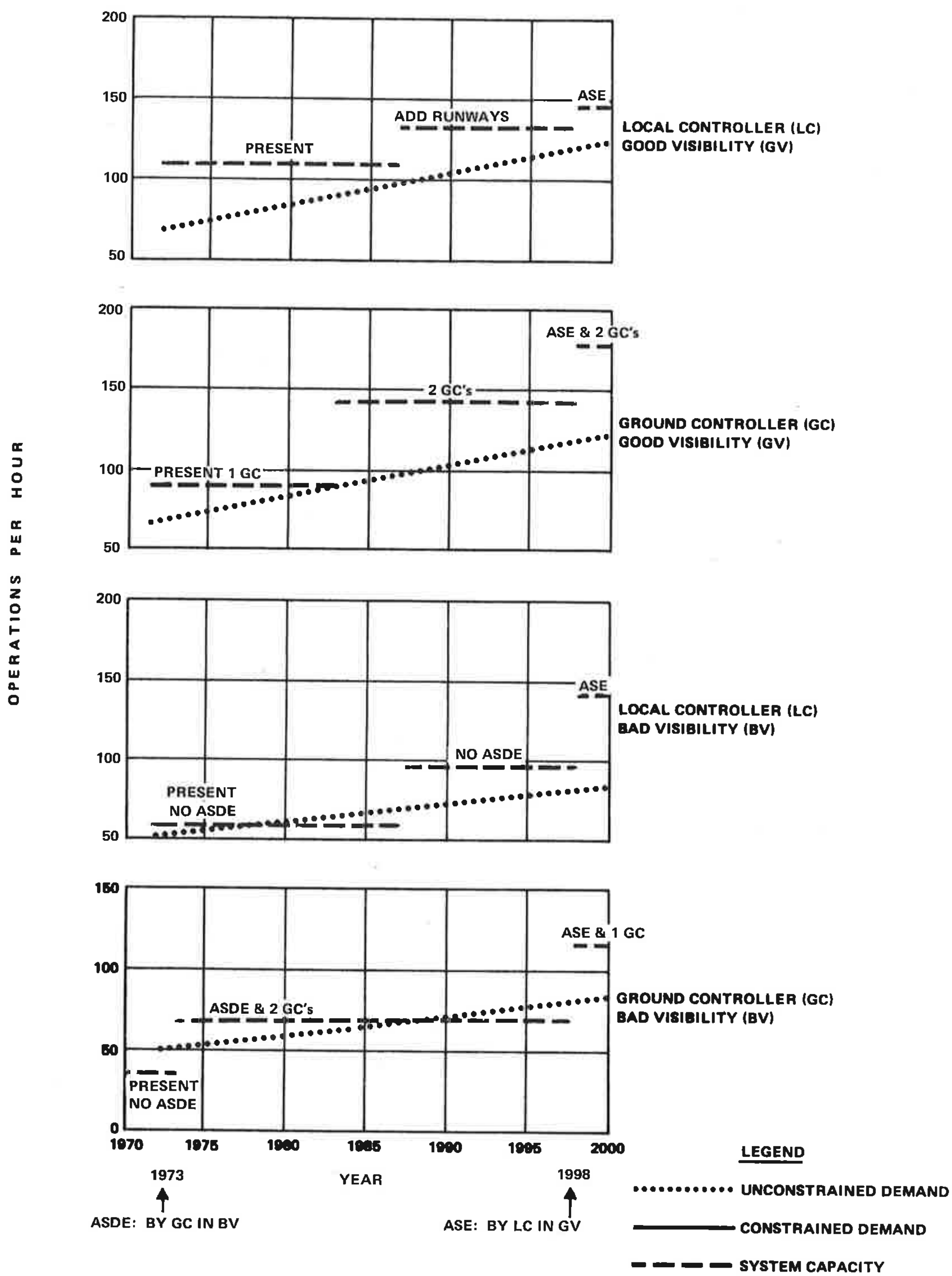


FIGURE 4-23
DETROIT METRO-WAYNE COUNTY: ASTC SYSTEMS DEPLOYMENT

until the ASE is needed around the turn of the century. For the GC, one GC will suffice until about 1983 when a second GC should be added.

For bad visibility conditions, an ASDE is justified at the present and that should be sufficient until the time that the ASE is deployed for GV conditions.

4.11 Newark International Airport

The following summarizes the general operational environment of EWR and presents an ASTC deployment plan.

4.11.1 Present Facilities and Operations

The airport layout for EWR is presented in Figure 4-24. The present configuration includes only runways 22R and 11. Runway 22L is not yet complete. Also, the new terminal is not yet in use. The buildings to the north of runways 11/29 are the present terminal buildings. The new terminal is under construction and should be opened soon. The air carrier runway is 22R. Runway 11 is used for GA traffic. The ASDE at EWR is used primarily by the LC for runway clearance.

There are currently 32 gates at EWR for an estimated gate capacity of 51 oph which is compatible with the estimated 54 air carrier oph on the air carrier runway.

4.11.2 Future Facilities and Operations

The future runway configuration will consist of the set of dual lane runways for air carrier operations and the single runway for GA operations for an estimated total capacity of 108 oph in good visibility conditions and 58 oph in bad visibility conditions. A major problem may exist with the location of the present control tower in relation to the new terminal. It is located nearer the old terminal, making only a small portion of the ramp area in the new terminal visible from the tower.

The future gate complex consists of up to 83 gates for an estimated capacity of 133 oph, which is sufficient for the demand constrained by the runway configuration.

4.11.3 Deployment Time Phasing

The ASTC system deployment time phasing is shown in Figure 4-25. In good visibility conditions, the new runway configuration should meet the peak hour demand until 1988 when the ASE system will be required by the LC. One GC should be able to handle the

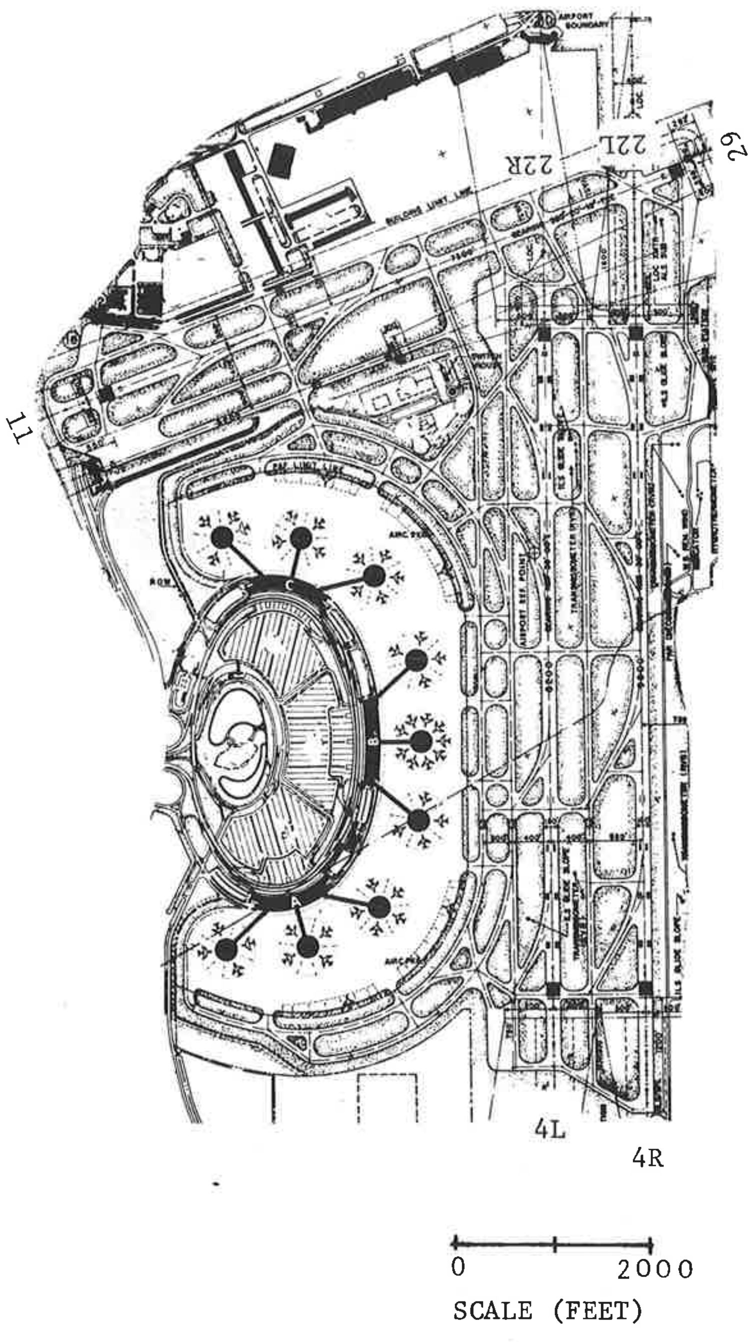


FIGURE 4-24
NEWARK INTERNATIONAL AIRPORT (EWR)

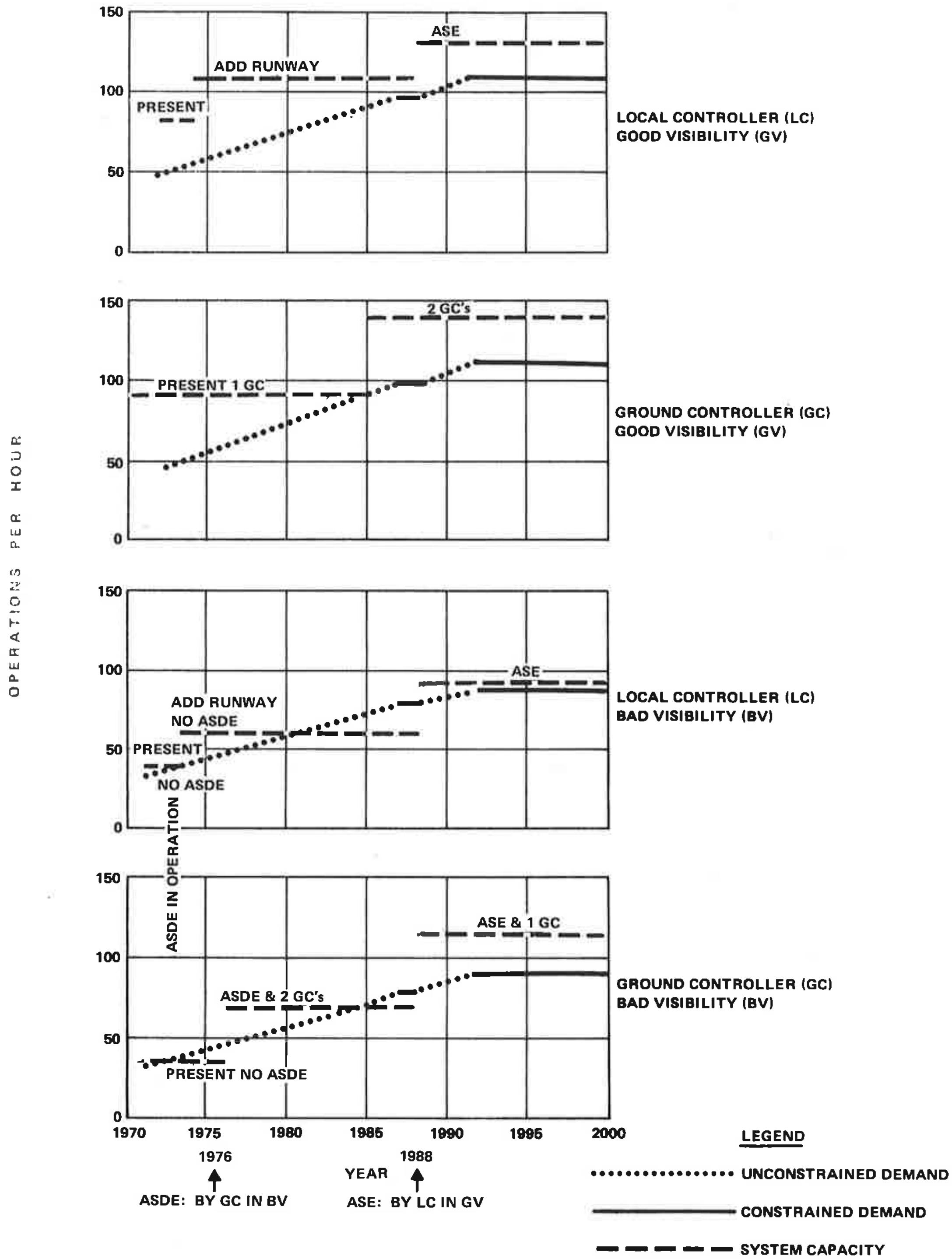


FIGURE 4-25
NEWARK INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

good visibility traffic until about 1985 when a second GC should be added. It is likely, that if an ASE is deployed for the LC in 1988, one GC with an ASE system could handle the traffic.

In bad visibility conditions, the ASDE is justified economically for the GC by 1976. The ASDE is, at present, providing benefits to both controllers.

4.12 Philadelphia International Airport

The following summarizes the general operational environment of PHL and presents an ASTC deployment plan.

4.12.1 Present Facilities and Operations

The current and projected layouts of the Philadelphia International Airport are shown in Figure 4-26. The major taxiway bottleneck appears to be the outer taxiway in front of piers B and C due to the closure of the inner taxiway, in front of these piers, to through traffic. This makes the outer segment a single lane two-way traffic segment and results in both increased ground control workload and traffic delays. The projected taxiway reconstruction plans do not appear to resolve this problem. A possible solution to this problem, assuming that the inner taxiway segment will not be reopened, would be to require aircraft arriving on runway 27R to exit at about pier A so that all flow on the outer taxiway is to the east and to require all traffic arriving on 9L to exit east of pier D to make the flow on the outer in a west direction only in this case. The present taxiway system also has a sequencing problem because of single lane taxiways. This problem should be resolved by construction of the new taxiway system which appears to have adequate by-pass capability. Control workload would be reduced by these improvements.

The present runway system, assuming utilization of R17-35 for general aviation and R9-27 for air carriers, has a variable capacity depending on the direction of operation on these runways. For the combination of runways 9 and 17, the runways can be operated almost independently, under VFR conditions, with landings on both runways exiting before reaching the intersection. Departures would have to be phased, however, unless the GA aircraft can be vectored away from 27 prior to reaching the intersection. The capacity of this runway, assuming a 65 to 35 carrier to general aviation mix, should be in the neighborhood of 81 operations per hour in good visibility conditions. The capacity

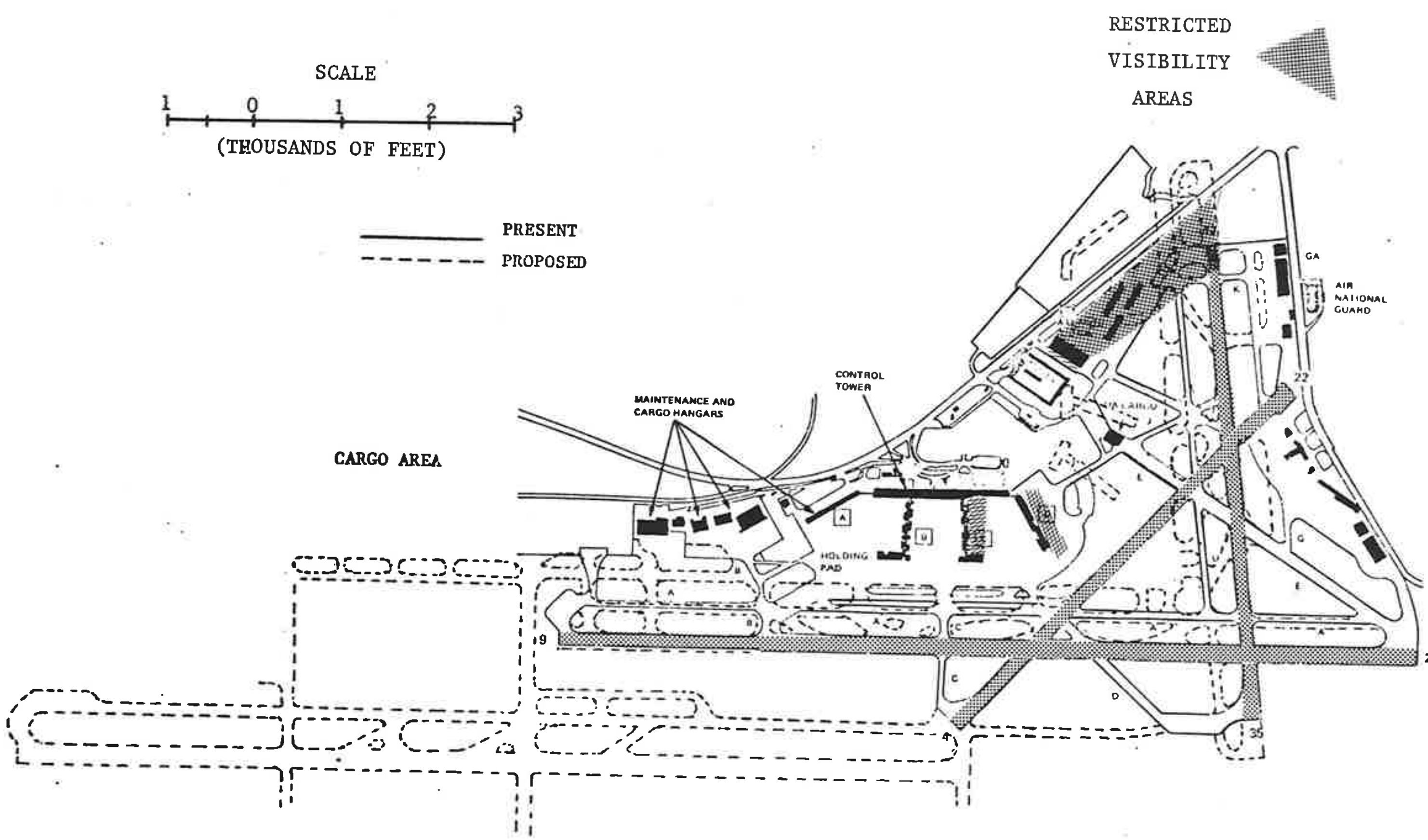


FIGURE 4-26
PHILADELPHIA INTERNATIONAL AIRPORT (PHL)

of the 35-27 pair would be lower due to arrival and departure phasing requirements with the phasing in of general aviation having to be accomplished by the local controller. This will result largely in substitution of general aviation landings for carrier departures with a possible peak capacity of the pair of 65 operations per hour in good visibility conditions. The corresponding capacities in reduced visibility conditions would be 40 oph for both configurations. The GV capacities are at about the level as the peak hour demand.

The present gate complex of 45 converts to an aircraft handling capacity of 72 operations per hour. Consequently, no major gate delays are expected since the gate capacity is also about the same as the present peak hour demand.

4.12.2 Future Facilities and Operations

The projected runway configuration will increase the capacity in the 9-27 direction to 108 peak operations per hour. At the same time the phasing in of general aviation aircraft will become easier and should be accomplished without penalty to carrier departures.

The expansion to 88 gates will provide a capacity of 140 oph which will easily accommodate the constrained demand in the future.

4.12.3 Deployment Time Phasing

The ASTC system deployment time phasing is shown in Figure 4-27. The runway improvements at PHL are required now to meet the growing peak hour demand in good visibility and an ASE system will be justified for the LC in 1981 to meet the demand. For the GC in good visibility, an additional controller will be required in about 1976, but with the deployment of the ASE system, one GC could again handle the projected demand.

For bad visibility conditions, an ASDE can be justified for the GC at the present time. Both controllers will also benefit considerably from the deployment of the ASE system for good visibility conditions.

4.13 Greater Pittsburgh International Airport

The following summarizes the general operational environment of PIT and presents an ASTC deployment plan.

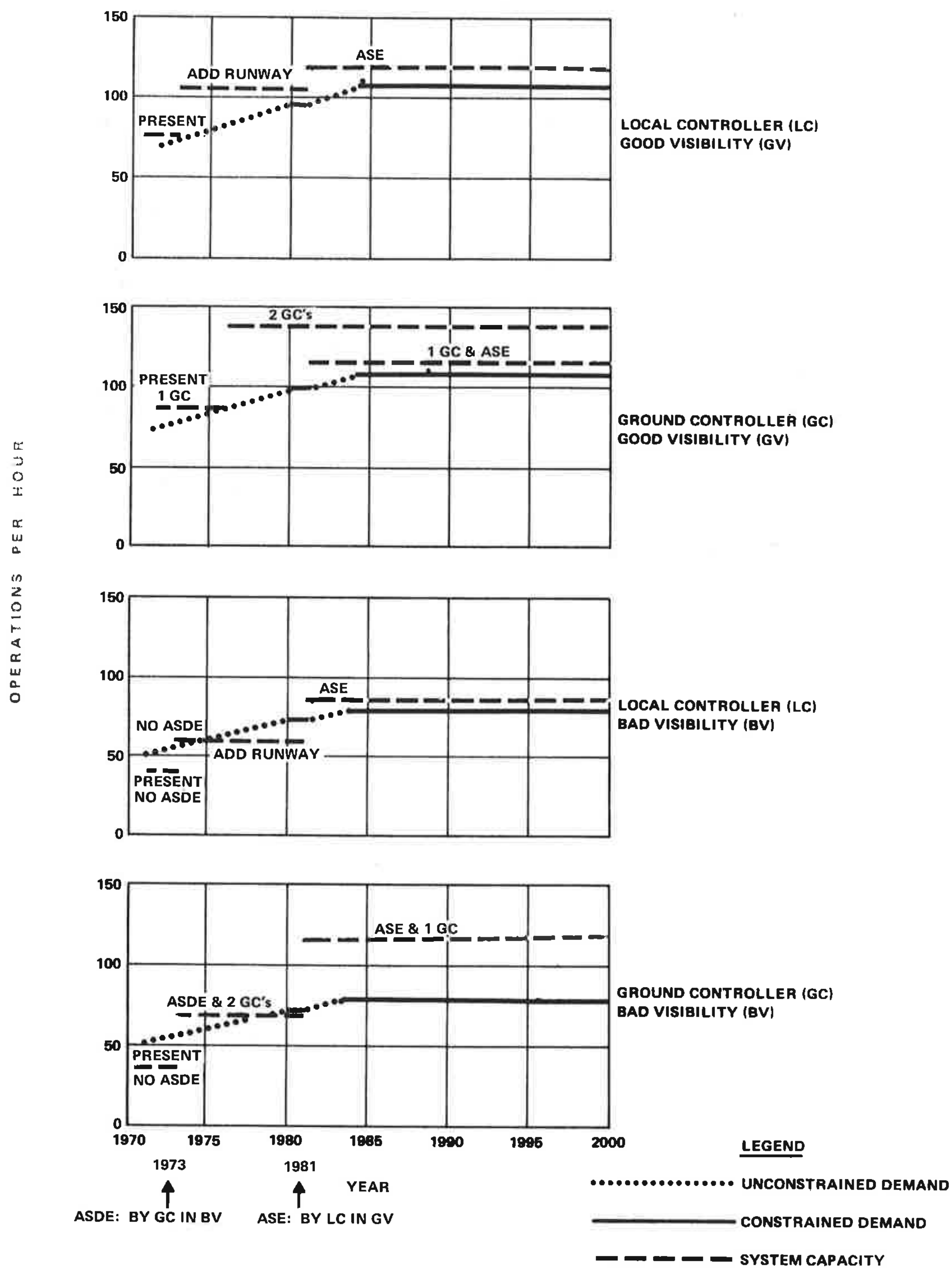


FIGURE 4-27
PHILADELPHIA INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

4.13.1 Present Facilities and Operations

The layout of PIT is shown in Figure 4-28. The air carrier runway pair (28-10) appears to be designed as an independent arrival/departure pair, but not an independent arrival pair, with a one directional flow pattern through the terminal area. The present capacity of this runway pair should be about 108 oph in good visibility conditons in the absence of traffic on the crossing runways, and could be increased in the future. The additional capacity achievable by utilization of the crossing runways, is estimated to be on the order of 15% by reference to operations of 4 crossing runways at the Chicago O'Hare complex where 2 runways were exclusively GA. The total runway capacity would be perhaps as high as 140 operations per hour with reduced ATC separations. The achievement of these capacities in both the 10 and 28 directions would also be subject to improvement of exit taxiways and provision of a full length parallel taxiway to 28R. Also, if mixed arrival/departure operations were allowed on 28R-10L, a dual parallel taxiway to the present N taxiway would be required to achieve the above capacities.

The present gate complex, consisting of 38 gates, should provide a capacity of 61 oph which is considerably below the peak hour demand levels.

4.13.2 Future Facilities and Operations

Runway/taxiway expansion plans for PIT were not available at the time of the survey. However, plans were available to expand the gate complex to about 105 gates for a capacity of 168 oph which would be sufficient to meet the projected peak hour demands.

4.13.3 Deployment Time Phasing

The ASTC deployment time phasing is shown in Figure 4-29. For good visibility operations, the present runway system will constrain the demand by 1976 and accordingly an ASE will be justified for the LC by 1978. Two GC's are presently needed for good visibility operations but when the ASE is deployed one GC will suffice.

In bad visibility operations, an ASDE is presently justified for the GC and will barely suffice to meet the future constrained demand.

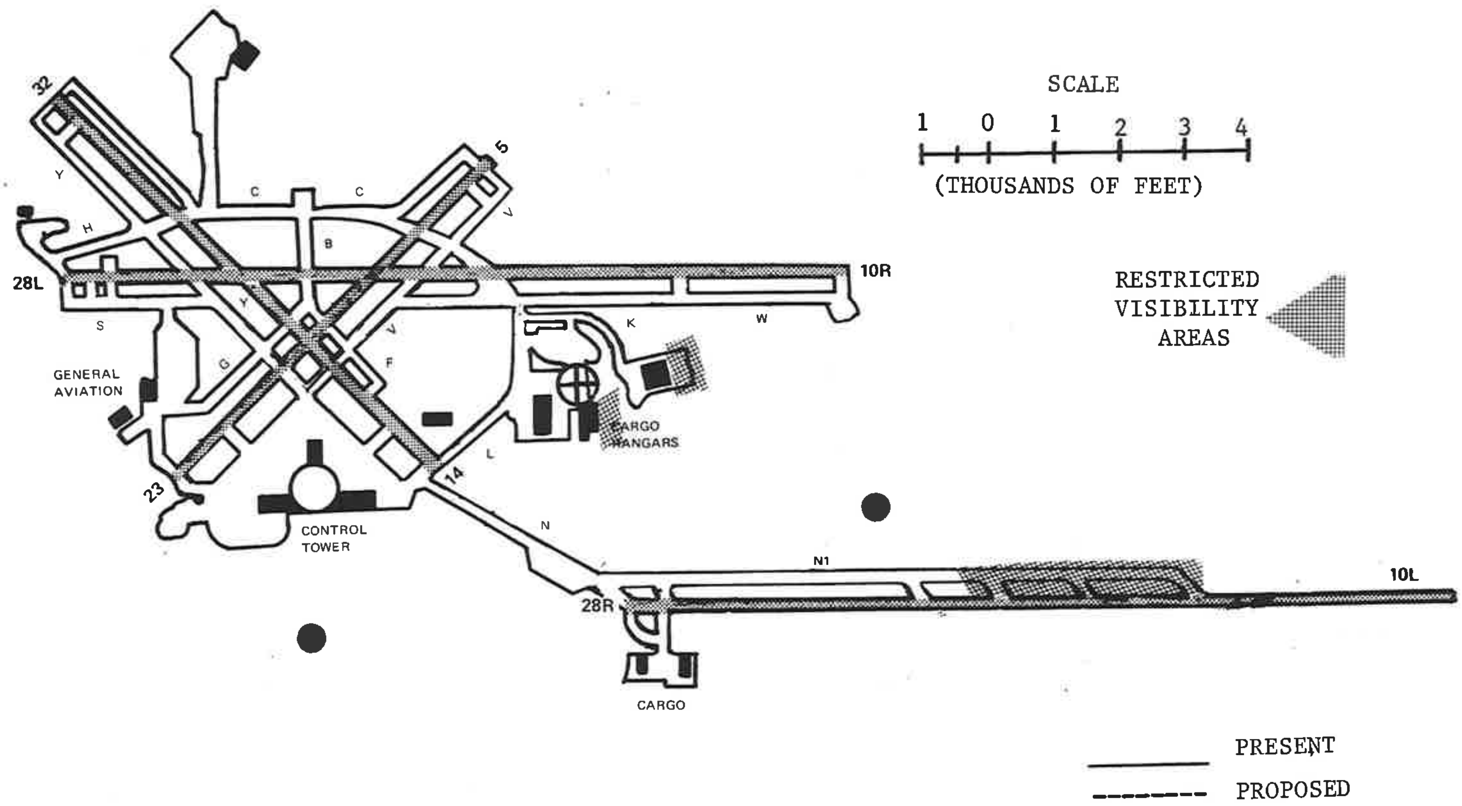


FIGURE 4-28
GREATER PITTSBURGH INTERNATIONAL AIRPORT (PIT)

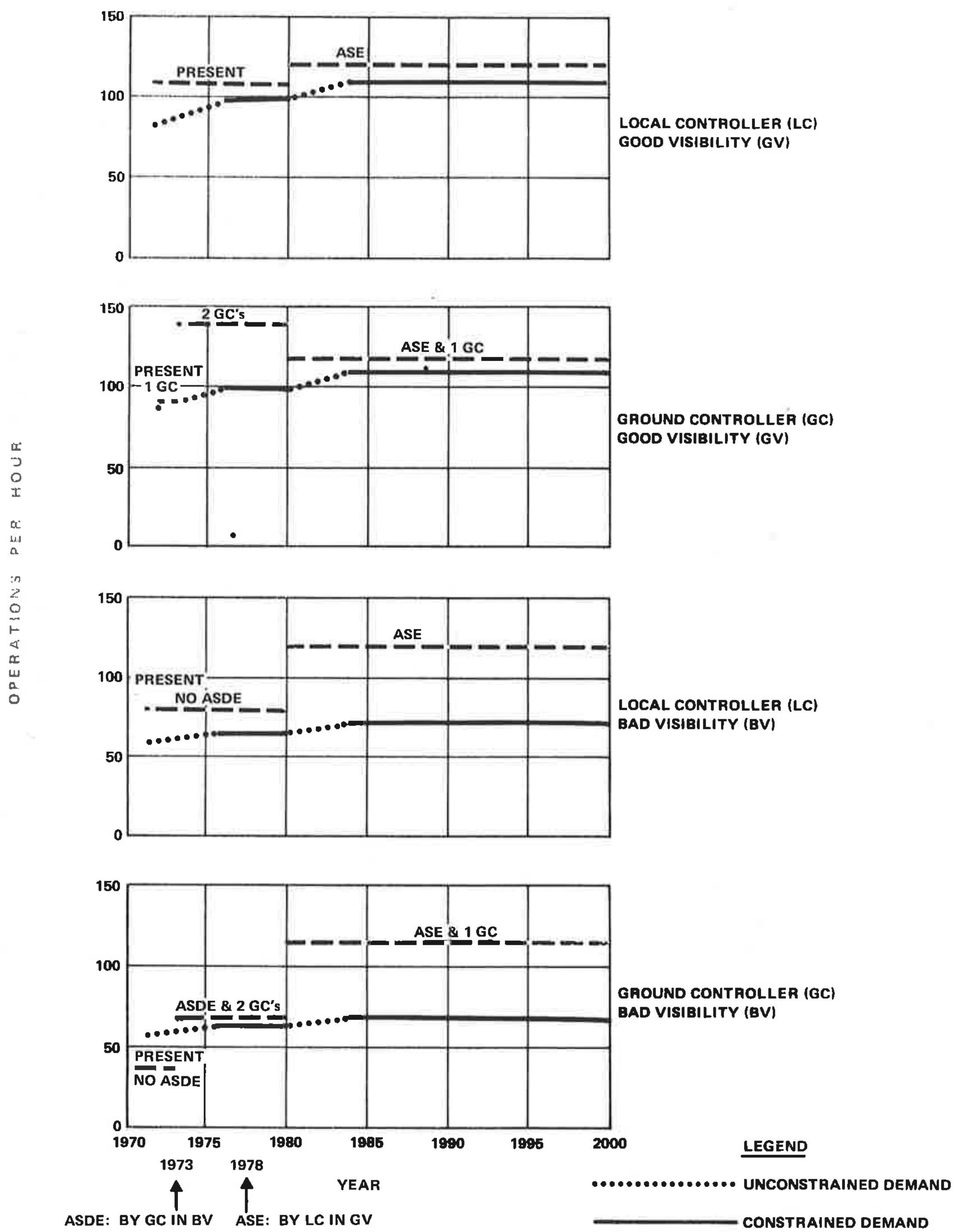


FIGURE 4-29
GREATER PITTSBURGH: ASTC SYSTEMS DEPLOYMENT

4.14 Cleveland-Hopkins International Airport

The following summarizes the general operational environment of CLE and presents an ASTC deployment plan.

4.14.1 Present Facilities and Operations

The CLE runway/taxiway/terminal facility layout is shown in Figure 4-30. The runway system, as operated at the present time, is a single runway system, inasmuch as commercial traffic is concerned, with the main runway being 23L-5R. Additional windrose coverage is given by runways 18R-36L and 10L-28R. The parallels to these runways are occasionally used for commercial landings but are generally dedicated to light GA aircraft. The 23R-5L parallel is too close to be used independently even under VFR conditions when jet traffic is involved. Nominally, the possibility of utilizing crossing runway configurations for commercial traffic appears to exist for the combinations of R5/23, R10/29, and R18, 36. This could increase peak commercial arrival/departure capacity, under favorable wind conditions, to 90-100 operations per hour. However, with the carrier traffic demand at only 45% of the 274,000 yearly operations, single runways for air carrier operations should provide sufficient capacity (estimated at 40 operations/hour) and at the same time provide the needed GA capacity on the parallel runway. The main taxiway problem in the present configuration appears to be the single lane access-egress from and to the general aviation area on taxiways J and R. This will require a solution in terms of additional concrete when the ground controller approaches workload and communication channel saturation.

The present gate complex, consisting of 40 gates, appears to be adequate for the current air carrier peak hour demand of 48 oph with a potential capacity of 64 operations per hour. Since the projected carrier demand increase is only 20% over a 10-year period the planned increase to 58 gates appears to be more than adequate. The possible expansion to 65 gates would appear justifiable only if some of the general aviation demand on runway capacity be replaced by air carrier operations.

4.14.2 Future Facilities and Operations

The projected airport expansions, shown in Figure 4-30, provide for runway extensions in the 18-36 directions to bring the length in this direction to FAA regulation takeoff standards for some of the heavier jets. The construction of a new parallel to 23 will enable the airport to operate the 23 pair independently in VFR conditions. With some exit upgrading the peak operations capacity of the dual lane runways may approach 108 operations per hour.

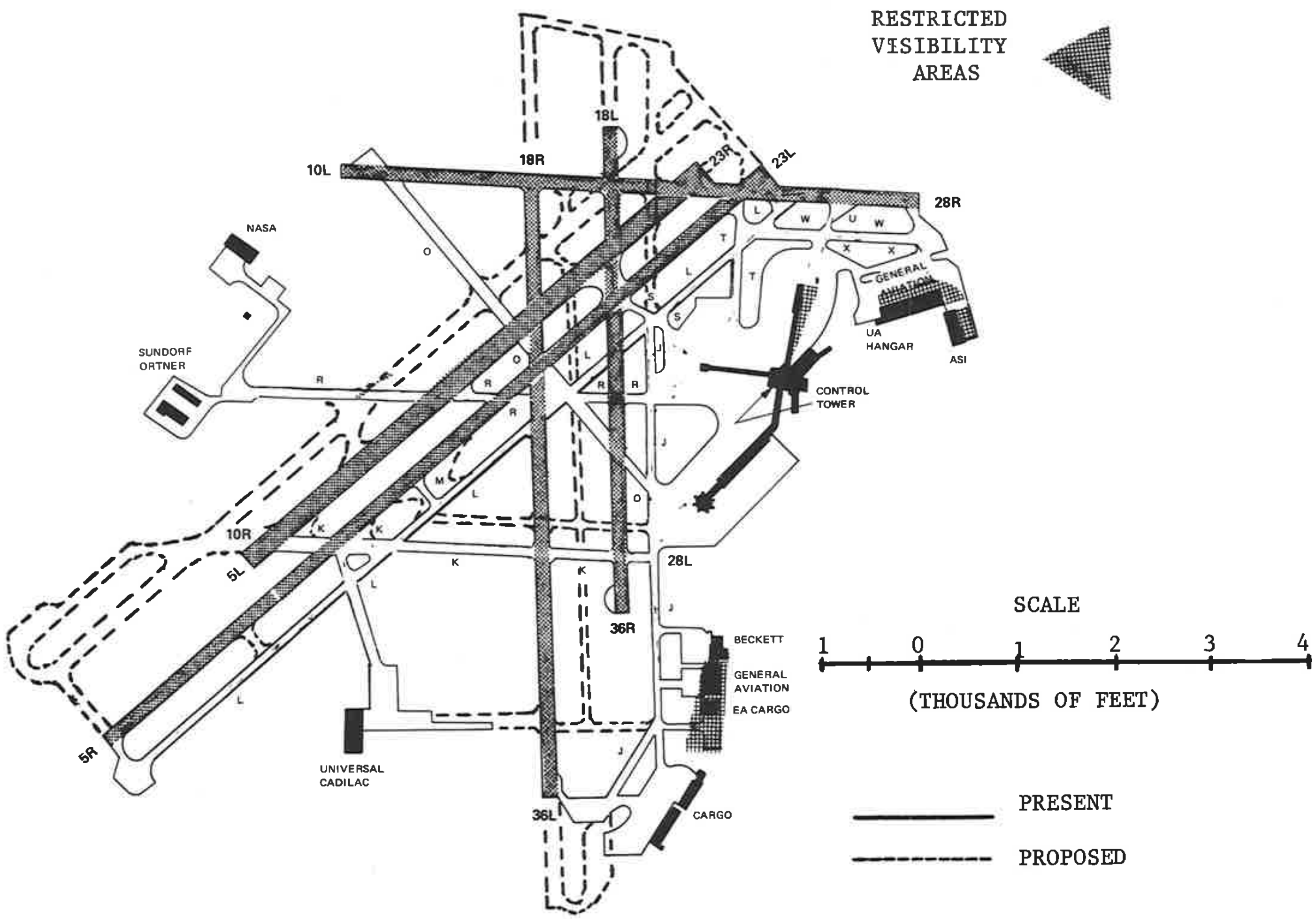


FIGURE 4-30
CLEVELAND-HOPKINS INTERNATIONAL AIRPORT (CLE)

The expansion of the gate complex as described above should be sufficient to meet the projected demand.

4.14.3 Deploymmnt Time Phasing

The ASTC system deployment time phasing is presented in Figure 4-31. For good visibility operations, the expansion of the runway system is needed at the present to meet the peak hour demand. By 1980, the ASE system will be justified to increase the LC/runway capacity, at which time the deployment of ASE can prevent the addition of a second GC.

For bad visibility operations, an ASDE can, at present, be justified for the GC.

4.15 Friendship International Airport

The following summarizes briefly the general operational environment of BAL and presents an ASTC deployment plan.

4.15.1 Present Facilities and Operations

The airport layout of BAL is presented in Figure 4-32. The runway configuration consists of three crossing runways, 4/22, 10/28 and 15/33. The air carrier runways are 10/28 and 15/33 and runway 4/22 is used primarily for GA traffic. Using either air carrier runway and runway 4/22 for GA as a crossing runway, at least a capacity of 81 oph should be attained which can easily meet the present peak hour demand. The taxiway configuration appears to be adequate for the existing traffic.

There are currently 20 gates at BAL for an estimated capacity of 32 oph which is sufficient to meet the present air carrier peak hour demand of 26 oph.

4.15.2 Future Facilities and Operations

As indicated in Figure 4-32, the expansion plans consist of a parallel runway to R15/33 and associated taxiways. Also, additional taxiways parallel to the existing runways are planned. The capacity of the new runway system should be about 108 oph.

The gates are to be expanded to as many as 60 gates for an estimated capacity of 96 oph which should easily handle the air carrier peak hour operations in the future.

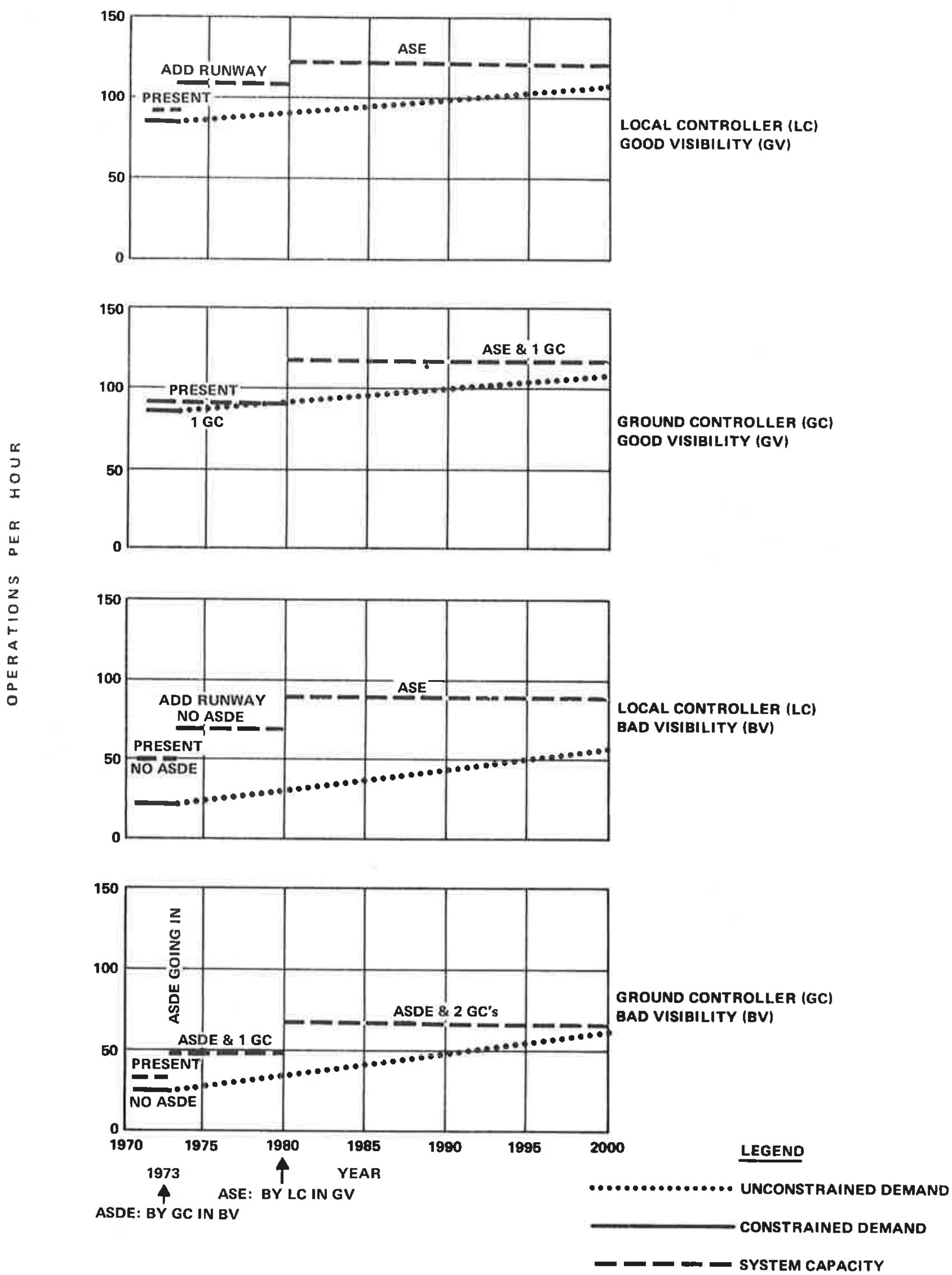


FIGURE 4-31
CLEVELAND-HOPKINS INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

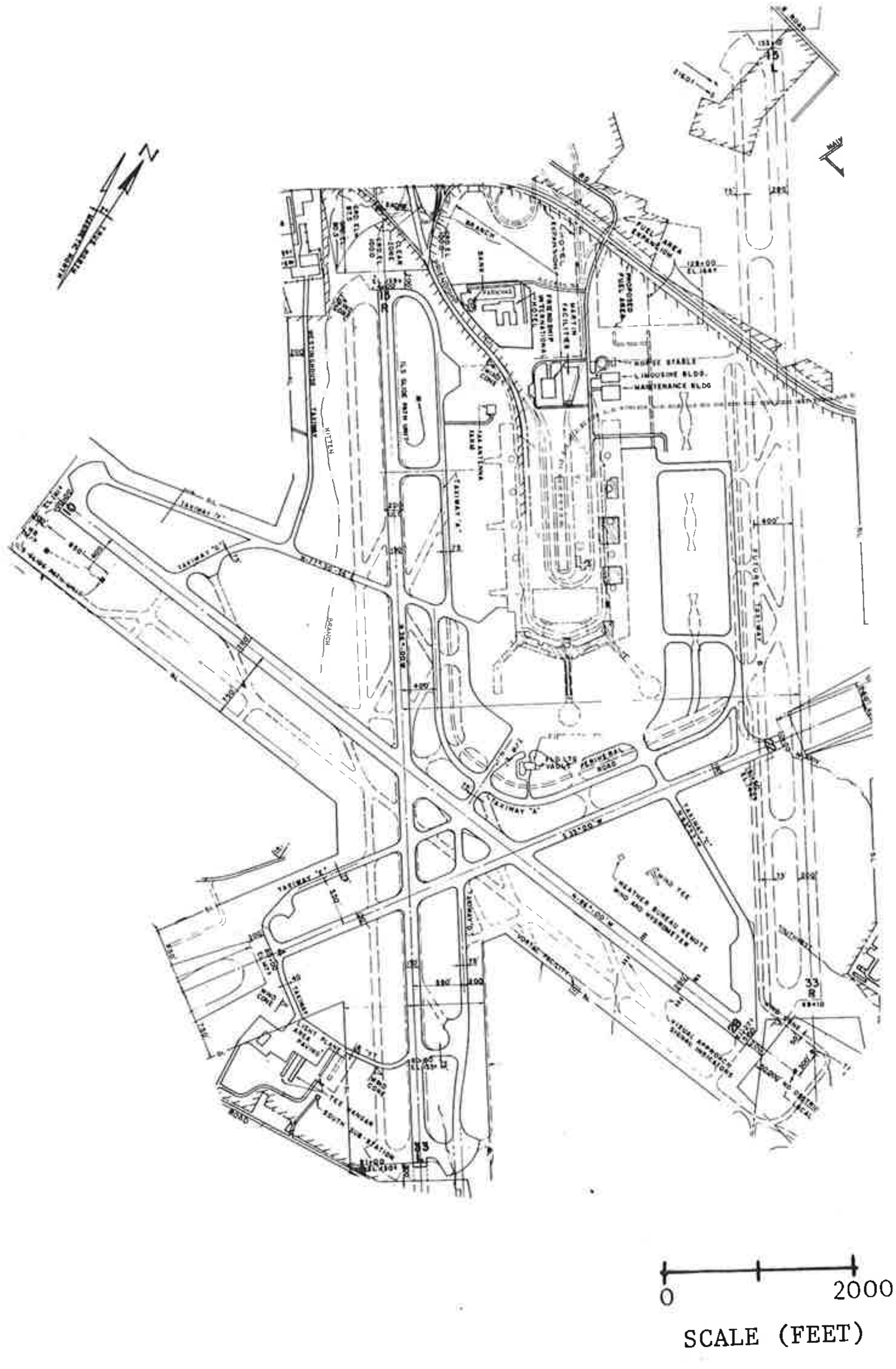


FIGURE 4-32
BALTIMORE-FRIENDSHIP INTERNATIONAL AIRPORT (BAL)

4.15.3 Deployment Time Phasing

The ASTC deployment time phasing is presented in Figure 4-33. For good visibility operations the new runway should be needed by about 1980 and by 1990 an ASE can be justified for the LC. This deployment may prevent the addition of a second GC at about the same time.

For bad visibility operations, an ASDE cannot be justified until 1983, when the GC delays will justify it.

4.16 Seattle-Tacoma International Airport

The following summarizes the general operational environment of SEA and presents an ASTC deployment plan.

4.16.1 Present Facilities and Operations

The Seattle-Tacoma runway/taxiway complex is similar to the south complex of LAX. The airport layout is shown in Figure 4-34. The main runways, 16-24, are analogous, in both layout and usage, to Los Angeles. The general aviation runway, at the westerly part of the airport, is analogous to runway 26 at Los Angeles and is also a VFR-only runway. The traffic density of general aviation aircraft and/or air carriers being towed across the main runway pair should be lower at Seattle-Tacoma than at Los Angeles.

The visual surveillance capability is quite adequate at the present time and should improve with the construction of a new tower. ASDE surveillance provides excellent coverage of the runway/taxiway system with the exception of the taxi areas east of the concourses. Overall, the surveillance capability is significantly better than at the Los Angeles airport. The incidence of CAT II or worse weather is also similar to LAX.

The present gate system consisting of 32 gates, should be capable of supporting 51 operations per hour at an equal arrival/departure mix to support the present peak hour demand of about 31 air carrier oph.

4.16.2 Future Facilities and Operations

Currently, there are no plans for expansion except in the gates, which are to be increased to 62 gates. This should yield a gate capacity of about 100 oph which should easily satisfy the future air carrier demand.

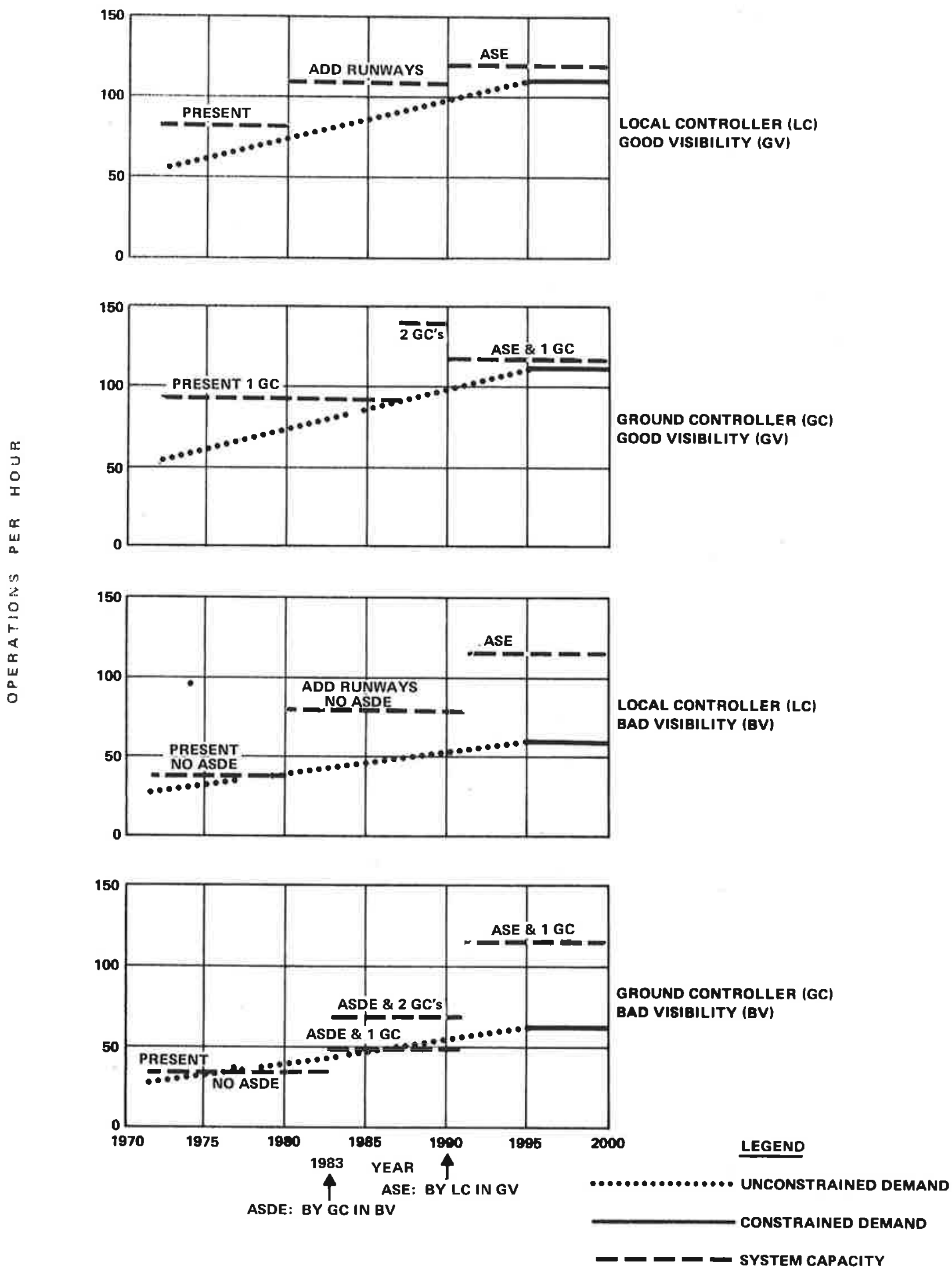


FIGURE 4-33
BALTIMORE-FRIENDSHIP INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

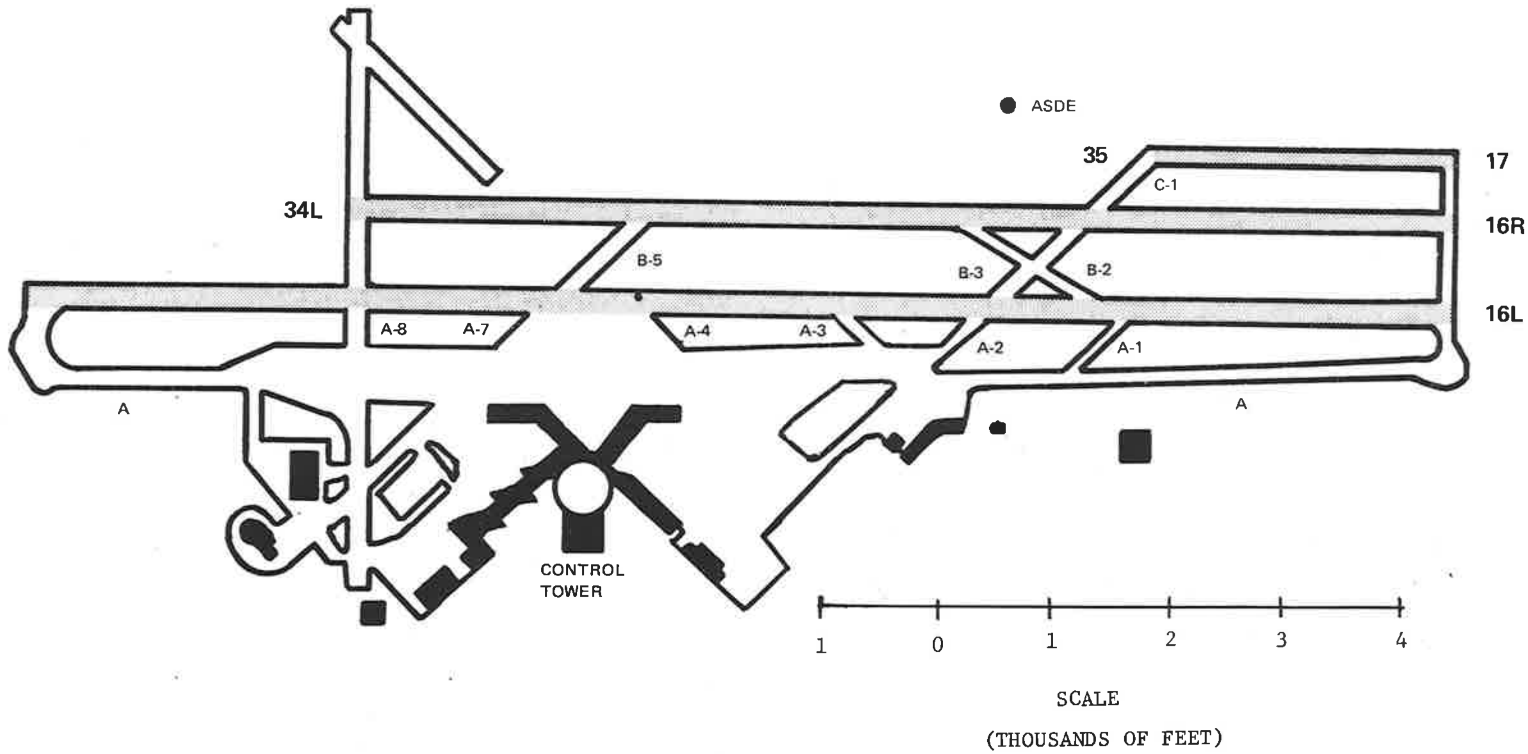


FIGURE 4-34
SEATTLE-TACOMA INT'L AIRPORT (SEA)

4.16.3 Deployment Time Phasing

The ASTC deployment time phasing is shown in Figure 4-35. For good visibility operations, the present runway system should suffice until about 1983 when an ASE system can be justified for the LC.

For bad visibility operations, the ASDE is presently justified for the GC.

4.17 Phoenix Sky Harbor International Airport

The following summarizes briefly the general operational environment of PHX and presents an ASTC deployment plan.

4.17.1 Present Facilities and Operations

The airport layout for PHX is presented in Figure 4-36. Presently, there are two parallel runways, one for air carrier operations and the other for air carrier traffic. The two runways are operated as two separate airports. The runway capacity for air carrier operations is well above the present demand. A GC problem does exist when one runway is under repair, since adequate taxiways do not exist between the two runways. When a strong crosswind condition occurs, they do use one of the two taxiways between the runways for GA operations. They have one LC for each runway and one GC for the whole airport.

Currently, there are 37 gates for an estimated gate capacity of 59 oph, which is well above the air carrier demand.

4.17.2 Future Facilities and Operations

The future expansion of PHX is shown in Figure 4-37. Essentially, a second air carrier runway will be added to provide a set of air carrier dual lane runways for an estimated capacity of 81 air carrier oph.

The gates are to be expanded to 84, which will easily accommodate future demands.

4.17.3 Deployment Time Phasing

The ASTC deployment time phasing is shown in Figure 4-38. Only the air carrier demand is plotted because the air carrier and GA operations are separate. Bad visibility data were not available for PHX. MIA weather data were used in the calculations. Tower personnel stated that bad visibility operations are almost never a problem.

There appears to be no requirement for ASTC system deployments at PHX in the near future, except that the additional runway should be installed before about 1992.

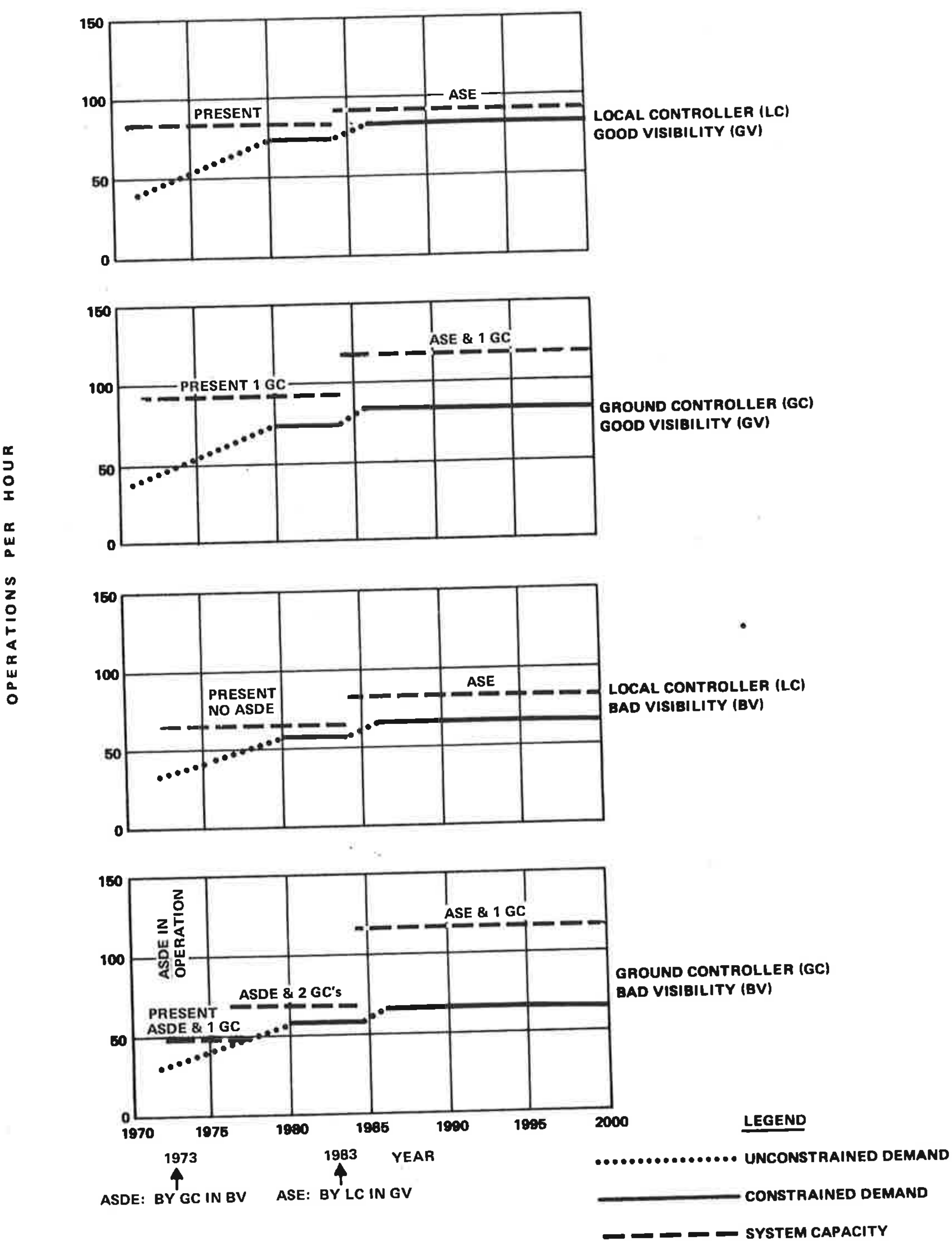


FIGURE 4-35
SEATTLE-TACOMA INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

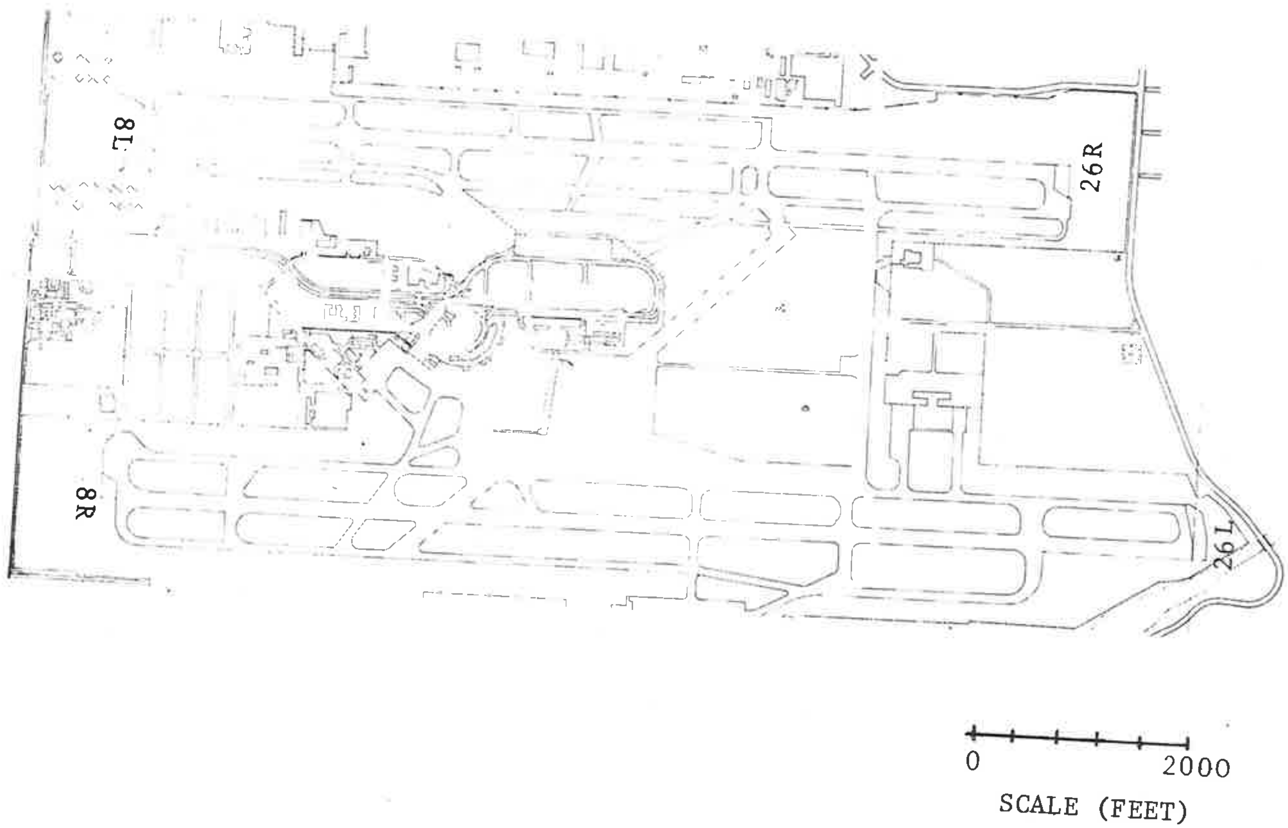


FIGURE 4-36
PHOENIX SKY HARBOR INTERNATIONAL AIRPORT (PHX): 1972 LAYOUT

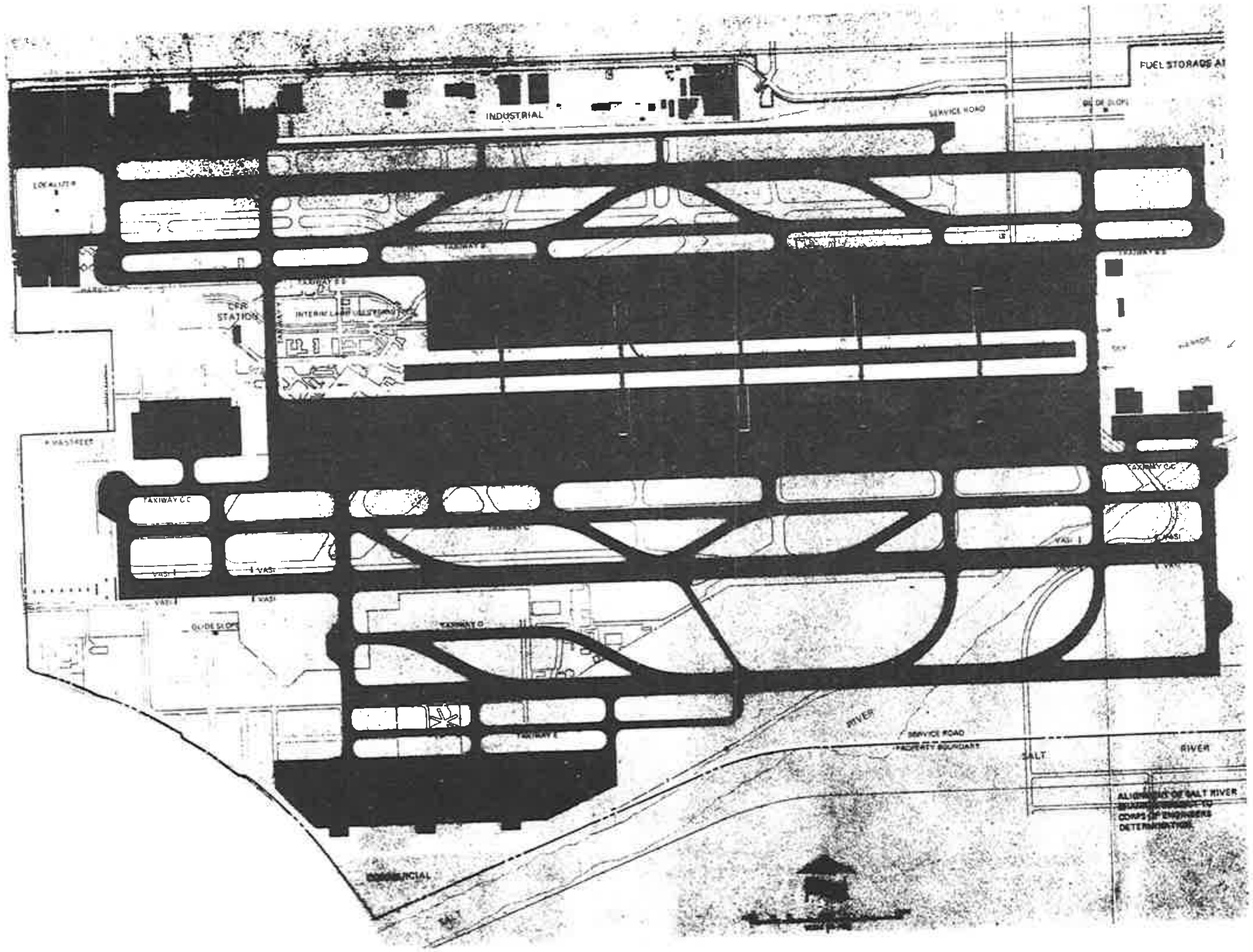
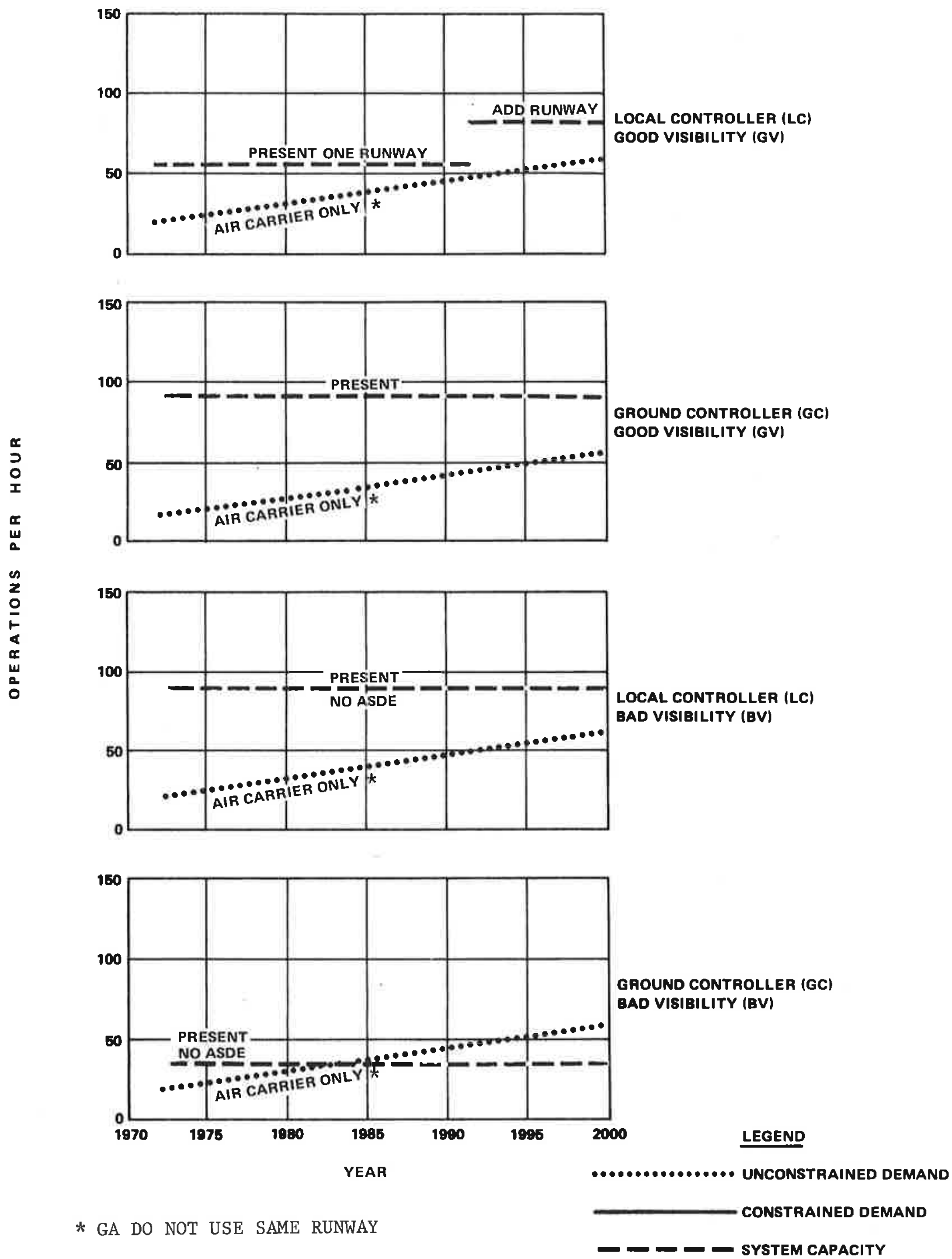


FIGURE 4-37
PHOENIX SKY HARBOR INTERNATIONAL AIRPORT (PHX): FUTURE LAYOUT



* GA DO NOT USE SAME RUNWAY

FIGURE 4-38
PHOENIX SKY HARBOR INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

4.18 Metropolitan Oakland International Airport

The following summarizes briefly the general operational environment of OAK and presents an ASTC deployment plan.

4.18.1 Present Facilities and Operations

The airport layout for OAK is presented in Figure 4-39. As at PHX, the airport operates as two distinct airports, with two separate control towers. Runway 11/29 is for air carrier operations and the other three crossing runways are for GA operations. The two sides of the airport are connected by a single one-lane taxiway for those GA aircraft which infrequently need to use the air carrier runway. The single runway capacity of the air carrier runway is sufficient to handle peak hour air carrier demand for some time to come. The single GC also has a sufficient capacity to handle this same demand.

There are, presently, 10 gates for an estimated capacity of 16 oph to easily handle the air carrier peak hour demand of 11 oph.

4.18.2 Future Facilities and Operations

The projected runway expansions are shown on Figure 4-39. However, neither one of the proposed parallels to R 11/29 are likely since the single runway is sufficient through this century and both additional runways would require fill in the San Francisco Bay.

The gates are to be expanded to as many as 30 gates for a resulting capacity of 48 oph, which will also be sufficient through this century.

4.18.3 Deployment Time Phasing

The ASTC deployment time phasing is shown in Figure 4-40. As at PHX, only the air carrier demand versus capacities are plotted.

There appears to be no requirement for ASTC deployments in the near future.

4.19 Bradley International Airport

The following summarizes the general operational environment of BDL and presents an ASTC deployment plan.

4.19.1 Present Facilities and Operations

The present and future airport layout of BDL is presented in Figure 4-41. Presently there are three intersecting runways.

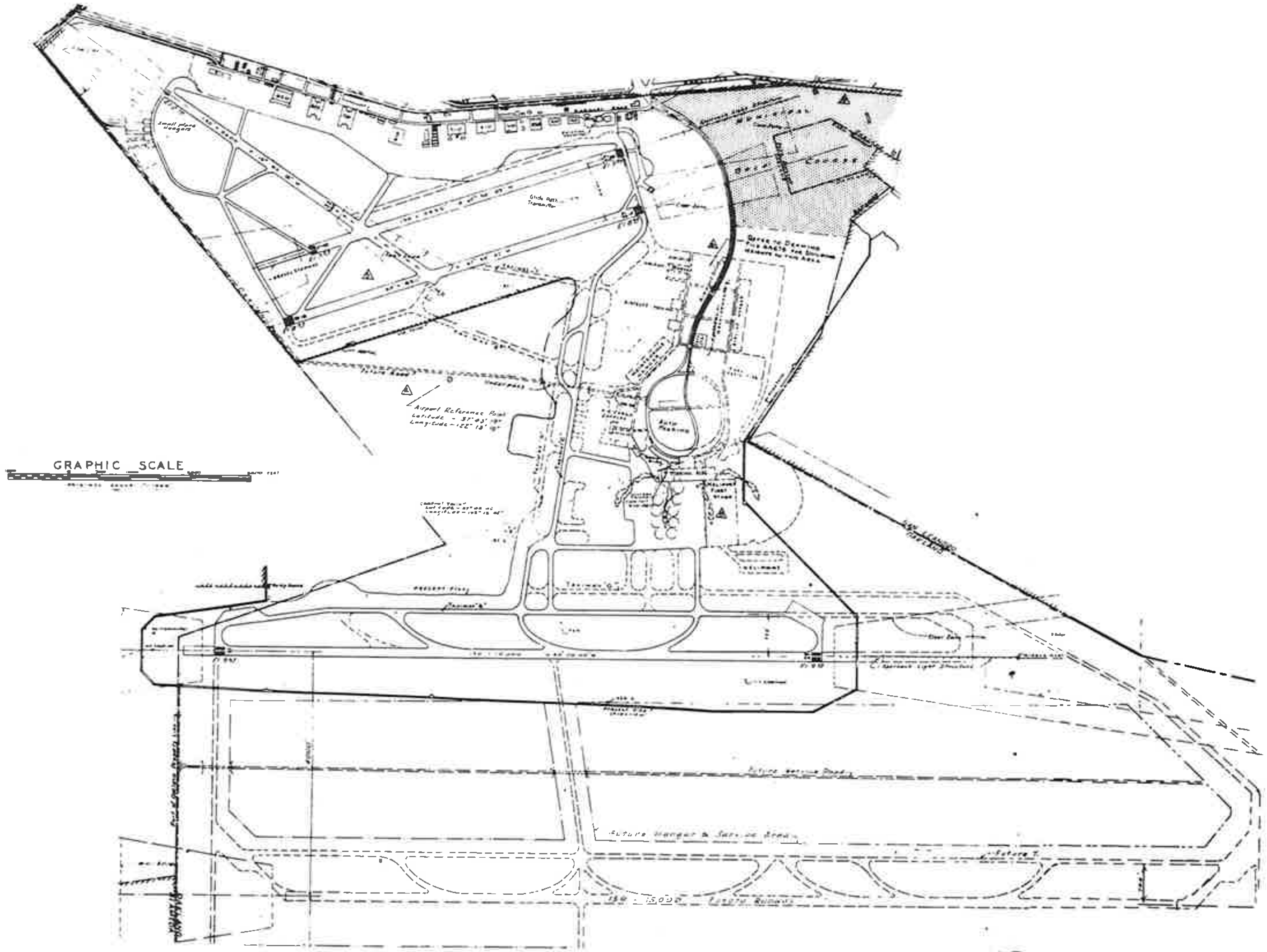
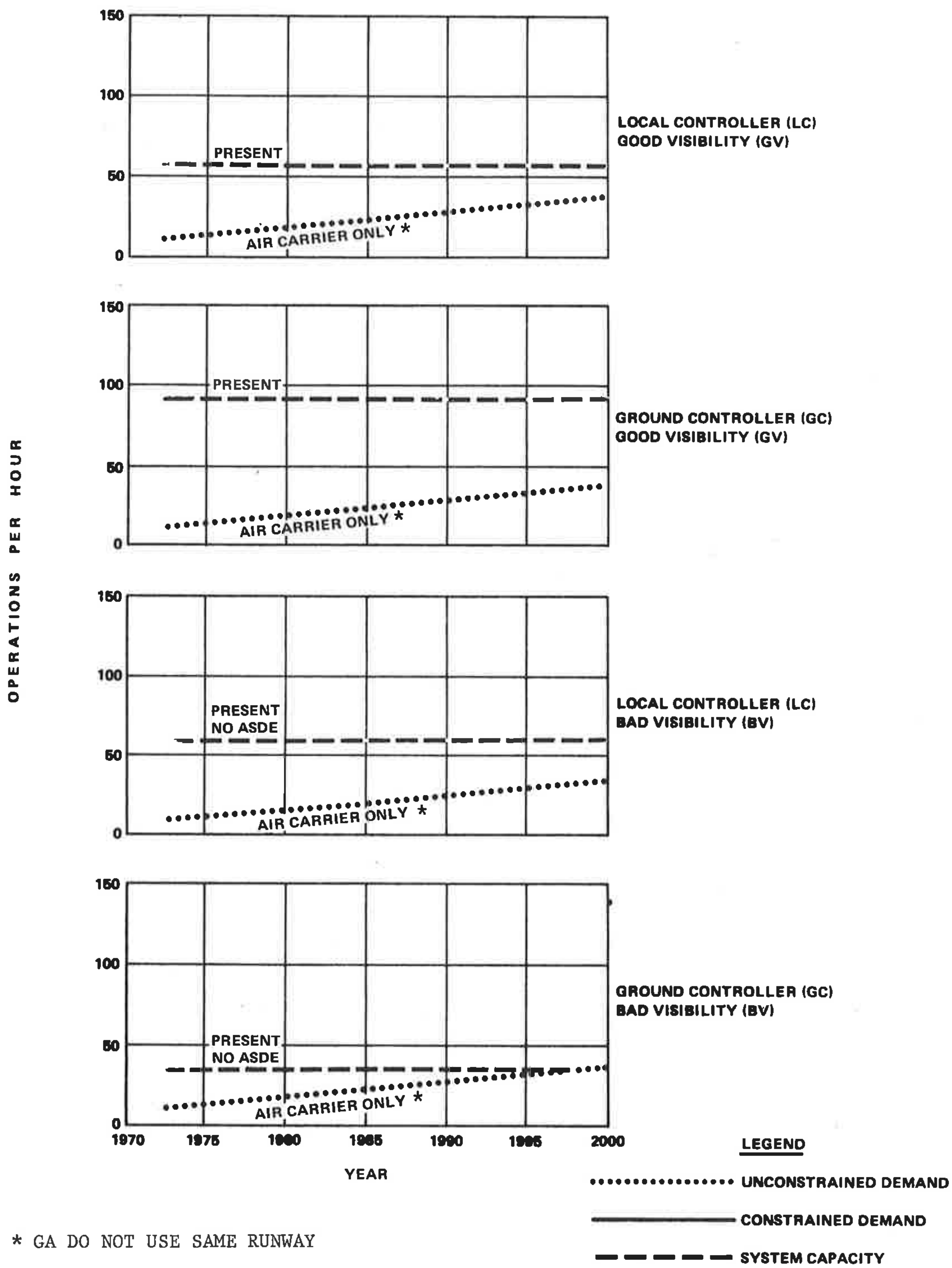


FIGURE 4-39
METROPOLITAN OAKLAND INTERNATIONAL AIRPORT (OAK)



* GA DO NOT USE SAME RUNWAY

FIGURE 4-40
OAKLAND INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

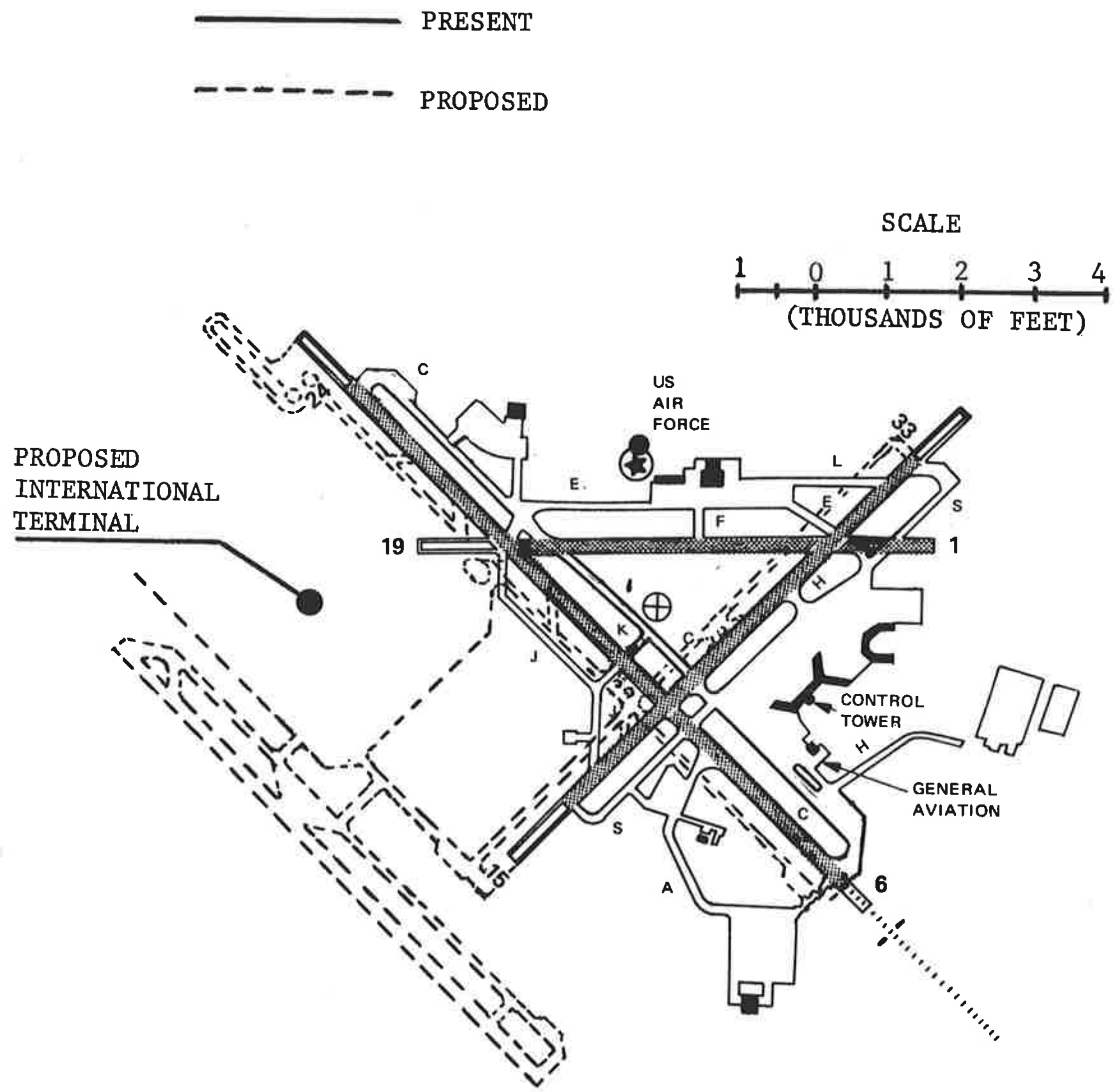


FIGURE 4-41
BRADLEY INTN'L AIRPORT (BDL)

Runways 6/24 and 15/33 are used for air carrier operations and GA operations occur on any of the three runways. The demand is about evenly split between air carrier and GA operations. Runway 1/19 is often used as a taxiway for departures on R24 because when R24 is used for arrivals and departures, the parallel taxiway from taxiway K into the terminal area must be used for arrivals. Any of the runway configurations can easily handle the air carrier demand.

The gate complex, presently, consists of 13 gates for an estimated capacity of 21 oph versus the air carrier peak hour demand of 17 oph.

4.19.2 Future Facilities and Operations

The projected runway addition is shown in Figure 4-41. This will increase the LC/runway capacity to about 108 oph in good visibility conditions which will accommodate the air carrier demand for some time to come.

The gates are to be increased to 50 for a capacity of about 80 oph which is well above any projected air carrier demands.

4.19.3 Deployment Time Phasing

The ASTC deployment time phasing is shown in Figure 4-42. It appears that there is little justification for ASTC system deployments until near the turn of the century. An ASDE can be justified by about 1992 for the GC in bad visibility. The deployment of an ASE for good visibility conditions is questionable since the relatively large demand growth is based on GA operations.

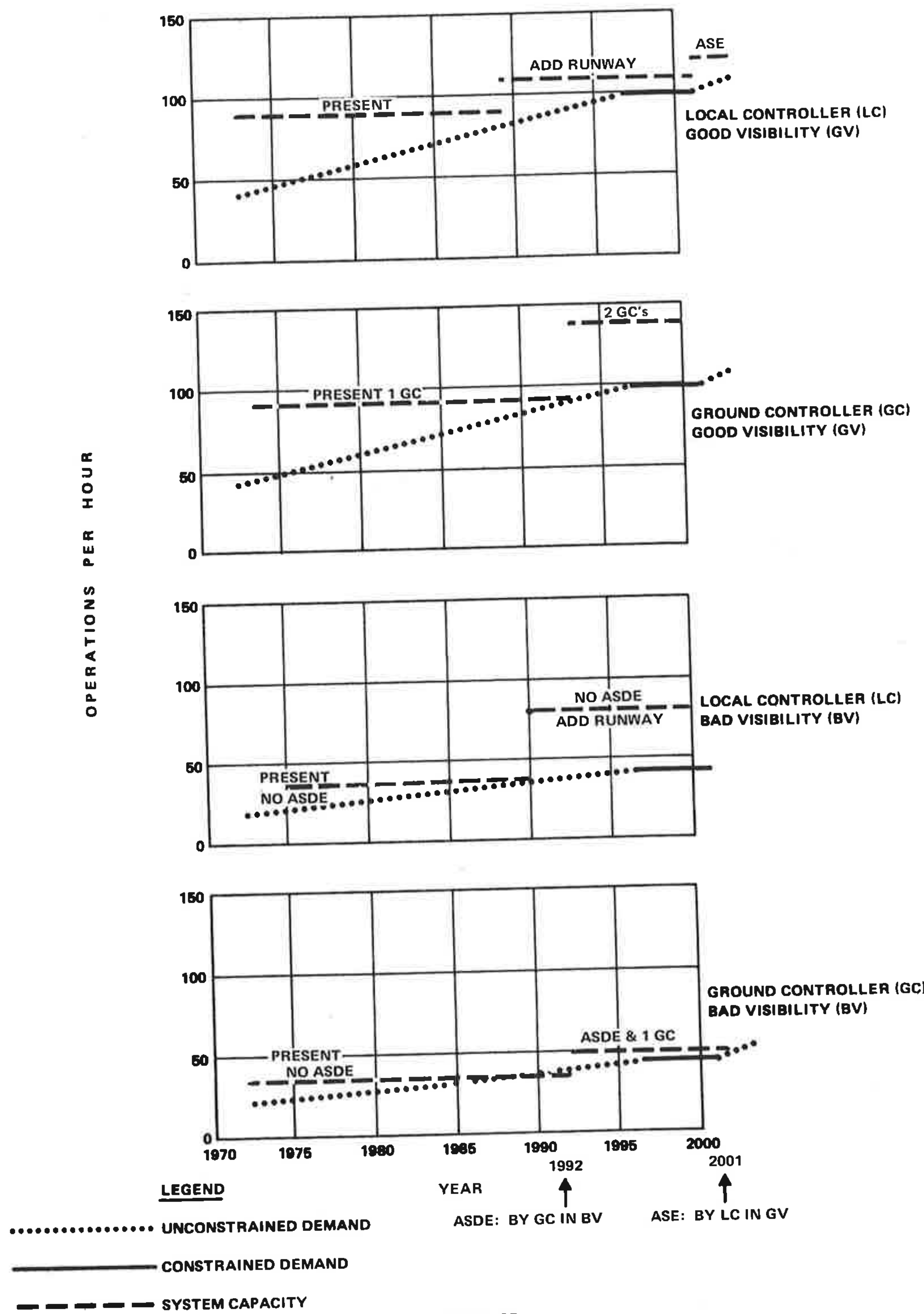


FIGURE 4-42
BRADLEY INTERNATIONAL: ASTC SYSTEMS DEPLOYMENT

5. DEPLOYMENT SUMMARY

A summary of the deployment time phasing charts from Section 4 is presented in Table 5-1. The assumptions made are as follows:

1. Category II and IIIa operations are assumed to exist at all 19 airports now. Thus some of the airports which show a current need for ASDE will not actually need an ASDE until the late 1970's. This assumption was made to simplify the computations and is considered valid since new ASDE deployment is not scheduled until the late 1970's, (Reference 2).

2. Metering and spacing to provide precisely managed arrival spacing is assumed to be installed at the same time as the Advanced Surveillance Equipment. Thus those units required for local control alone will not actually be required until the late 1970's. The rationale for this assumption is similar to Item 1 above.

Table 5-1 does not include deployment of the AIC and STR Systems. Although these alternative were considered, it was determined that they were not required for the following reasons:

1. The ASE provided the greatest payoff of all systems considered and hence was deployed first.

2. Neither the AIC system or STR system provided any improvements to LC operations.

3. Almost all of the airports become runway limited, and the ASE system is the only candidate system that affects the capacity of the LC/runway system.

4. Given that the ASE system is deployed, the airports are still runway limited at a lower level than the estimated capacity of ground control.

This latter reason is a major finding of the deployment analyses. Of the 17 airports that could justify an ASE system, 12 justified it for the LC in good visibility conditions, and given the deployment of ASE for the LC, the GC capacity was sufficient to meet any future demand that is constrained by the LC/runway system. The five airports that could justify an ASE for any of the other controller/ visibility combinations earlier than the LC in good visibility

TABLE 5-1

POTENTIAL ASTC DEPLOYMENTS

AIRPORT	ASDE		ASE	
	DATE	DETERMINING FACTORS*	DATE	DETERMINING FACTORS*
ORD	1973 ¢	GCBV	1973	LCGV,GCGV,GCBV
LAX	1973 ¢	GCBV	1976	GCBV
ATL	1973 ¢	GCBV	1975	GCBV
JFK	1973 ¢	GCBV, LCBV	1982	LCGV
SFO	1973 ¢	GCBV	1978	LCGV
LGA	1973	GCBV	1982	LCGV,GCGV
MIA	-	-	1974	LCGV
DCA	1973	GCBV	1973	LCBV
BOS	1973 !	GCBV	1984	LCGV
DTW	1973	GCBV	1995	LCGV
EWR	1976 ¢	GCBV	1988	LCGV
PHL	1973	GCBV	1981	LCGV
PIT	1973	GCBV	1978	LCGV
CLE	1973 !	GCBV	1980	LCGV
BAL	1983	GCBV	1990	LCGV
SEA	1973 ¢	GCBV	1983	LCGV
PHX	-	-	-	-
OAK	-	-	-	-
BDL	1992	GCBV	2001	LCGV

* DETERMINING FACTORS:

GCGV - Ground Control in Good Visibility
LCGV - Local Control in Good Visibility
GCBV - Ground Control in Bad Visibility
LCBV - Local Control in Bad Visibility
¢ - ASDE Currently Installed and in Operation
! - ASDE Currently Installed but not in Operation

were ORD, LAX, ATL, LGA, and DCA.

By the time the ASE system is available in 1980, it appears that about eight airports can justify the system. If the initial deployment is to all airports which will justify the system prior to 1985, then in 1980-1982, 13 airports will receive the ASE. Of the 19 airports surveyed, the total deployment for the ASE system appears to be 17 through the year 2001.

In the meantime, it is recommended that all the ASDEs currently installed should be used. By the time the new ASDE is available in 1976, it appears that about five airports which do not now have ASDE will warrant it. If the initial deployment is only to those airports which will not get ASE on initial deployment but will justify ASDE prior to 1985 then in 1976-1978, three airports will receive the new ASDE. This also assumes current ASDE replacement. This number is low but this is because of the large ASE deployment. Many more ASDEs are expected to be deployed at smaller airports not considered in this study which will not warrant an ASE prior to 1985.

APPENDIX A

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APPENDIX B

LIST OF ABBREVIATIONS AND ACRONYMS

AC	Air Carrier
ACTE	Automatic Clearance Transmission Equipment
AGSE	Automatic Gate Status Equipment
AIC	Autonomous Intersection Controller
ARO	Airport Reservation Office
ARTS	Automated Radar Terminal System
ASDE	Airport Surface Detection Equipment
ASE	Advanced Surveillance Equipment
ASR	Airport Surveillance Radar
ASTC	Airport Surface Traffic Control
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATL	Atlanta International Airport
BAL	Friendship International Airport
BDL	Bradley International Airport
BOS	Boston-Logan International Airport
BV	Bad Visibility
C_D	Yearly Aircraft Delay Costs
C_m	Cost per minute of aircraft delay
C_s	Yearly System Cost
CAT	Category of Weather
CCTV	Closed Circuit Television
CLE	Cleveland-Hopkins International Airport
D	Minutes of Aircraft Delay
DABS	Discrete Address Beacon System
DAS	Data Acquisition Subsystem
DCA	Washington National Airport
DS	Display Subsystem
DTW	Detroit-Metropolitan Wayne County Airport
EWR	Newark International Airport
FAA	Federal Aviation Administration
FY	Fiscal Year
GA	General Aviation
GC	Ground Controller or Ground Control
GV	Good Visibility

ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
JFK	J. F. Kennedy International Airport
LAX	Los Angeles International Airport
LC	Local Controller or Local Control
LGA	LaGuardia Airport
MIA	Miami International Airport
N	Hourly demand rate in oph
OAK	Metropolitan Oakland International Airport
oph	Operations per hour
ORD	Chicago O'Hare International Airport
P	Performance Capacity in operations per hour
PHL	Philadelphia International Airport
PHX	Phoenix Sky Harbor International Airport
PIT	Greater Pittsburgh International Airport
PS	Processor Subsystem
RWY	Runway
SEA	Seattle-Tacoma International Airport
SFO	San Francisco International Airport
STR	Standard Taxiway Routing
TCA	Terminal Control Area
VFR	Visual Flight Rules
VHF	Very High Frequency
VNY	Van Nuys Airport
Z	Number of busy hours for an airport

APPENDIX C

SAMPLE CALCULATION FOR ASTC DEPLOYMENT ANALYSIS

1. PURPOSE

The sample calculations in this appendix indicate how the inputs on Table 4-1 in the report are used to determine the ASTC deployment time phasing. Atlanta International Airport (ATL) shown in Figure 4-9 in the main body of the study is used for the example.

2. LOCAL CONTROLLER (LC), GOOD VISIBILITY (GV)

The unconstrained demand in peak operations per hour (oph) for the LC in GV is:

$$\phi_{GV} = 84\ (438000 + 30100T)/369000 \qquad \text{(C-1)}$$

where:

a_o = 438000 operations in 1973

a_1 = (739000 - 438000)/10 operations per year

T = years after 1973.

The capacity of the three runways is:

P = 124 oph, LC in GV, no ASE.

The demand is:

d = P/1.1 = 113 oph.

Letting d = ϕ_{GV} in equation (C-1) above, this occurs in:

T = 2 years from 1973 or in 1975.

Hence, 4th runway needed by 1975 which gives:

P = 162 oph, LC in GV, no ASE,

and from (C-1)

T = 7 years from 1973 or in 1980.

ASE will be available in 1980:

P = 180 oph, LC in GV, ASE,

and from (C-1)

T = 9 years from 1973 or in 1982.

In 1982 the demand curve is constrained and the peak demand, d, is 164 oph for the LC, runway capacity in GV.

The above provides the baseline plot of the unconstrained/constrained peak oph demand lines.

Figure C-1 is a plot of air carrier (AC) oph for ATL in 1973 from Reference 6, and the oph are ranked in descending order of magnitude. Examination of Figure C-1 indicates:

n_o = 2 peaks up through 1982,

Z = 16 hours = Busy hours.

From equations (3-5) with:

a_1 = 30100 oph,

a_2 = 438000 + 30100 T_1, (C-2)

= 708900 GV oph in 1982,

P = 180 oph, then

T_s = 18 years = 1982 + 18 = 2000.

Hence in the year 2000 the demand in each of the 19 busy hours will be 164 oph. The year 1990 is shown on Figure C-1 where equation (3-6) yields n = 10 peaks. The value of AC oph in the 19th hour in 1973 is 31 oph. Replacing 84 by 31 in equation (C-1) and solving gives:

N_2 = 80 oph for year 1990 or T = 17 years,

= 61 oph for 1982,

= 37 oph for 1973.

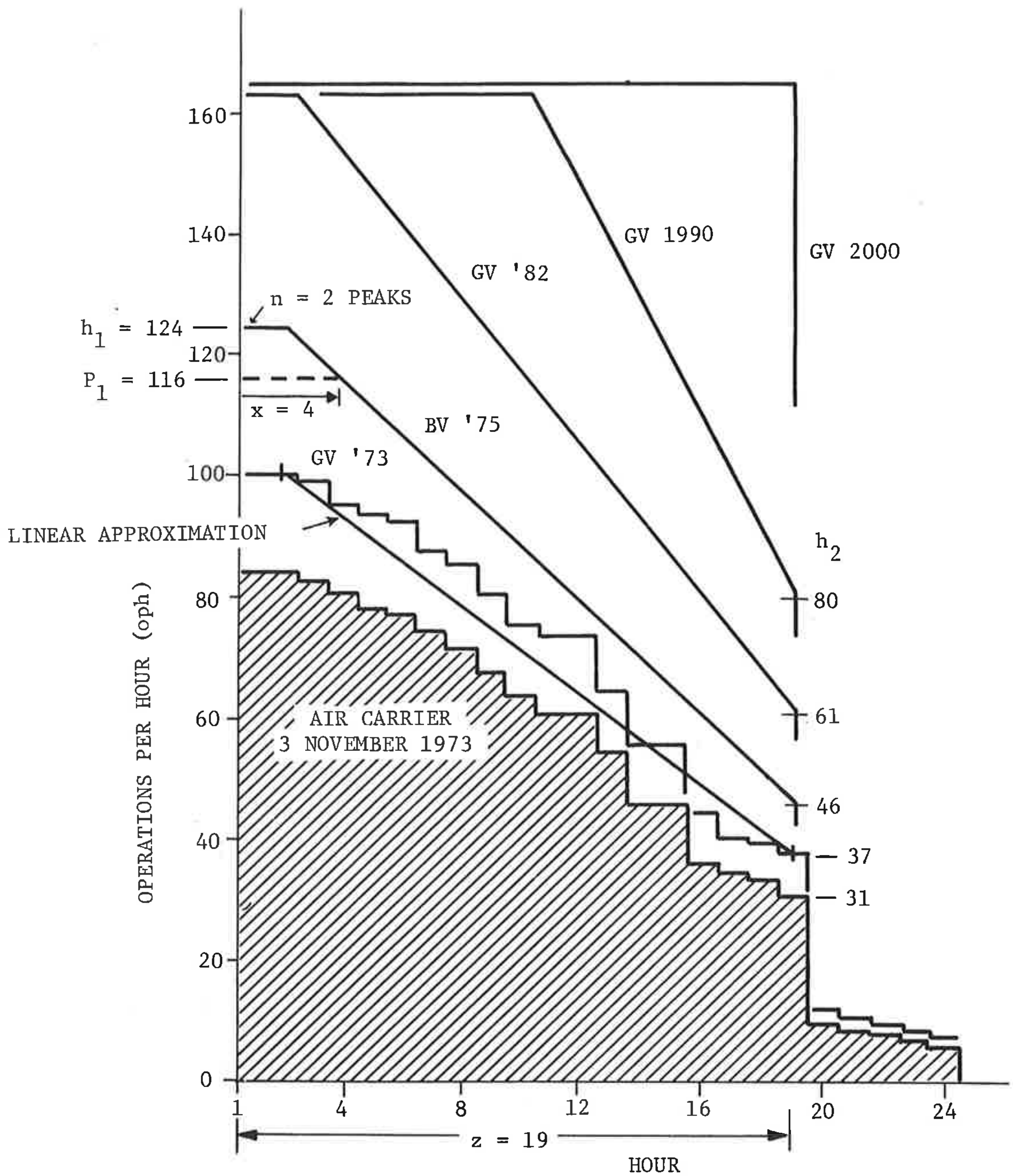

FIGURE C-1
ATLANTA OPERATIONS PER HOUR RANKED BY ORDER OF MAGNITUDE COVERING A 24 HOUR DAY

Check on cost-justification of ASE in 1980 is done by equation (3-3) where:

$$C_s = \$181060 + \$4030r \qquad (C-3)$$

$$= \$229420$$

$r = 12$ receivers,

and

$C_m = \$10/\text{min}$

$d = 164$ oph

$n \geq C_s/(100C_m d) = 1.56 \approx 2$ peak hours.

Hence ASE is justified in 1980 since actual peaks hours equal n from above equation.

3. GROUND CONTROL (GC), GOOD VISIBILITY (GV)

The constrained/unconstrained demand lines for the LC in GV are transferred to the GC in GV presentation in Figure 4-9. The values of P = 130, 138, and 175 oph for the GC on Table 4-1 yield the cut-off lines shown on Figure 4-9.

The P = 138 oph line intersects the unconstrained demand in 1979. However, ASE is not available until 1980. The one year offset is not considered constraining on the demand.

4. LOCAL CONTROL (LC), BAD VISIBILITY (BV)

The unconstrained/constrained demand lines for LC in BV have the same break point as the LC in GV lines which is the year 1982. The unconstrained demand line with only 20% GA operating is:

$$\emptyset_{BV} = 84\ (382800 + 22900\ T)/369000 \qquad (C-4)$$

From Table 4-1 the values of P_1 and P_2 are:

no ASDE and 3 runways $P_1 = 90$, $P_2 = 124$,

no ASDE and 4 runways $P_1 = 116$, $P_2 = 162$,

with ASE and 4 runways $P_1 = P_2 = 180$,

$f = 11.3$/year,

$t = 3.0$ hours,

$Z = 19$ hours.

Using the ratio $\emptyset_{BV}/\emptyset_{GV}$ and adjusting Figure C-1 distribution lines and peaks gives for 1980:

$n = 2$ peaks,

$h_1 = 124$ oph,

$h_2 = 116$ oph.

Then in BV for equation (3-7) in the main part of the study with the appropriate values from above:

$x = 4$ where $P_1 = 116$ line intersects distribution line through h_1 and h_2,

$N_1 = 116 + (124-116)(2+1/2[6-2])/6$,

$19N_2 = (148/124)[2(124)+1/2(19-2)(124+116)]$,

$C_D = \$42743$ per year,

$$C_D \begin{cases} < \text{Cost of ASDE} = \$82000 \\ < \text{Cost of ASE} = \$229420. \end{cases}$$

ASDE & ASE not justified for LC in BV in 1980.

5. GROUND CONTROL (GC), BAD VISIBILITY (BV)

Procedure given in Section 4. above is applied to GC in BV in 1973 and in 1975:

1973

$h_1 = 87$, $h_2 = 32$, $n = 2$, $z = 19$, $N_2 = 72$, $P_2 = 138$

and for $P_1 = 35$ no ASDE, $x = 18$, $N_1 = 64$;

and for $P_1 = 64$ ASDE, $x = 10$, $N_1 = 78$.

No ASDE C_D = \$2052619.

ASDE C_D = 272493.

Annual Difference = \$1780126.

Hence ASDE is certainly justified in 1973.

1975

$h_1 = 98$, $h_2 = 38$, $n = 2$, $z = 19$, $N_2 = 83$, $P_2 = 138$

and for $P_1 = 68$, $x = 10$, $N_1 = 86$ then:

C_D = \$383637 for ASDE and 2 GC's

$> C_s$ for ASE

ASE is justified in 1975.