FTA RUNWAY CAPACITY MODEL (RUNCAP) AND DELAY SIMULATION (DELAYSIM) ANALYSIS FOR LOGAN AIRPORT

April 1994

System Resources Corporation

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Prepared for
Volpe National Transportation Systems Center
Cambridge, MA

Prepared by
Flight Transportation Associates, Inc
Cambridge, MA

FTA-TM-503-2r1 (Revision)

and
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PREFACE

This document is a revision to FTA-TM-503-2r1. Revisions to the text of the report were accomplished to clarify the methods and weather minima used for visual operations at Logan Airport. No other changes have been made. The simulation input and results have not been altered from the previous version.

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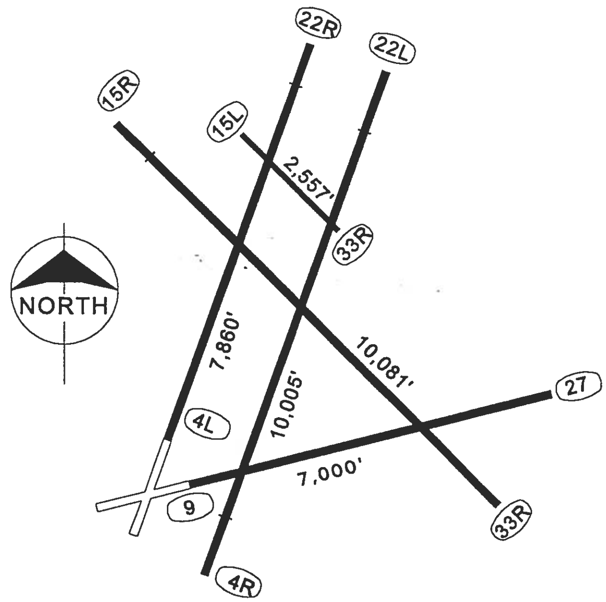

Figure 1 Boston Runway Layout

1. BOSTON LOGAN OPERATIONS

Figure 1 depicts the existing runway layout at Boston Logan International Airport. The centerline separation between Runways 4L and 4R is 1,500 feet. The manner in which the runways are used is dependent upon several factors including: weather, traffic demand, compliance with noise abatement procedures, and the type of aircraft operation (jet versus propeller). For the Enhanced Preferential Runway Advisory System (PRAS), FTA has compiled a series of runway configurations which include the mix of jets and props and the assignment of aircraft to runways. For this investigation, a configuration consisting of runways 4L, 4R, and 9 was selected.

1.1 RUNWAY USE

When wind conditions and traffic demand favor the use a 4L, 4R, and 9 runway configuration, the division of arriving aircraft between runways 4L and 4R is based primarily on ceiling and visibility. Two weather categories and their associated runway assigments were chosen for purposes of comparison; Basic VFR and Category I. In Basic VFR conditions, the cloud ceiling is at least 1,000 feet above the ground and the average sector visibility at the airport is at least 3 miles. Under Category I conditions, the ceiling and visibility are less than 1,000 feet and 3 miles, but not less than 200 feet and 1/2 mile. Table 1 shows the typical runway assignments based on these weather conditions.

TABLE 1
LOGAN AIRPORT RUNWAY ASSIGNMENTS (4L, 4R & 9)

Basic VFR Conditions					Category I Conditions				
% of Ops	4L	4R	9	Total	% of Ops	4L	4R	9	Total
Arr-Jet	0	100	0	100	Arr-Jet	0	100	0	100
Arr-Prop	50	50	0	100	Arr-Prop	0	100	0	100
Dep-Jet	0	24	76	100	Dep-Jet	0	24	76	100
Dep-Prop	50	5	45	100	Dep-Prop	50	5	45	100
For both cases above, the current mix of jets to props is 57% to 43%									

Jet departures are not permitted to routinely operate on Runway 4L due to local noise abatement policies. Jet arrivals are rarely assigned to Runway 4L since there is no ILS. Otherwise runways 4R and 4L are used in a mixed mode of operation (for both arrivals and departures). Runway 9 is used strictly as a departure runway. The differences in Table 1 are due to the assignment of arriving aircraft to Runway 4L. During Basic VFR conditions, visual separation is used and aircraft on final to Runway 4R are "side stepped" for a visual approach to Runway 4L. Under Category I conditions, all aircraft are assigned Runway 4R for arrival since 4L is not equipped with an instrument landing system (ILS). Even under Category I conditions, some visual operations may be assumed to occur. For example, aircraft may circle from the 4R ILS to land on 4L (minima 800 and 1) or visual separation may be used.

1.2 AIRCRAFT FLEET MIX

Based on data obtained from the May issue of the *Official Airline Guide*, the weight classes of current operations at Logan can be broken into the following: Heavy 7.1%, B-757 (L7) 5.1%, Large 68.8%, and Small 19%. The results of applying these figures to the jet/prop mix of 57% to 43%, and to the runway assignment percentages are shown in Table 2.

TABLE 2
CURRENT LOGAN AIRPORT RUNWAY ASSIGNMENTS (4L,4R & 9)

Basic VFR Conditions				Category I Conditions			
% of Ops	4L	4R	9	% of Ops	4L	4R	9
Arr-H	0.00	7.10	0.00	Arr-H	0.00	7.10	0.00
Arr-L7	0.00	5.10	0.00	Arr-L7	0.00	5.10	0.00
Arr-L	12.00	56.80	0.00	Arr-L	0.00	68.80	0.00
Arr-S	9.50	9.50	0.00	Arr-S	0.00	19.00	0.00
Total Arr			100.00	Total Arr			100.00
Dep-H	0.00	1.70	5.40	Dep-H	0.00	1.70	5.40
Dep-L7	0.00	1.22	3.88	Dep-L7	0.00	1.22	3.88
Dep-L	12.00	11.95	44.85	Dep-L	12.00	11.95	44.85
Dep-S	9.50	0.95	8.55	Dep-S	9.50	0.95	8.55
Total Dep			100.00	Total Dep			100.00

1.3 SEPARATION STANDARDS

Under IFR conditions, separation standards consist of time and radar miles. For this analysis, only IFR separation standards have been used. Tables 3 through 5 illustrate the IFR standards in use at Logan Airport. Due to the distance of 1,500 feet between Runways 4L/R, they are treated as a single runway for wake vortex separation.

Table 3
Existing IFR Radar Arrival-Arrival Separations (Nautical Miles)

Weight Class and Runway Assignment for **Lead** A/C	Weight Class and Runway Assignment for **Trailing** A/C									
	H-4L	L7-4L	L-4L	S-4L	H-4R	L7-4R	L-4R	S-4R	H-9	NH-9
H-4L	4.0	5.0	5.0	6.0	4.0	5.0	5.0	6.0	No Arrivals to Runway 9	
L7-4L	3.0	3.0	3.0	4.0	3.0	3.0	3.0	4.0		
L-4L	2.5	2.5	2.5	4.0	2.5	2.5	2.5	4.0		
S-4L	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5		
H-4R	4.0	5.0	5.0	6.0	4.0	5.0	5.0	6.0		
L7-4R	3.0	3.0	3.0	4.0	3.0	3.0	3.0	4.0		
L-4R	2.5	2.5	2.5	4.0	2.5	2.5	2.5	4.0		
S-4R	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5		
H-9	No Arrivals to Runway 9 NH = Non-Heavy									
NH-9										

Table 4
Existing IFR Departure-Departure Separations (Seconds)

Weight Class and Runway Assignment for **Lead** A/C	Weight Class and Runway Assignment for **Trailing** A/C									
	H-4L	L7-4L	L-4L	S-4L	H-4R	L7-4R	L-4R	S-4R	H-9	NH-9
H-4L	120	120	120	120	120	120	120	120	0	0
L7-4L	60	60	60	60	60	60	60	60	0	0
L-4L	60	60	60	60	60	60	60	60	0	0
S-4L	60	60	60	60	60	60	60	60	0	0
H-4R	120	120	120	120	120	120	120	120	30	30
L7-4R	60	60	60	60	60	60	60	60	30	30
L-4R	60	60	60	60	60	60	60	60	30	30
S-4R	60	60	60	60	60	60	60	60	30	30
H-9	0	0	0	0	30	30	30	30	120	120
NH-9	0	0	0	0	30	30	30	30	60	60

30 sec. given for departures to cross Runway 4R/9 intersection

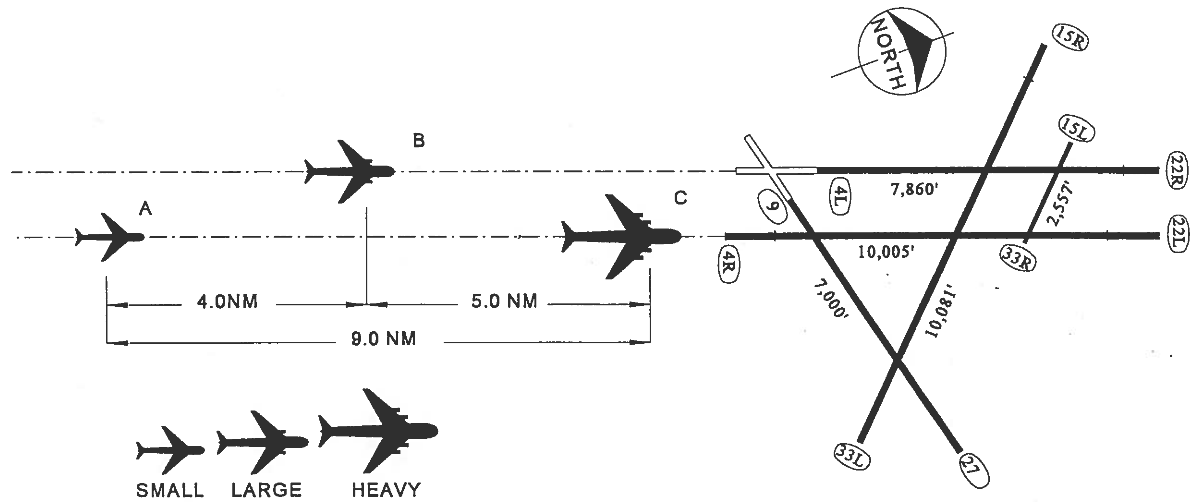

Figure 2 Current Situation - No Diagonal Separation Applied

Currently, IFR separation is applied as shown in Figure 2. Even though aircraft B and C are not on the same final approach course, 5 miles must be maintained between them. Between A and B, 4 miles is required which results in a total of 9 miles between aircraft A and C.

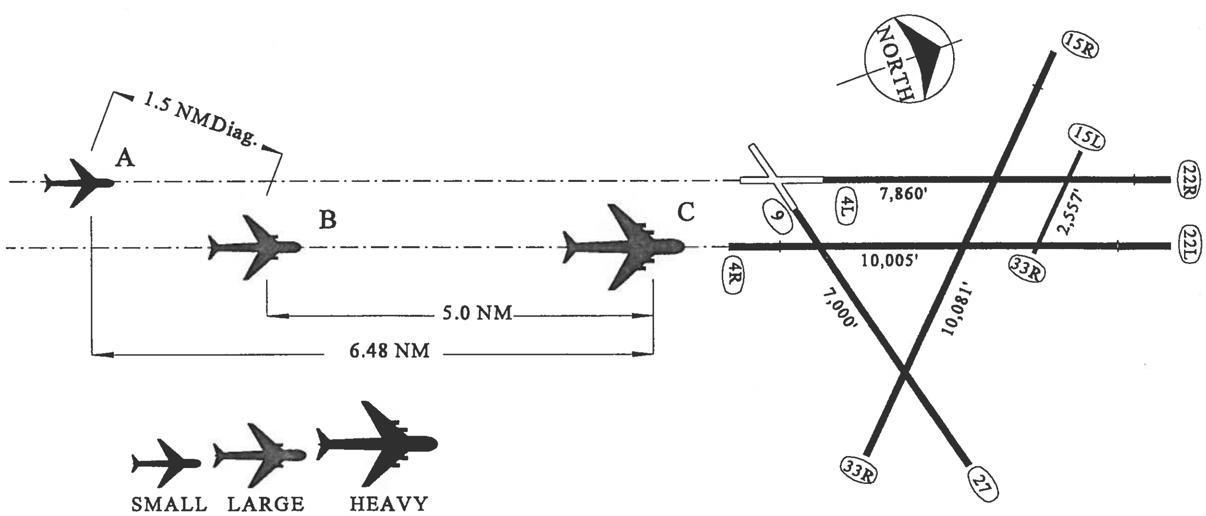

Figure 3 1.5 Mile Diagonal Separation Applied Only Between Large and Small Aircraft

In Figure 3, 1.5 miles diagonal separation is applied between Large and Small aircraft only. Aircraft A (Small) is separated from aircraft B by 1.5 miles, and aircraft B (Large) must remain 5 miles behind C (Heavy). This results in 6.48 miles between A and C. The assumption has been made that 1.5 miles separation may only be used when enough of a crosswind exists to prevent wing-tip vortices created by arrivals to Runway 4R from affecting arrivals to Runway 4L. This means that, under such conditions, 1.5 miles could not be used between a 4L arrival and a subsequent 4R arrival of a smaller weight class.

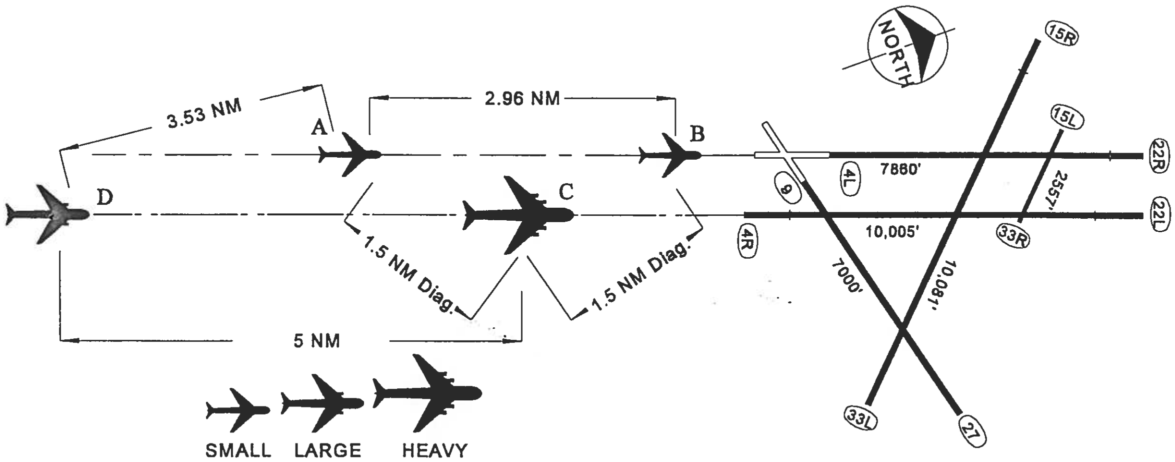

Figure 4 1.5 Mile Diagonal Separation Applied to All Weight Classes

In Figure 4, separation is being applied between aircraft A, C, and B. This results in 2.96 (3) miles between aircraft A and B. Separation is also applied between aircraft C and D, resulting in 3.5 miles diagonal spacing between aircraft A and D. The same assumption concerning the crosswind component exists for this scenario. Care must be taken to apply the correct separation standard. As can be seen in the figure, 1.5 miles diagonal separation applied between aircraft A and D, results in insufficient separation between C and D. Diagonal separation may never be less than 1.5 miles, and in-trail separation must comply with minimum wake vortex standards (either 3, 4, 5 or 6 miles).

3. RUNCAP ANALYSIS

Each of the three scenarios (current separations, 1.5 miles between Large and Small, and 1.5 miles between all classes) was initially created to reflect the current Logan fleet mix. These were then altered to reflect an increase in the percentage of Heavy aircraft and in the percentage of jet traffic. A fleet mix consisting of 15 percent Heavy aircraft and 65 percent jet operations was analyzed along with a fleet of 35 percent Heavies and 75 percent jets. Variations of each of the RUNCAP scenarios were then created to reflect departure percentages of 40, 50, and 60 percent. In all, 36 distinct scenarios were created.

3.1 BASIC ASSUMPTIONS

Several assumptions were required to define the scenarios. These included:

- An ILS exists on 4L
- A crosswind negates the affect of 4R vortices on 4L arrivals
- Only IFR separation standards are used
- No changes to existing in-trail radar separations were made
- Runways are used as illustrated in Tables 1 and 2
- Jet traffic to/from 4L will continue to be discouraged
- Departure/Arrival separation is unchanged from current standards
- Departure operations on 4L and 4R are dependent
- 30 seconds was allowed for departures to clear the 4R/9 intersection

- Aircraft will maintain similar speeds on final
- Controller workload levels will be decreased through automation

3.2 RUNCAP RESULTS

Tables 6 through 8 present the results of the RUNCAP analysis for the current fleet mix, 15 percent Heavy aircraft and 35 percent heavy aircraft respectively. The figures represent the saturation capacity in hourly operations.

TABLE 6
RUNCAP RESULTS: CURRENT LOGAN AIRPORT AIRCRAFT MIX (7.1% Heavy Aircraft)

PRAS Runway Use	Separation Rules	Arrivals Only	40% Departures	50% Departures	60% Departures
CAT I	Existing Radar	29.04	47.94	59.92	69.39
BVFR	Existing Radar	29.04	48.10	60.13	71.79
BVFR	1.5 Radar Diagonal- L & S Only	33.63	55.00	68.75	77.75
BVFR	1.5 Radar Diagonal-All	35.23	57.31	71.64	79.02

TABLE 7
RUNCAP RESULTS: AIRCRAFT MIX = 15% Heavy Aircraft

PRAS Runway Use	Separation Rules	Arrivals Only	40% Departures	50% Departures	60% Departures
CAT I	Existing Radar	27.38	45.30	56.62	66.39
BVFR	Existing Radar	27.38	45.58	56.98	68.37
BVFR	1.5 Radar Diagonal- L & S Only	29.52	48.60	58.42	69.22
BVFR	1.5 Radar Diagonal-All	30.67	50.27	62.83	69.74

TABLE 8 RUNCAP RESULTS: AIRCRAFT MIX = 35% Heavy Aircraft					
PRAS Runway Use	Separation Rules	Arrivals Only	40% Departures	50% Departures	60% Departures
CAT I	Existing Radar	25.11	41.54	51.93	60.97
BVFR	Existing Radar	25.11	41.82	52.27	62.72
BVFR	1.5 Radar Diagonal- L & S Only	26.28	43.44	54.30	63.36
BVFR	1.5 Radar Diagonal-All	27.75	45.57	56.96	64.24

There is no difference between the Arrivals Only capacity for the Cat I and BVFR runway configurations in each table due to the fact that existing radar separation standards treat the two runways as one. Aircraft are not normally assigned to Runway 4L under Cat I conditions, but up to 20 percent of all arrivals (Large and Small prop aircraft) will land on 4L when the weather meets BVFR standards. The slight increase in mixed capacity when using existing radar standards and the BVFR runway assignments is due to the decrease in runway occupancy times encountered when arrivals use Runway 4L. Significant increases in capacity are realized with the application of diagonal separation. However, as the percentage of Heavy aircraft in the fleet increases, this benefit is greatly reduced.

4. DELAYSIM ANALYSIS

Once the results from the RUNCAP simulation are available, they may then be used as input for another FTA program known as Delay Simulation (DELAYSIM). This application simulates the operation of an airport over a variety of possible weather, runway use, and time horizons. DELAYSIM is used to estimate the effect of various policies over a period of time on airport capacity and aircraft delays. This program has been used extensively in the Logan Airport Enhanced Preferential Runway Advisory System (ENPRAS) project.

4.1 INPUT FOR DELAYSIM

The primary input parameters for DELAYSIM include a description of possible runway configurations with associated capacities, historical weather data, and an operational strategy. In conjunction with the ENPRAS project FTA, the FAA, and MASSPORT have defined a basic set of 55 possible runway configurations for Logan Airport. Each configuration is unique and includes an associated capacity based on FAA Engineering Performance Standards (EPS) or RUNCAP values. Also included in each configuration are the weather conditions under which it may be considered for use. FTA added one configuration to the basic set to reflect the proposed Wake Vortex Separation Rules. This consisted of Runways 4L, 4R, and 9 with capacities reflecting RUNCAP results achieved applying diagonal separation to all aircraft weight classes. The availability of the configuration was also constrained to crosswind conditions that would be insufficient to push vortices from Runway 4R to Runway 4L. As defined by System Resources Corporation, this condition is assumed to exist when a crosswind component originating from the east of Runway 4R is less than or equal to 4.9 knots. Finally, the ceiling and visibility values associated with the availability were limited to Category I conditions. During Category II conditions Logan does not use Runway 9 for departures and the visibility is such that reduced separations are considered impractical (aircraft would taxi at slower speeds, and the tower would require sufficient spacing between operations to prevent congestion on the ground). When the weather is better than Category I conditions, the application of visual separation rules greatly increases the capacity, even beyond that achieved utilizing reduced wake vortex separation rules.

Weather information for DELAYSIM is composed of historical data obtained from the National Weather Service. FTA has obtained over ten years of data for Logan. For this analysis, weather for the year 1987 was selected as an unexceptional example of conditions for the area.

The operational strategy involves defining the long-term goals of the airport. This can include tactics intended to maximize capacity, to meet noise exposure goals or a combination of other alternatives.

When selecting a runway configuration, DELAYSIM matches the weather conditions and operational strategy against the constraints associated with each configuration. This includes the runway orientation, configuration capacity, and weather constraints associated with configuration availability.

4.2 RESULTS OF THE ANALYSIS

The operational strategy selected was to maximize capacity. By hours of the day over the entire year, the 1987 weather data consists of over 80% VFR conditions and less than 20% IFR. The month during this year containing the highest percentage of IFR hours was April while June was an average month. The DELAYSIM analysis was initially limited to these two months. The first simulation runs included only the 55 original runway configurations. This provided a baseline for comparison with the second simulation runs that included the new configuration. The tables below provide a synopsis of the results.

TABLE 9
DELAYSIM RESULTS FOR APRIL 1987 (HIGHEST IFR MONTH)

Scenario	WVC % Utilization by Operations	Capacity Range During Cat I Conditions (Total Operations)	Total Delay (Hours)	Average Total Delay (Min)	% of Operational Delays Over 15 Minutes
With WVC	17.2	51 - 63	63,661	111	39
Without WVC	0	42 - 57	69,955	122	40

WVC = Wake Vortex Configuration

TABLE 10
DELAYSIM RESULTS FOR JUNE 1987 (AVERAGE IFR MONTH)

Scenario	WVC % Utilzation by Operations	Capacity Range During Cat I Conditions (Total Operations)	Total Delay (Hours)	Average TotalDelay (Min)	% of Operational Delays Over 15 Minutes
With WVC	3.5	61 - 68	36,222	60	20
Without WVC	0	56 - 68	38,286	63	20

A full year simulation was also conducted to estimate the effect of the proposed separation rules. The results of this run are in Table 11.

TABLE 11
DELAYSIM RESULTS FOR FULL YEAR 1987

Scenario	WVC % Utilzation by Operations	Capacity Range During Cat I Conditions (Total Operations)	Range of Total Delay (Thousands of Hours)	Range of Average TotalDelay (Min)	Range in % Operational Delays Over 15 Minutes
With WVC	3.5	56 - 63	2 - 64	4 - 111	3 - 39
Without WVC	0	51 - 60	2 - 70	4 - 122	4 - 40

Ranges are the low and high values over 12 months

In DELAYSIM, each configuration is assigned a unique number. The Wake Vortex Configuration is #138, while the same configuration without the reduced separations is #131. In a situation where both of these configurations are available, #138 would be chosen since it provides higher capacity. In a case where the crosswind limitations of #138 are exceeded, #131 would be chosen. The 1987 weather data did not result in any cases in which the Wake Vortex Configuration was not selected due to unfavorable crosswinds: it was always selected over #131. This allows comparison of the two configurations over the entire year. Table 12 illustrates the advantages of using the reduced separation rules.

TABLE 12
COMPARISON OF RWYS 4L, 4R, & 9 DURING CAT I WEATHER

Scenario	% Utilization by Operations	Capacity with 50% arrivals and 50% departures	Average Delay (Min)
With Reduced Separation	3.5	60.5	111.18
Without Reduced Separation	3.2	52.1	156.67
% Change	0.3	16.1	29.0

By allowing use of reduced separation, the utilization of the 4L, 4R, 9 configuration is increased by 0.3 percent. This is due to an increase in capacity of 16.1 percent (60.5 operations versus 52.1) resulting in selection of the 4L, 4R, 9 configuration over all other available configurations more frequently. Finally, by allowing the reduced separations, the average delay is reduced by 29 percent for this configuration.

4.3 CONCLUSIONS

Operations to Runways 4L, 4R, and 9 at Logan are restricted by several factors. The two primary constraints are the weather and noise abatement policies. Apparently, when the weather is Category I, wind conditions at Logan do not favor this configuration more than 3 to 4 percent of the time. Additionally, the surrounding communities and the airport authority have reached agreements to limit the types of operations permitted on certain runways and to use runways in a manner that equitably distributes noise. The results of this analysis lead to the conclusion that the reduction of wake vortex separations would not greatly benefit Logan Airport over time. For the small percentage of time that the weather is Category I and the configuration is available, however, delays would be reduced significantly.

At similar airports in the United States, it may be possible that the use of closely spaced parallel runways during IFR conditions is more frequent. At these airports, noise policies may not be as restrictive. In such a case, reduced wake vortex separations may prove to be much more advantageous over the long term than appears to be the case for Logan Airport.

5. OTHER ISSUES

Several additional issues must be explored in order to demonstrate the feasibility of the 1.5 mile diagonal spacing as proposed in this memorandum. These issues would primarily concern the safety of such an operation. The strategy modeled would require changes to the current rules for dependent approaches to parallel runways separated by less than 2,500 feet. A safety substantiation process would be necessary to demonstrate that the new strategy is consistent with current accepted levels of safety. The following sections briefly discusses other areas which must be investigated further.

5.1 CONTROLLER WORKLOAD AND EQUIPMENT

The decrease in separation between IFR operations and the complexity of applying diagonal separation would significantly increase demands upon the controller. In order to offset the increased workload, advanced automated systems could be adapted or developed specifically for this type of operation. Such systems might include displays similar to the Converging Runway Display Aid (CRDA) now in use at Logan Airport. The CRDA provides a "ghost" target showing the required separation between successive approaches to converging runways. The use of ghost targets would free the controller from determining appropriate separation standards; each subsequent arrival is simply vectored to the ghost.

Additional equipment requirements may include high-update radar with a high resolution display. Such a system currently exists and is known as the Precision Runway Monitor (PRM). This equipment allows the controller to closely monitor the progress of aircraft on final approach. Additionally, algorithms provide short-term collision alerts based on projected flight paths. This aids the controller in identifying and resolving potential conflicts.

Due to higher levels of IFR traffic, the need for voice communications will increase. The provision of a data-link system such as Mode-S would allow routine communications such as airport conditions and weather to be up-linked directly to the aircraft from the ATC facility. This would free controllers from the need to make routine, standard transmissions and allow voice communications to be concentrated on control instructions.

5.2 BLUNDER DETECTION AND RESOLUTION

With parallel runways separated by as little as 1,500 feet, it must be demonstrated that potential losses of required separation can be quickly detected and resolved. Consideration must be given to pilot/controller reaction times, and the procedures to be used in the event of a blunder. The existing PRM system has been used to monitor independent parallel arrival operations for runways separated by less than 4,300 feet but not less than 3,400 feet. Further investigation in this area is required.