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AIRPORT SURFACE TRAFFIC CONTROL CONCEPT FORMULATION STUDY

VOLUME III - OPERATIONS ANALYSIS OF O'HARE AIRPORT - PART II

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16. Abstract

This four volume report presents system concepts for use in semi-automated airport surface traffic control at all positions in the tower cab of the major airports. The control functions and data requirements of a Ramp Control System, a Ground Control System, and a Local Control System are presented. The concept development process has been based upon an extensive study of cab operations at O'Hare Airport. This effort has included extensive delay analysis, study of communication tapes, and personal observations of the widely-varying situations that are faced by tower controllers. Following the Operations Analysis effort, a detailed study of requirements was performed and is presented in Volume IV of this report. This requirements effort provided an estimate of the performance requirements of a surveillance sensor that would be required in a TAGS (Tower Automated Ground Surveillance) system for use in both good and poor visibility conditions. Detailed studies were made of the complex type of conflicts to be solved by both the Ground and Local Controllers and operational levels and densities were developed. One particular TAGS system concept (employing an ATCRBS Trilateration Surveillance Subsystem) is described in Volume I and an estimate is made of its deployment potential at major airports. Backup material on this concept in the form of a working paper is held by TSC. This working paper also includes synthetic digital display concepts for the three systems which have been summarized in Volume I.

17. Key Words
Airport delays, requirements capacity analysis, communications, synthetic displays, ATCRBS Trilateration, deployment estimates

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PREFACE

At tower-equipped airports, the controllers in the tower cab are responsible for those aspects of Airport Surface Traffic Control (ASTC) requiring centralized management: issuing clearances for aircraft to land, taxi, or take off; establishing routing patterns for arriving and departing aircraft on the runway/taxiway network so as to minimize delays; sequencing aircraft movements on runways and taxiways and at critical intersections to ensure safety; and controlling the movements of service or emergency vehicles on the airport surface. Because of the expertise of the controllers and pilots, the ASTC system has worked well most of the time. However, the unfortunate incidents at Chicago-O'Hare (20 December 1972) and Boston-Logan (31 July 1973) have pointed out certain deficiencies; e.g., the system's surveillance capability when visibility is poor.

Initiated by the Federal Aviation Administration (FAA), the ASTC program is in the process of implementing several near-term system improvements. However, it is expected that these improvements, while adequate for the 1970's, will not be adequate to meet the more stringent long-term requirements of the 1980's.

The approach which has been taken in the present study is to concentrate on the Nation's most active and, in one sense, most mature airport; i.e., Chicago-O'Hare. In performing the study at O'Hare, the cooperation of the Airport Traffic Control Tower, the City of Chicago Department of Aviation, and the FAA Great Lakes Region was essential to the success of the effort. Mr. Paul S. Rempfer, of the Transportation Systems Center (TSC), acted as technical monitor for the Government. In addition, Messrs. Rempfer and L. Stevenson, also of TSC, performed the theoretical analysis of local area capacity which is presented in Section 5.3.3.1 of Volume III.

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SECTION 5 - OPERATIONAL/FUNCTIONAL ACTIVITY ANALYSIS

5.1 GENERAL

The purpose of this section is to present the results of the quantitative analyses of the O'Hare ASTC System operations. The operations environments for the periods selected for detailed analysis of the ASDE films and controller communications recording are described. Following this, results of the data analyses are presented for the areas of:

1. Aircraft flow analysis, including traffic flow statistics for the ramp, ground taxi, and local control areas.
2. Controller workload analysis, both communications and non-communications.
3. Cockpit crew workload analysis, both communications and non-communications.

5.2 TRAFFIC OPERATIONS ENVIRONMENTS FOR DATA ANALYSIS PERIODS

As noted in several earlier portions of this report, the airport operating mode and the runway configuration in use are the primary determinants in the direction of ground traffic flow and, therefore, can be expected to influence taxi times and delays. In addition, the nature of the runway configuration could be expected to influence traffic flow for departures after reaching the runway queue as well as arrival operations. For these reasons it was decided that the data analysis would be performed in a manner that allowed examination of the differences in airport operations as a function of runway configuration and operating mode (i.e., Arrivals from the East or Arrivals from the West). Thus, various traffic operations periods represented in the ASDE films and controller communications recordings made by TSC and CSC were selected for detailed study to derive a data base for the

1. Analysis of traffic flow statistics
2. Controller workload statistics

3. Pilot workload analysis
4. ASTC system effectiveness assessment

5.2.1 Selection of Operational Periods for Study

The following guidelines and criteria were generally employed in the selection of the various operational periods for detailed analysis:

1. The runway configuration met the general definition of the two operating modes; that is, during a sample time period of one hour it was possible to identify one primary arrival runway among the northside and southside runways to which approaches were made from generally the same direction, east or west. This did not rule out occasional arrivals on another runway.

2. There was no runway configuration change during the sample period. Because runway configuration influences the ground taxi flow pattern, changes in configuration would result in differing taxi operations for which ground movements data could not be considered from the same statistical sample for analysis purposes. In addition, such changes tend to introduce additional influences on traffic movement delays which would be difficult to distinguish in the ASDE films.

3. The sample time periods of interest were restricted to weekdays and, more specifically, to hours of normal traffic, i.e., between 0800 and 2100 local time.

4. Periods representing normal visual operations in either east or west mode would constitute the primary samples for analysis. The basis for this criteria was the decision that the data derived should support the following study analyses of ASTC functional performance and design definition. Since future ASTC systems would function and be of primary value during normal operating traffic volumes, if these volumes are to increase as predicted, the supporting data should be drawn primarily from such operational periods.

5. Sample periods representing other than normal visual operations would be selected if they

   a. met criteria 1-3 above;

   b. exhibited a "normal" constraint on airport operations due to reduced visibility.

6. Satisfactory ASDE films and controller communications recordings were available to permit the analysis of traffic flow statistics and controller communications activities, particularly under reduced visibility conditions.

7. The traffic operations volume (i. e., total number of operations) represented a moderate to heavy level of traffic.

Using these criteria, the operations environments represented in the 40 TSC data runs (80 hours of operations) and the quality of the data available for analysis were reviewed. The potential runs for analysis were first narrowed down to twelve that met criteria 1 through 5. Runway occupancy counts were made from the ASDE films on these runs to verify the runway configuration and to measure the total traffic volume. Based on these results, the choice of eight runs (four for each mode of operation) for analysis was made. These runs all represented normal visual operations periods.* For the various TSC runs involving non-visual conditions, several were definitely eliminated because they did not satisfy criteria 5a or 5b. The decision was deferred for a few of these runs, pending the availability of suitable non-visual operations periods from the CSC data collection, because they did not satisfy criteria 6 (i. e., no ASDE films were available or interference between ground control channels did not permit investigation of the effects of these conditions on controller communications activity).

These same selection criteria were applied to CSC data resulting in the choice of five runs for analysis. Three of the runs represented operations under Category I and Category II conditions. The choice of two of these runs holds special significance. The first of these runs includes Category I conditions for the first hour of the collection period and deterioration of conditions to Category II

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*The analysis for one of these runs was terminated because of difficulties with the ASDE film.

early in the second hour. Thus, the data derived from this run allows examination of the transition for Category I to Category II operations. The second of these runs was made later in the same day, also under Category I conditions, and exhibits the effects on airport operations resulting from the extreme disruption caused by the preceding Category II situation.

The operational environments represented in the selected data periods are summarized in Table 5-1. From the table it may be seen that a total of 14 operational periods were analyzed, including five "Arrival from the East" mode and four "Arrival from the West" mode under good visibility conditions, and five "Arrival from the West" mode under low visibility conditions (which is the normal mode for such conditions). Traffic volumes ranging from approximately 100 to 140 operations per hour, excluding Run CSC #8b, were observed. In addition, both Dual (i.e., independent intersecting arrivals) and Parallel (i.e., independent parallel arrivals) approach modes of runway operation were covered.

Table 5-1. Summary of Operational Environments for Data Periods Selected for Detailed Analysis

Run No.	Day of Week	Time of Day (Approx)	Mode of Operation	Primary Runways				Operations		Visual Conditions (Ceil./Vis.)	Other Remarks
				North		South					
				Arr.	Dep.	Arr.	Dep.	Arr.	Dep. RW(GC)		
TSC 15	Wed.	0900/1000	West	14L	9L	9R	22L	52	59(49)	25,000' scattered 2 mi smoke/haze	Dual approaches
TSC 20	Thur.	0830/0930	East	22R	32R	27L	27L	64	64(74)	25,000' & overcast 7 mi clear	Dual approaches
TSC 24	Sat.	740/820	West	14L	14L	-	-	21	15	<200' solid <3/8 mi	Centerline lights on 14R inoperative
TSC 29	Tues.	1800/1900	West	14L	4L	9R	4R	58	54(54)	10,000' scattered 6 mi smoke/haze	Dual approaches
TSC 33	Wed.	1645/1745	East	27R	32R	27L	22L	74	68(68)	25,000' thin/broken >15 mi clear	Parallel approaches
TSC 35	Thur.	1000/1100	East	27R	32R	32L	27L	49	57(57)	Unlimited 15 mi clear	Dual approaches
TSC 37	Thur.	1530/1630	West	14L	9L	14R	9R	71	69(51)	25,000' thin/scattered, 15 mi	Parallel approaches
TSC 39	Fri.	0830/0930	West	14L	4L	9R	4R	64	76(76)	4600' broken 8 mi rain	Dual approaches
CSC 5	Wed.	1640/1740	East	27R	32R	32L	27	70	65(68)	25,000' broken 6 mi haze	Dual approaches
CSC 7	Thur.	1445/1545	West	14L	9L	14R	9R	53	20(57)	300' overcast; 1/2-1-1/2 mi fog/haze	Parallel approaches
CSC 8a	Fri.	0850/0950	West	14L	9L	14R	14R	56	46(48)	300' indefinite 1/2 to 1 mi fog	Parallel approaches
CSC 8b[3]	Fri.	0950/1050	West	14L[2]	14L	-[2]	-	7[2]	31(28)	>100' solid >1/4 mi heavy fog	14L only runway Open for hour, mostly departures
CSC 9	Fri.	1315/1415	West	14L	9L	14R	27L	61	56(54)	400' indefinite 1-1/2 mi fog	Parallel approaches Large # gate delays[4]
CSC10	Wed.	1830/1930	East	27R	32R	32L	27L	70	53(46)	Unlimited 12 mi clear	Dual approaches

Table 5-1 NOTES

1. Operations counts indicate number of aircraft observed in runway operations, RW, and in ground taxi operations (GC), during period. This difference stems mainly from starting and ending of specific times for analysis hour, thus beginning with aircraft left from pre-analysis period or aircraft cutoff at end of analysis period.

2. In this period heavy fog brought conditions below landing/departure minimums for 14R very early in period allowing only one arrival; waiting departures were routed to 14L. Fog conditions allowed only three arrivals on 14L in early part of period and lifted for a few minutes midway through period to allow three more arrivals before closing in again for balance of period.

3. The ASDE film was reduced for this run but no analysis of the data was made because the conditions resulted in abnormal traffic operations for departures only. However, communications analysis was performed to study the impact of these conditions on controller activity.

4. Heavy fog conditions in morning (Run 8b) caused major disruptions of flight schedules. Continuing low visibility level during rest of morning perpetuated disruptions resulting in a large number of gate delays. As a point of interest, low level visibility continued throughout the day, including another period of dense fog in early evening. Thus, disruption of schedules continued throughout the day and at a point in the evening all arrivals were stopped to let backed up departures out and then all departures stopped to let arrivals in.

5.3 AIRCRAFT FLOW ANALYSIS

A major part of the operational analysis at O'Hare has consisted of an examination of the aircraft flow statistics for the three main areas of interest, namely, the Ramp (or Carrier) area, the Ground Controllers' area, and the Local Controllers' area. The Ramp area has been defined for the purposes of this analysis as that inside the concourse fingers. The Ground Controllers' area has been defined to include the remainder of the airport surface excluding the departure queue and active runways. These latter two areas have been defined as the Local Controllers' area which is of interest to the ASTC program. Each aircraft moves through these three areas irrespective of its flight phase (i. e., arrival or departure). The examination of these three areas has taken into account the operational differences between them, wherein the north and south side runways at O'Hare are handled by separate Local Controllers. On the other hand, the Ground Controllers' operation is based not on geographic separation but rather on aircraft flight phase--one controller for arrivals and another for departures. Each of the eight ramp areas, of course, handles both arrivals and departures so that both Ground Controllers must consider the impact of ramp area operations on their respective traffic. Figure 5-1 illustrates the flow of aircraft through these areas.

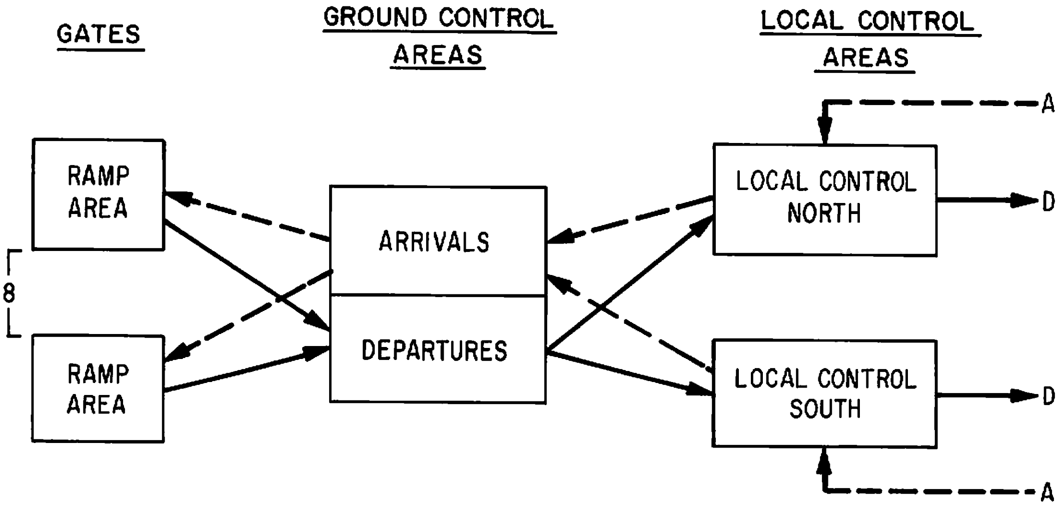

Figure 5-1. Aircraft Flow Between Movements Analysis Areas

The traffic flow in each of these areas is analyzed to derive statistical parameters for nominal movement times and delays in relation to the volume of traffic flowing in the area during the period. In addition, queuing analysis models are employed to derive an average density (Q) or number of aircraft flowing in each of the movement areas at any time.

The aircraft delays which occur in the several parts of the surface traffic control system are influenced by parameters unique to the particular movement area. Delays in the ramp areas are more influenced by airline scheduling than by runway operations levels. Departure delays in the Local Control area will be highly influenced by arrival traffic. To establish a common basis for combining the various delays, all values were normalized to an average delay per operation. This permits a comparison of delays at various points in the total system. The simple model to be used for comparison and/or addition of the various delays contains the following components:

Ramp Area Delay
Penalty Box Delay
Ground Control Delay
Local Control Delay

Other possible delays may be experienced while the aircraft is at the gate or while the aircraft is under approach control. Neither of these has been evaluated in this analysis. Delays at turnoff for arrivals have been investigated and occur so seldom that they will not be considered as a significant component of the overall delay model.

Descriptions of the data analysis and results for each of the three movement areas are presented in the following paragraphs.

5.3.1 Ramp Area

5.3.1.1 Data Collection

During the period January 16 to 18 and January 23 to 25, 1974, visual observations were made at Chicago's O'Hare Airport terminal area to determine aircraft movement characteristics within the ramp area. During this period, approximately 350 individual aircraft movements were recorded within several ramp areas for both arriving and departing aircraft. TSC ASDE film data taken during February and March 1973 was also used for determining activity in the various ramp areas.

The principal parameters of interest for arrival flights consisted of total taxi time and hold time, if any. For departing aircraft the time intervals of interest were separated as follows:

1. Pushback operation
2. Engine start time (waiting period between end of pushback to start of taxi)
3. Taxi time
4. Hold time

The techniques used for obtaining these parameters were described in Section 2.

The concourse configurations together with gate numbering schemes are shown in Figure 5-2 to aid in the identification of the location of the ramp areas described in this report. With the exception of the K ramp (Gates 1-11), all ramp areas are described in this report by two alpha-characters which relate to a specific area enclosed between two adjacent concourses.

VFR conditions generally prevailed throughout most of the visual observation period. The first of two exceptions occurred on 17 January around 0900 when the visibility was somewhat reduced due to fog and haze. The data collected

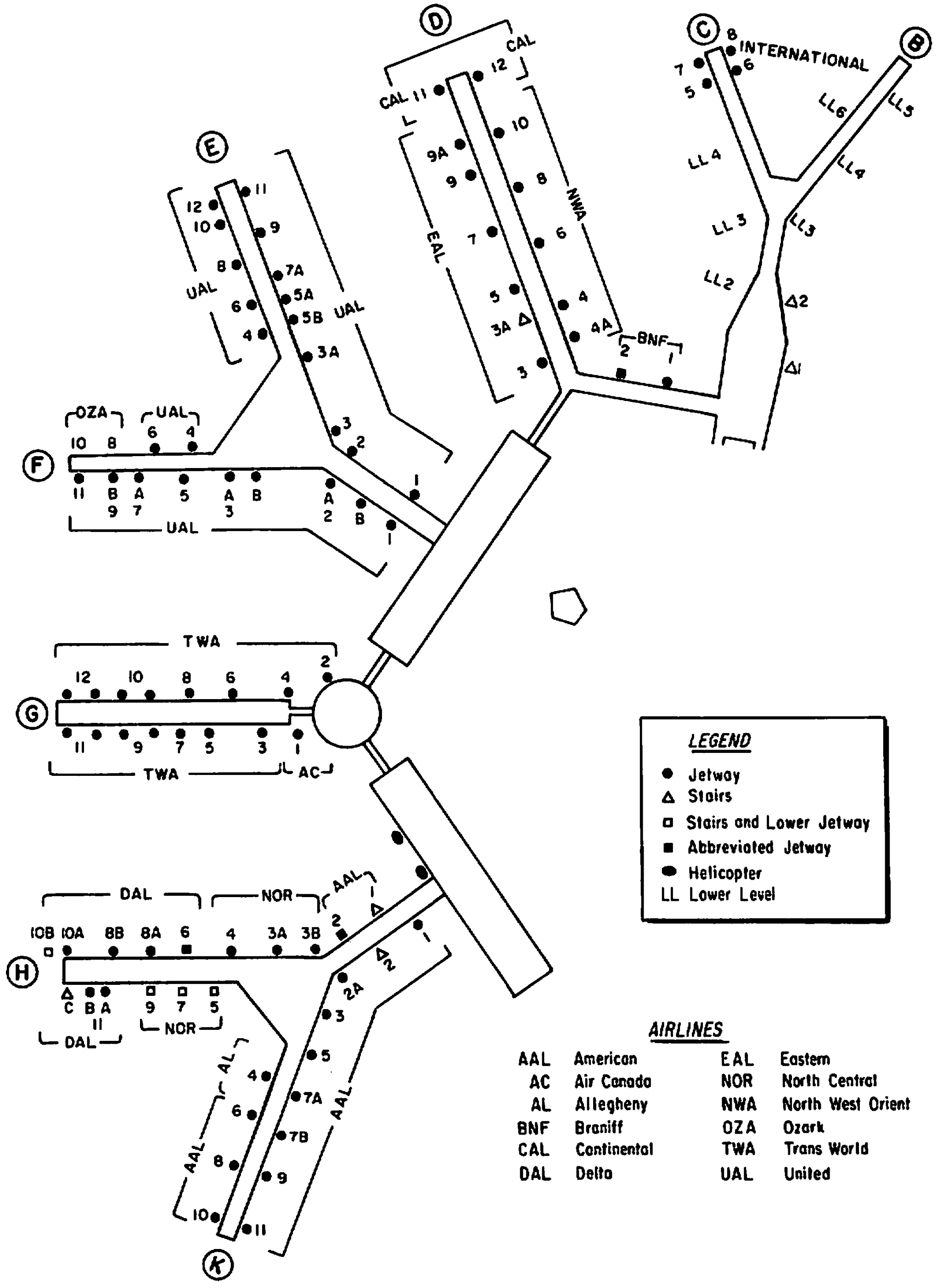

Figure 5-2. Gate Assignments

during this period was not indicative of any perceptual difference in aircraft movement within the ramp area and is, therefore, included in this report.

The second exception occurred on the morning of 18 January. An attempt was made to record data on the K and HK ramp areas. Visibility conditions, however, deteriorated steadily throughout the observation interval with reported RVRs of 1000 or less due to patchy fog which occasionally obscured the outer edge of the concourses. Also, ceilings were, at times, below 100 feet which had a significant impact on overall airport operations both during these morning hours and later on in the day when conditions had improved. Many flights were subsequently canceled. Since conditions outside of the ramp area were considered to be abnormal (lack of arrivals, delayed departures and long queues) with the result that almost no activity existed at the gate, this ramp area data has not been included in this report.

5.3.1.2 Data Results

Table 5-2 provides ramp usage data for TSC Runs 35, 33, 20, 29, and 37 on both a numerical and percentage basis. The numbers represent aircraft movement either in or out of the specific ramp area from or to the identified runways as collected from the ASDE films. The letter "A" following the runway number indicates arrival aircraft that proceeded to a specific ramp area while the letter "D" indicates departing aircraft that left a ramp area and proceeded to a specific runway. Ramp areas FG and GH appear to be uniformly the most active with movements of 20-22 aircraft per hour. Note, however, that in three of the runs the general aviation area (Butler) experienced comparable traffic.

Table 5-2. Ramp Usage Data (1 of 2)

Ramp Area	A-C	CD	DE	EF	FG	GH	HK	K	Other	Total
Run #35 10:07-11:07										
RW 32R D	2	5	4	1	6	3	4	3	1	
32L A	1	4	4	2	4	6	2	1	1	
27L D		1	5	3	6	5	3	2	1	
32L D					1					
27R D	1									
22R A	1						1			
27R A	6	3	1	1	4	5		1		
Total	11	13	14	7	21	19	10	7	3	105
Percent	10	12	13	7	20	18	9	7		
Run #33 16:45-17:45										
RW 22L D	1	3	4	1	4	6	4	3	1	
32R D	4	3	5	5	5	6	2	2		
32L D	4	2		1					1	
27L D				2	1					
22R A	6						2			
27R A	6	5	4		6	4	1	2	1	
27L A	2	4	3	7	3	6	4	4	1	
Total	23	17	16	16	19	22	13	11	4	142
Percent	16	12	11	11	14.5	15	9	8		
Run #20 8:40-9:40										
RW 22R A	7	4	3	5	3	3	2	3	3	
27L A	2	2	8	5	6	4	6	1	1	
27R A	2									
27R D	1	2		2	3	3	1	1	1	
27L D	5	3	4	4	4	3	7	4	2	
32R D	2	1	6	2	4	3	2	3		
Total	19	12	21	18	20	16	18	12	7	143
Percent	13	8	15	13	14	11	13	8	5	

Table 5-2. Ramp Usage Data (2 of 2)

Ramp Area	A-C	CD	DE	EF	FG	GH	HK	K	Other	Total
Run #29 18:02-19:02										
RW 9R A	2	3		6	5	5	2	2	4	
14L A		2	3	2	3	5	3	4		
4L D		3	1	2	2	3	4	4	1	
4R D	3.8	1.8	5.8	4.8	3.8	3.8	1.8	1.7	0.7	
Total	5.8	9.8	9.8	14.8	13.8	16.8	10.8	11.7	5.7	99.0
Percent	5.9	9.9	9.9	14.9	13.9	17.0	10.9	11.8	5.8	
Run #37 15:36-16:36										
RW 14L A	9	2	2		2	3	6	6		
14R A	2	6	6	6	7	4	2	2		
22R A	2									
9L D	10	2	2		3	6	1	3		
4L D						1				
9R D	1	6	5	5	7	6	2	1	1	
Total	24	16	15	11	19	20	11	12	1	129
Percent	19	12	12	9	15	16	9	9	1	

From the data given in Table 5-2, the estimated "Break Point"* for the eight ramp areas is as follows:

Run #	35	33	20	29	37
Est. Break Point Location	FG	F	F	FG	F

A summary of peak traffic flow as extracted from Table 5-2 is given in Table 5-3. From this table it appears that O'Hare is running about 1.4 operations/hour/gate for the jetway terminal areas during their peak periods. Ramp parking increases this capability greatly in AC and EF giving a weighted mean of about 1.6 operations/hour/gate. With a mean service time of about 45 minutes/turnaround (see paragraph 5.3.1.3) measured at O'Hare, this gives an average gate utilization (i.e., percent gates occupied at any instant) of 60 percent.

$$\frac{\text{Operations/Hour}}{\text{Gate}} (1.6) = \frac{\text{Operations/Turnaround (2) x Gate Utilization}}{\text{Hours of Service/Turnaround (.75)}}$$

This 60 percent is consistent with the results of preliminary requirements at O'Hare (Reference 8). It will be seen in paragraph 5.3.2.3 that there exists substantial gate delays during peak periods and, therefore, 1.6 operations/hour/gate can be considered a peak capacity estimate. This would result in an overall peak gate capacity of 150 operations/hour at O'Hare (with 94 gates).

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*Break Point is the physical median for traffic origination and destination, i.e., 50 percent of the traffic originates before this point. This impacts on controller decision-making with respect to routing of traffic.

Table 5-3. Peak Traffic Flow--Ramp Area

Ramp Area	A-C	CD	DE	EF	FG	GH	HK	K
Peak AM	19.0	13.0	21.0	18.0	21.0	19.0	18.0	12.0
Peak PM	24.0	17.0	16.0	16.0	19.0	22.0	13.0	12.0
Gates	8.0	13.0	15.0	9.0	14.0	16.0	10.0	9.0
Peak Operations/ Hour/Gate	3.0[1]	1.3	1.4	2.0[2]	1.5	1.4	1.8	1.4

[1] General aviation ramp parking gives many effective gates.

[2] Ozark ramp parking gives 13 effective gates.

A summary of pertinent visual ramp observation data is given in Table 5-4. The data is grouped into three categories:

1. Run Identification

   This grouping contains a run number, the ramp area identification, and the date of observation. These run numbers are for the visual ramp measurements only and should not be correlated with other CSC run numbers given in this report.

2. Overall Ramp Activity Summary

   Included in this grouping are the starting and ending times of the observation period, the number of arriving and departing aircraft and the operations rate per hour (arrivals and departures) during the total observation period.

3. Average Aircraft Flow Durations

   The data provided here are average values calculated on individual runs and include all information for the total observation period. Runs 3 and 5 and runs 4 and 6 have been combined and the data tabulated in the rows corresponding to runs 3 and 4, respectively. The duration for each element is in seconds with the exception of Gate Occupancy time, which is shown in minutes.

Table 5-4. Aircraft Flow Data - Ramp Area

Run Identification			Activity			Average - Aircraft Flow Durations (seconds)							Avg Gate Occup. Time* (min.)
						Arrivals		Departures					
Run No.	Ramp Area	Date	Time Interval	No. of Arrivals/ Departures	Ops/Hr	Ramp Service Time	No. of Holds	Ramp Service Time	No. of Holds	Push-Back Time	Start Time	Taxi Time	
1	DE	1/16	1553 1753	15/12	13.5	66.0	0	185	0	57	68	60	52(3)
3	DE	1/17	0700 0800	6/5	11.0	69.0	0	206	0	96	55	56	58(5)
5	DE	1/ 17	0820 0920	1/8	9.0	Results included with Run #3 above							
11	DE	1/24	1700 1845	15/18	19.0	74.0	1	205	1	82	72	50	41(7)
DE Subtotals				37/43		70.0	1	199	1				
2	FG	1/16	1555 1755	20/16	18.0	80.0	2	182	0	42	83	57	50(11)
4	FG	1/17	0700 0805	6/10	14.6	76.0	1	243	5	60	87	65	58(6)
6	FG	1/17	0815 0935	11/7	13.5	Results combined with Run #4 above							
12	FG	1/24	1700 1905	21/20	19.7	65.0	0	209	3	90	59	54	43(14)
FG Subtotals				58/53		72.5	3	212	8				
7	GH	1/17	1705 1815	11/11	19	62.0	0	224	4	79	65	49	45(4)
10	GH	1/24	0815 1015	21/23	22	100.0	3	216	5	89	52	56	40(9)
GH Subtotals				32/34		87.5	3	218	9				
8	HK	1/23	1635 1905	21/20	16.4	65.0	1	160	0	66	54	39	39(15)
9	K	1/23	1630 1910	18/20	14.2	90.0	6	181	4	66	54	60	48(8)
Overall Averages						75.0		200		73	64	54	46

*Note: Values in parentheses indicate the number of aircraft for which a gate occupancy time could be computed.

5.3.1.3 Supporting Data Analysis for Visual Observations

As indicated previously, the entries provided in Table 5-4 are average values obtained from the data for specific observation periods. While these values do have some significance in certain applications, they are restrictive since they do not convey any information as to the spread of values observed between different samples. In order to demonstrate the variations that were observed, cumulative distributions of the various parameters were prepared by combining the data collected during all of the runs shown in the table.

The reason for combining the data, instead of presenting it on an individual run basis, is due to the relatively small number of samples contained in any given run. For example, the maximum number of samples in either departures or arrivals is twenty-one, so that any sample period represents approximately five percent of the total sample population. Thus, the weighting of any sample period is too large for any reasonable presentation of a distribution.

Figure 5-3 demonstrates the variability of Ramp Service Time for arrivals as a percentage of total observations. The plot is relatively linear for cumulative percentages up to 90 percent and has a shallow slope indicating a relatively uniform distribution of the amount of time required from the time of entry to docking. This is consistent with the fact that the gates are located at various distances from the end of the concourse where the timing history of each aircraft first begins and indicates that 90 percent of the arrivals experienced no ramp delays.

The remaining 10 percent of the traffic exhibited increasingly longer arrival durations which were the result of holds or a slow down in taxi speed caused by various activities in the ramp area. These activities include such factors as:

1. Gate area not clear of ground vehicles
2. Pushbacks of other aircraft
3. Jetway operator not on station
4. Vehicles moving about in ramp area

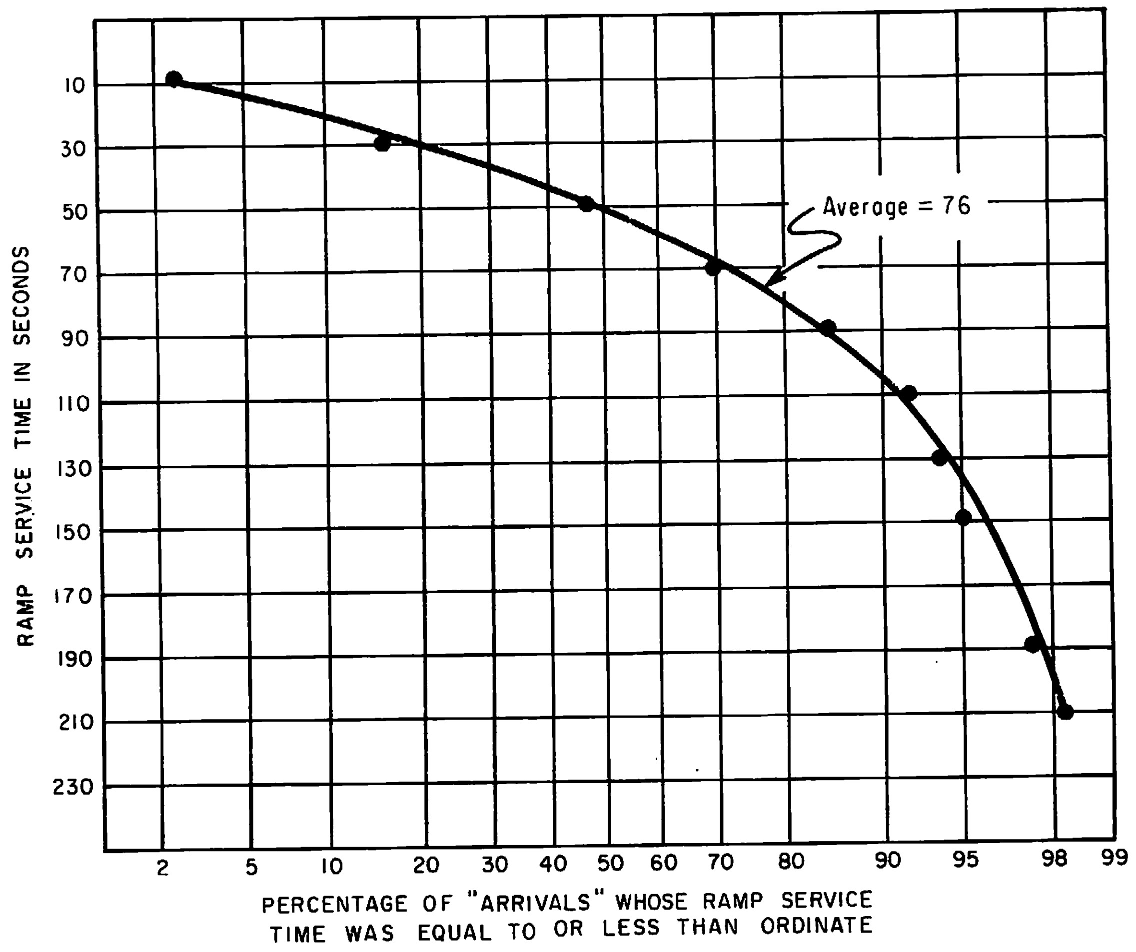

Figure 5-3. Distribution of Ramp Service Times for "Arrivals"

Figure 5-4 depicts the cumulative distribution of Ramp Service Time for departures as measured from the time pushback started until the aircraft cleared the outer edge of the concourse. Since this time duration includes four separate intervals, i. e., pushback, engine start, taxi, and holds, the variability can be expected to be, and is indeed shown to be, significantly greater than that observed for arrival durations. The plotted data appears to be broken into three segments: up to 50 per cent, between 50 per cent and 85 per cent, and beyond 85 percent. Starting with the lower percentile segment, each segment exhibits an increased slope from that of the previous segment. This characteristic is discussed further in relation to the data shown in Figure 5-5.

Cumulative distributions as well as the calculated average values of the taxi, engine start, and pushback time intervals are shown in Figure 5-5 as curves A, B, and C, respectively. Curve A exhibits an essentially uniform slope throughout the entire range. This is considered to be due to the fact that in virtually all cases the pilot of the aircraft is in a position to evaluate the situation in the ramp area between himself and the outer edge of the concourse during the interval between the end of the pushback operation and the start of the taxi operation. Consequently, if he determines a conflict exists he will either delay the start of the taxi operation or else he will taxi slowly in anticipation of a resolution of the conflict before he would be required to hold. Approximately 68 per cent of the samples completed the taxi operation in less than or equal to the average value of 54 seconds.

Curve B, which depicts the distribution of sample intervals between the completion of pushback and start of taxi, i. e., "engine start" time, demonstrates a considerably greater variation in the amount of time required. Factors which contribute to this variability are the "pilot conflict resolutions" discussed above and differences in time required for aircraft checkout procedures, engine startup, etc. The average value of "engine start" time was 64 seconds.

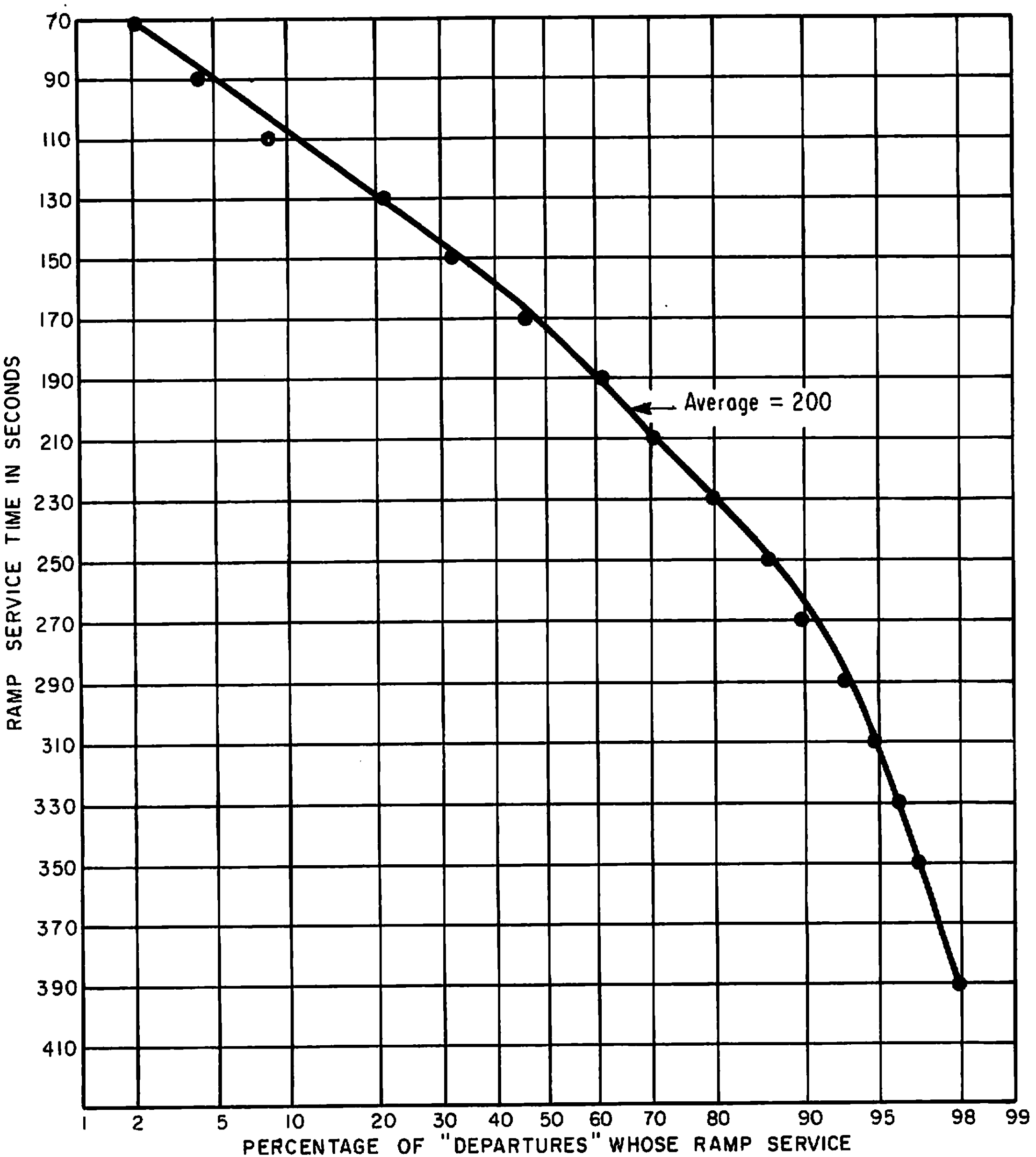

Figure 5-4. Distribution of Ramp Service Times for "Departures"

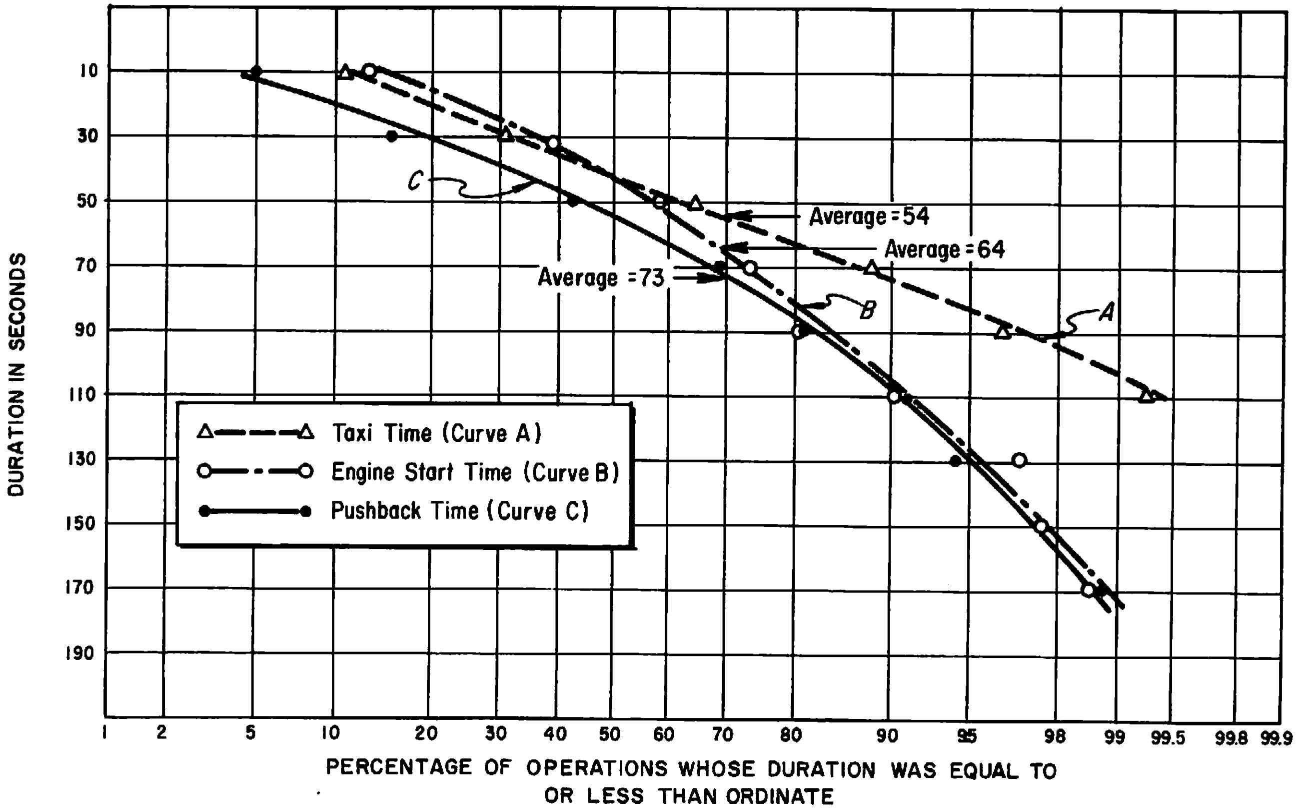

Figure 5-5. Distribution of Operation Durations

The variability of pushback times around the average value of 73 seconds is shown in Curve C. Basically, the amount of time required for this operation is a function of the size of the aircraft, the relative location of the gate from which the aircraft departed, other activities in the immediate vicinity of ramp area utilized (vehicle movements, other aircraft pushbacks, etc.) and the specific checkout procedures required for the nose-wheel assembly of different aircraft. With respect to the latter operation, it was of interest to note that the time required for checkout of the DC-8 was observed to be somewhat longer than for comparable or smaller size aircraft. It was subsequently learned that previous experience with this aircraft has necessitated a more comprehensive examination of this mechanical assembly at the completion of the pushback operation.

The data plotted in Figure 5-6 show the variability in Gate Occupancy times for aircraft which arrived and departed within the observation intervals of each run. These values represent the actual elapsed time between docking as an arrival and start of pushback as a departure. It should be noted that the upper limit (maximum time possible) is dictated by the length of the longest observation period (160 minutes). Obviously, aircraft that were already at gates at the start of an observation period as well as aircraft arriving towards the end of an observation period are automatically excluded from this presentation. The average of the 82 gate occupancy measurements was 46 minutes with the 10 per cent and 90 percent points of the distribution at 24 minutes and 58 minutes, respectively.

5.3.1.4 Analysis of Arrival and Departure Holds

A summary of the results of the ramp area hold analysis is given in Table 5-5. The actual number of arrivals and departures is repeated from Table 5-4 to permit a comparison between the number of holds and the total number of operations for each observation interval (run). The ratio of aircraft encountering holds to the total number of aircraft observed (arrivals or departures) is expressed in percentages. In addition, the average duration of each type of hold is also given.

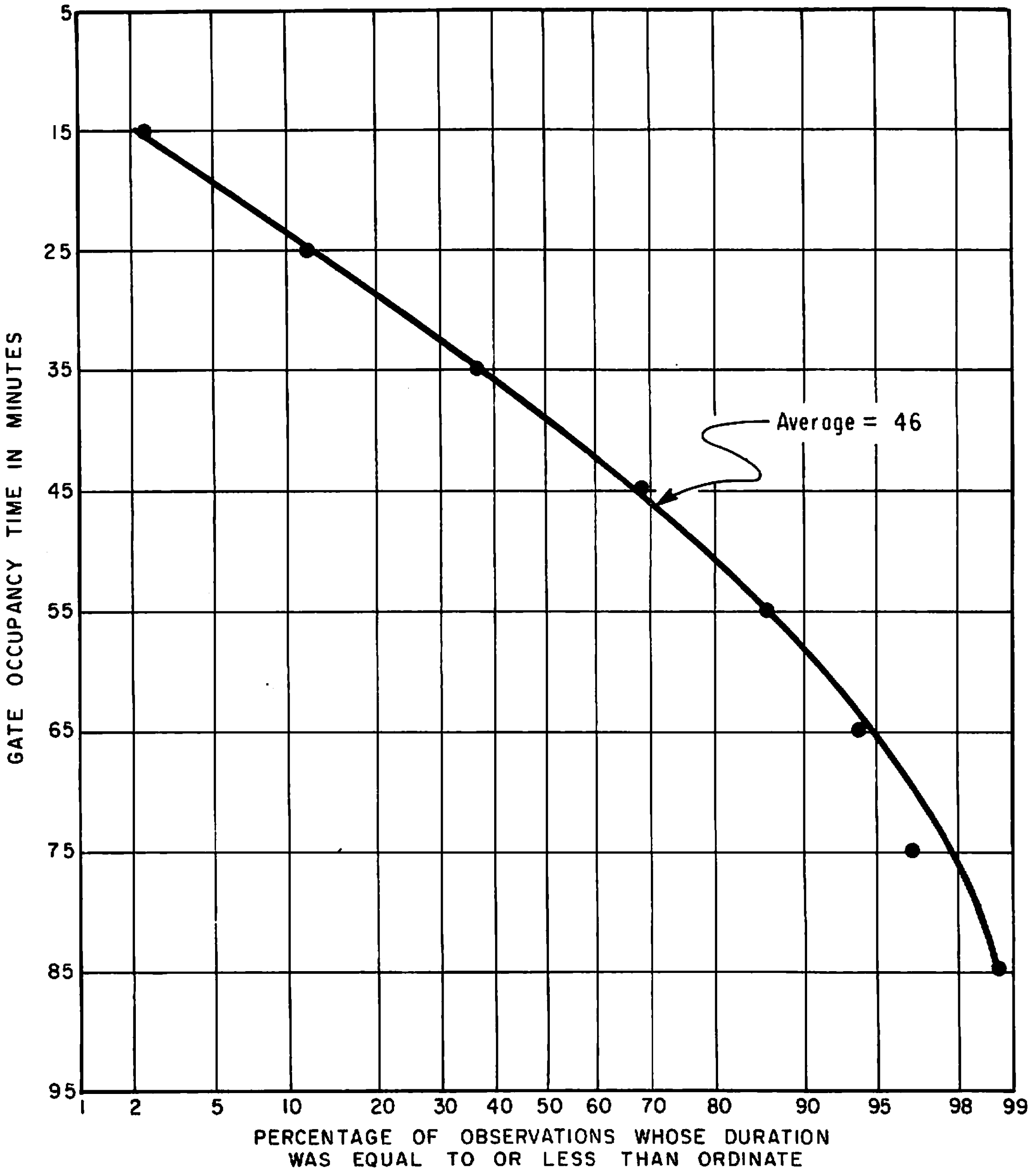

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Figure 5-6. Distribution of Gate Occupancy Times

Table 5-5. Arrival and Departure Hold Analysis

Run No.	No. of Arrivals	No. of Holds	No. of Departures	No. Holds
1	15	0	12	0
2	20	2	16	0
3&5	7	0	13	0
4&6	17	1	17	5
7	11	0	11	4
8	21	1	20	0
9	18	6	20	4
10	21	3	23	5
11	15	1	18	1
12	21	0	20	3
	166	14	170	22
Ratio "Holds" to Arrivals or Departures		8.4%	13%	
Average "Hold" Duration		90 sec	67 sec	

The majority of the arrival holds were observed to be caused by activities related directly to the aircraft's assigned gates (gate blocked by parked vehicles, gate not lighted or incorrectly positioned, etc.). In a few instances the delay was attributed to pushback operations of other aircraft or "exiting" aircraft. Since arriving aircraft timing did not commence until the outer edge of the concourse was passed, a considerable number of arrival holds on the inner circular taxiway or between the outer and the inner circular taxiways are not included in these statistics. However, these delays are included as part of the ground control analysis.

Departure holds could, in most instances, be attributed to near simultaneous departure operations by other aircraft in the ramp area. In a few cases, aircraft departing from one of the lower numbered gates (those closest to the main terminal building) were held for arriving aircraft which were to dock at one of the higher numbered gates.

5.3.1.5 Scheduling Effects

To determine possible effects of airline scheduling on ramp area activity, the ramp areas FG and GH were examined in more detail for TSC Run #33. Table 5-6 presents the time sequence of operations in these two areas. The average interval between ramp movements was 200 seconds for the FG ramp area and 171 seconds for the GH area. Table 5-7 presents summaries of the number of operations in each ramp area using the same data organized into 10-minute blocks between 16:45 and 17:45. A large traffic peak in the vicinity of 5 p.m. is apparent with 21 operations occurring in the 2 ramp areas in the 20-minute period from 16:55 to 17:15. Individual ramp usage rates as high as 0.7 aircraft/minute may be noted in both ramp areas.

The ramp operation is such that several departures are often in the pushback mode at the same time. Notice the pairs of departures at 17:09 in area FG and 17:11 and 17:27 in area GH. This "batch" method of operation appears to

Table 5-6. Selected Ramp Area Activity (Run #33) 1645-1745

RAMP AREA - FG		RAMP AREA - GH	
Time of Entry or Exit	Time Interval (Seconds)	Time of Entry or Exit	Time Interval (Seconds)
16:47:47 D		16:46:36 D	
17:01:06 D	199	16:52:37 D	360
17:01:36 D	30	16:54:12 D	95
17:02:21 D	45	16:56:08 A	116
17:05:30 D	189	16:58:52 D	164
17:08:16 A	166	16:59:12 A	20
17:09:22 D	76	17:00:25 A	73
17:09:55 D	33	17:04:37 A	252
17:10:09 A	14	17:04:51 A	14
17:11:38 D	89	17:04:57 D	6
17:14:08 A	150	17:05:58 A	61
17:16:09 A	121	17:07:09 A	71
17:23:45 A	456	17:10:59 D	230
17:28:01 A	256	17:12:00 D	61
17:28:58 D	57	17:16:34 A	274
17:29:30 A	32	17:18:27 D	113
17:33:07 A	217	17:27:20 D	533
17:36:50 A	223	17:28:45 D	85
17:40:49 D	239	17:33:17 D	272
		17:42:28 D	551
		17:43:09 A	41
		17:44:44 A	95

19 A/C (Avg Interval = 200 sec) 22 A/C (Avg Interval = 171 sec)

Table 5-7. Ramp Activity by 10-Minute Periods (Run #33)

	Ramp FG Operations	Ramp GH Operations	Total
16:45 - 16:55	1	3	4
16:55 - 17:05	3	7	10
17:05 - 17:15	7	4	11
17:15 - 17:25	2	2	4
17:25 - 17:35	4	3	7
17:35 - 17:45	2	3	5

offer advantages in reducing ramp area delays for departures. However, it may result in increased Local and/or Ground Control delays, since it tends to have aircraft move in "platoons" rather than individually.

5.3.1.6 Ramp Area Occupancy

Aircraft movement in an active ramp area may also be described in terms of an occupancy factor. This occupancy factor is defined in terms of the number of aircraft serviced and the ramp service time required. Therefore, it pertains only to the ramp area through which aircraft physically move and specifically excludes aircraft after they have docked as well as any empty gate areas. The relationship for obtaining an average occupancy factor is given as:

$$Q = \lambda_a \overline{T}_{ca} + \lambda_d \overline{T}_{cd}$$

where

Q = The average Occupancy factor

λ_a, λ_d = The number of arrivals and departures, respectively, to or from the ramp area within a specific time period

$\overline{T}_{ca}, \overline{T}_{cd}$ = The average ramp service times for arrivals and departures, respectively, for that ramp area

Using the average ramp service times given in Table 5-4 ($\overline{T}_{ca}$ = 75 sec and $\overline{T}_{cd}$ = 200 sec) and assuming $\lambda_a = \lambda_d$ = 11 operations per hour,

$$Q = \frac{(11)(75)}{3600} + \frac{(11)(200)}{3600} = 0.84$$

Short term (5-10 minute) peaks of twice this value will occur often. Because of the approximately 3 to 1 difference in service times between departures and arrivals, short term variations in the former will play the more significant role in influencing ramp density.

5.3.1.7 Summary of Ramp Area

It appears that the gate structure at O'Hare will and does support a traffic flow of 1.6 operations/hour/gate. This is consistent with a 60 percent gate utilization (i.e., 60 percent of the gates occupied at any one instant) and a mean turn turnaround time of 45 minutes. This translates to 150 operations/hour overall when considering O'Hare's 94 gates and is just in excess of their current quota.

Approximately 90 percent of all arrivals encounter no delay while taxiing in the ramps. The remaining 10 percent experience holds with an average duration of about 1.5 minutes primarily due to the gate not being ready, other pushbacks or service vehicle movement in the ramp area.

Approximately 10 percent of the departures experience holds with an average duration of one minute. In most instances the holds can be attributed to near simultaneous departures or waits for arrivals to dock. Once a departure is rolling, it experiences no slow downs.

The aircraft flow measurements made in the ramp area represent values obtained under VFR conditions and were primarily taken in the more active ramp areas. Significant values obtained from the 350 aircraft movements are as follows:

	Arrivals (secs)	Departures (secs)
Ramp Service Time	75	200
% of Aircraft "Held" in Ramp Area	8.4%	13%
Average Duration of "Hold"	90	67
Pushback Duration (Avg)	-	73
Engine Start Duration (Avg)	-	64
Taxi Duration (Avg)	-	54

While the maximum value of the ramp movement rate was less than 0.5 aircraft/minute (i.e., 22 aircraft in one hour were observed in Run #10) peak values over short intervals (5-10 minutes) showed movement rates of almost one aircraft per minute. On numerous occasions several aircraft have been observed exiting or entering behind each other.

It should be noted that "delays" at the gate are not included in the above parameters.

Gate occupancy time exhibited an average value of 46 minutes based upon 82 measurements and had a 10 percent to 90 percent spread from 24 minutes to 58 minutes.

5.3.2 Ground Controllers' Area

5.3.2.1 Data Base Generation for Flow Statistics

Figures 5-7 and 5-8 illustrate the timing relationships and definitions used for "Arrivals" and "Departures" which are handled by two separate controllers. The Ground Controllers' area of responsibility has been taken as that external to the Ramp Area but excluding active runways (except for crossing) and the turnoffs thereof.

To determine the operations level and associated delays the following procedure was used. For each runway a time history sheet of "Arrivals" and "Departures" was prepared as shown in sample data sheets of Table 5-8 using the aircraft flow events previously referenced. Next, a time period of one hour was selected; aircraft were included in the statistical sample based upon their entrance time into the Ground Controllers' area of responsibility. For departures, the criteria was that aircraft "LR" (Leave Ramp) time was within the hour while for arrivals "TO" (Turnoff R/W) time was used. For each aircraft observed in the selected hour, the following parameters were determined as shown in the sample Data Reduction sheets of Table 5-9 for departures and arrivals respectively. *

1. Departures:
   - T_{gd} - GC Service Time
   - T_{gdh} - Hold Time
   - T_{gdt} - Taxi (Movement) Time
2. Arrivals:
   - T_{gaw} - Entrance Delay
   - T_{ga} - GC Service Time
   - T_{gah} - Total Hold Time
   - T_{gat} - Taxi (Movement) Time
   - T_{caw} - Penalty Box Hold Time
   - T_{gah} - Taxi Hold Time

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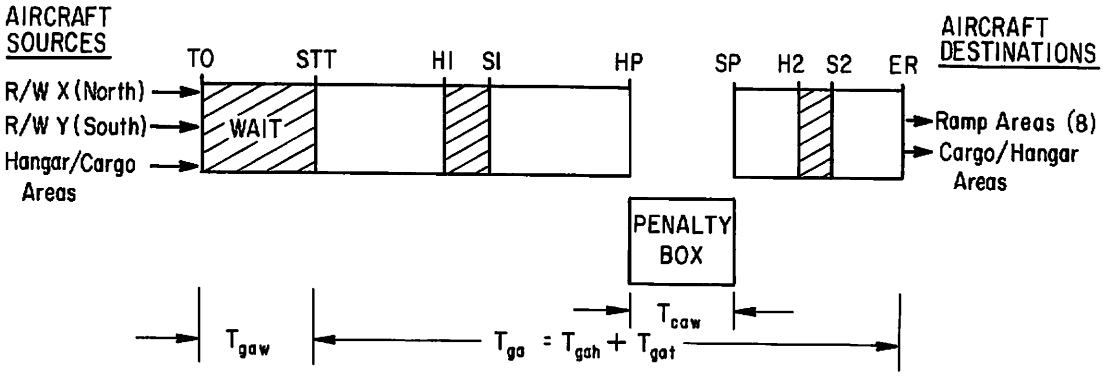
*The complete set of data reduction sheets for the Ground Controllers' area is provided in the Operational Analysis Data Supplement.



where

T_{gaw} = STT - TO — Entrance Delay at Turnoff

T_{ga} = $T_{gat} + T'_{gah}$ = ER-STT — GC Service Time (Arrivals)

T_{gat} = $T_{ga} - T_{gah}'$ — GC Taxi (Movement) Time

T_{gah}' = Σ (S1-H1) + (S2-H2) + __ + (SP-HP) — Total Hold Time

= $T_{caw} + T_{gah}$

where

T_{caw} = SP-HP — Penalty Box Hold Time

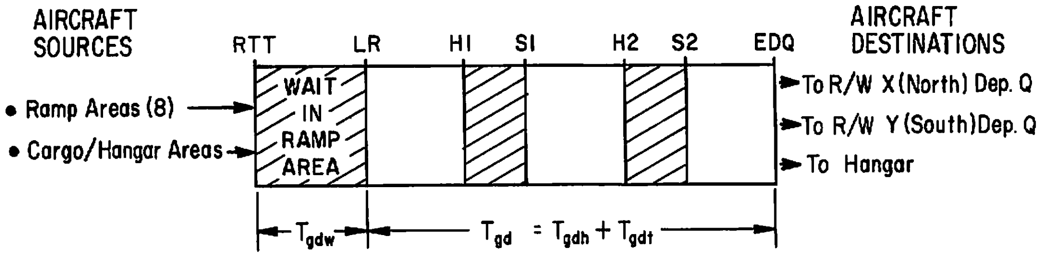
T_{gah} = $T_{gah}' - T_{caw}$ — Non-Penalty Box Hold Time

NOTES

1. The Hold in Penalty Box, of duration SP-HP, represents a delay due to gate unavailability rather than to taxiway congestion and is experienced by only some of the aircraft.

2. Subscript code - g = Ground Controllers' area
   a = Arrivals entering Ground Controllers' area
   w = Entrance delays
   h = Holds
   t = Taxiing (movement) times
   p = Penalty Box
   c = Carrier Area (Ramp Area)

Figure 5-7. Timing Relationships - Ground Controllers' Area - Arrivals



where

T_{gdw} = LR - RTT — Entrance Delay (Occurs in Ramp Area)

$T_{gd} = T_{gdt} + T_{gdh}$ — GC Service Time (Departures)

= EDQ - LR

$T_{gdh} = \Sigma$ (S1-H1) + (S2-H2) + __ — Total Hold Time

$T_{gdt} = T_{gd} - T_{gdh}$ — GC Taxi (Movement) Time

NOTES

1. T_{gdw} cannot be determined from ASDE films and was measured as part of ramp survey effort.

2. Subscript code - g = Ground Controllers' area
   d = Departures entering Ground Controllers' area
   w = Entrance delays
   h = Holds
   t = Taxiing (movement) time

Figure 5-8. Timing Relationships - Ground Controllers' Area - Departures

Table 5-8. Sample Data Sheet (1 of 2)

PAGE 1 RUN NO. 20 ASTC ORD ARRIVALS RUNWAY 27L

DATE 3-1-73 WEATHER ______ CEILING ______ VISIBILITY ______

No.	① OVER LAST LIGHT OL	② TURNOFF TO	③ START TAXI STT	④ ENTER RAMP AREA ER	RAMP ID	BEGIN HOLD 1	END HOLD 1	BEGIN HOLD 2	END HOLD 2	BEGIN HOLD 3	END HOLD 3	BEGIN HOLD 4	END HOLD 4
1	8 34 00	8 34 55		8 43 20	CAP Area								
2	8 36 20	8 37 06		8 41 46	A								
3	8 38 43	8 39 32		8 43 52	A	(Double check-RampArea - Small plane, hardly visible)							
4	8 40 12	8 40 57		8 43 11	DE								
5	8 41 54	8 42 43		8 44 57	DE	8 44 00	8 44 24						
6	8 43 42	8 44 24		8 46 39	HK	8 45 53	8 46 19						
7	8 46 07	8 46 45		8 48 07	HK								
8	8 47 54	8 48 37		8 56 41	EF	8 50 04	8 54 32						
9	8 49 29	8 50 24		8 52 39	GH								
10	8 51 06	8 51 45		8 58 40	FG	8 52 51	8 58 15						
11	8 52 55	8 53 24		8 58 00	DE	8 53 58	8 55 02						
12	8 54 34	8 55 27		8 58 25	GH	8 57 14	8 57 50						
13	8 56 25	8 57 18		9 04 38	EF	8 58 14	8 59 59	9 00 36	9 01 59	9 03 16	9 03 48		
14	8 58 02	8 58 33		8 59 41	FG								
15	8 59 42	9 00 26		9 02 57	DE								
16	9 01 18	9 02 05		9 03 25	FG								
17	9 03 57	9 04 37		9 07 28	DE								
18	9 05 15	9 05 55		9 07 36	EF								
19	9 06 39	9 07 16		9 09 35	HK								
20	9 08 04	9 09 39		9 13 32	GH								
21	9 10 42	9 11 21		9 13 16	HK								
22	9 12 10	9 12 52		9 16 20	FG	9 13 40	9 14 25						
23	9 14 17	9 15 03		9 16 46	EF								
24	9 15 49	9 16 28		9 17 59	HK	PB							
25	9 17 20	9 18 07		9 30 45	DE	9 21 55	9 26 07	9 29 14	9 30 02				
26	9 19 34	9 20 10		9 22 09	HK	9 20 25	9 20 49						
27	9 20 58	9 21 35		9 24 47	DE								
28	9 22 24	9 23 08		9 28 07	DE	9 24 09	9 27 00						
29	9 24 43	9 25 35		9 28 52	EF								
30	9 26 22	9 27 03		9 31 05	FG	9 26 23	9 29 28	9 29 40	9 30 30				
31	9 27 57	9 28 42		9 33 30	CD	9 29 24	9 30 12						
32	9 30 39	9 31 31		9 34 00	FG	9 33 06	9 33 35	Note 1					
33	9 31 50	9 32 58		9 36 47	E&K								

Note 1: Film darkened at 9:31:56 to 9:32:06 - Small plane difficult to trace After T.O.

Table 5-8. Sample Data Sheet (2 of 2)

ASTC ORD

PAGE 1 RUN NO 20 RUNWAY 32R

DEPARTURES

DATE 8-1-73 WEATHER______ CEILING ______ VISIBILITY______

No.	RAMP ID	LEAVE RAMP AREA LR	ENTER DEPARTURE QUEUE EDQ	No. OF AC IN QUEUE AT ENTRY	LEAVE DEPARTURE QUEUE LDQ	ON RUNWAY READY TO ROLL RTR	START TAKEOFF STO	BEGIN HOLD 1	END HOLD 1	BEGIN HOLD 2	END HOLD 2	BEGIN HOLD 3	END HOLD 3
1	E of K	8 34 20				8 35 57	8 35 57						
2	–	–				8 36 40	8 36 40						
3	DE	8 37 16				8 42 07	8 42 07						
4	FG	8 40 13				8 43 37	8 44 28						
5	DE	8 40 09				8 46 42	8 47 58	8 44 40	8 45 11				
6	DE	8 40 51	8 46 41	1	8 48 10	8 48 35	8 51 26	8 44 48	8 45 17				
7	FG	8 44 56	8 48 57	1	8 51 34	8 52 15	8 53 10						
8	FG	8 46 59	8 49 09		8 53 22	8 53 42	8 53 42						
9	DE	8 43 52	8 49 09		8 53 46	8 54 22	8 56 50	8 43 52	8 45 17	(Held at side of RAMP D)			
10	HK	8 48 22	8 51 42		8 58 29	8 58 40	8 58 40	8 48 34	8 49 47				
11	DE	8 47 10	8 52 25		8 59 17	8 59 59	9 00 50						
12	EF	8 59 09	9 02 41		9 03 00	9 03 30	9 04 28						
13	A	9 00 19	9 02 29		9 05 27	9 06 03	9 07 40						
14	EF	9 05 02	9 08 39		9 12 44	9 13 00	9 13 00						
15	CD	9 07 00	–		–	9 14 25	9 14 41	(Jumbo-bypassed queued A/C)					
16	AB	9 02 53	9 11 25		9 15 57	9 16 24	9 18 09	9 02 53	9 07 14	(RAMP Hold)			
17	GH	9 08 49	9 12 32		9 17 59	9 18 39	9 22 30						
18	FG	9 08 27	9 12 52		9 23 22	9 24 06	9 28 30						
19	K	9 12 42	9 14 27		9 31 41	9 32 10	9 33 35						
20	K	9 13 26	9 14 41		9 33 55	9 34 35	9 35 24						
21	DE	9 24 31	9 27 23		9 35 36	9 36 15	9 37 11						
22	HK	9 14 15	9 18 17		9 37 11	9 38 10	9 38 44	9 14 49	9 16 24				
23	K	9 19 24	9 20 29		9 39 06	9 39 48	9 40 27						
24	GK	9 18 19	9 22 40		9 40 53	9 41 20	9 41 20						
25	DE	9 32 09	9 35 08		9 42 50	9 43 29	9 43 29						
		NOTE: At times the A/C departing on 32R & 27R are in the same queue due to the closeness of the Runway entrances.											
26	GH	9 35 26	9 36 47		9 44 12	9 45 02	9 46 05						
27	FG	9 42 12	9 45 20		9 47 33	9 48 06	9 48 06						

Table 5-9. Sample Data Reduction Sheet (1 of 2)

RUN NO. 20 **DATE** 3-1-73 **GROUND CONTROLLER ANALYSIS**

RUNWAY 27R **DEPARTURES**

LR 8:40 - 9:40

No.	EDQ-LR $T_{gdt}+T_{gdh}$	Total Hold Time T_{gdh}	Taxi Time T_{gdt}
1	204	-	204
2	238	-	238
3	259	-	259
4	260	-	260
5	239	-	239
6	168	-	168
7	297	107	190
8	157	30	127
9	160	-	160
10	45	-	45
11	194	-	194
12	221	-	221
13	130	-	130
14	411	117	294
15	188	-	188
		ΣT_{gdh} 254	ΣT_{gdt} 2917
		No. Holds 3	N_a 15
			$\overline{T}_{gdt}$ 194

Table 5-9. Sample Data Reduction Sheet (2 of 2)

RUN NO. 20 **DATE** 3-1-70 **GROUND CONTROLLER ANALYSIS**

RUNWAY 27 L **ARRIVALS**

T. O. 8:40 to 9:40

No.	Wait Time T_{gaw}=SST-TO	ER-STT $T'_{gah}+T_{gat}$	Arrival Holds T'_{gah}	Taxi Service Time T_{gat}	Penalty Box Holds T_{caw}	Taxi Hold Time $T_{gah}=T'_{gah}-T_{caw}$
28	–	299	171	128	171	–
29	–	197	–	197	–	–
30	–	242	115	127	–	115
31	–	288	–	288	–	–
32	–	149	29	120	–	29
33	–	249	48	201	–	48
34	–	154	50	104	–	50
35	–	166	–	166	–	–
36	–	411	216	195	216	–

ΣT_{gaw} –		$\Sigma T'_{gah}$ 2080	ΣT_{gat} 5017	ΣT_{caw} 1456	ΣT_{gah} 624
No. Waits –		No. Holds 20	N_a 33	No. PB Holds 6	
			$\bar{T}_{gat}$ 152		

Taxi Queue Time ($\bar{T}_{ga}$) =

Next in the data reduction process was to sum the individual aircraft parameters for each runway. For departures, the following parameters were obtained:

N_d — Number of departure aircraft

$\sum T_{gdh}$ — Summation of all hold time

Number of Holds

$\bar{T}_{gdt}$ — Average taxi (movement) time

For arrivals the following summation values were obtained:

N_a — Number of arrival aircraft

$\sum T'_{gah}$ — Summation of all hold time

Number of all Holds

$\bar{T}_{gat}$ — Average taxi (movement) time

$\sum T_{caw}$ — Summation of all "Penalty Box" hold time

Number of Penalty Box Holds

$\sum T_{gah}$ — Summation of all hold time excluding Penalty Box hold time

These runway summation values were next used to develop a composite picture/summary of the aircraft flow within the total ground control (GC) area. Table 5-10 shows the results of the analyzed runs. In addition to the parameters previously discussed, these sheets present such parameters as average duration of Penalty Box "Holds" and other holds as well as the average time ($\bar{T}_g$) of the aircraft in the GC area as previously defined. From this parameter and the number of aircraft entering the GC area, the average hourly aircraft density, Q, may be determined as

$$Q = \left(\frac{N_a + N_d}{\Delta T} \right) \bar{T}_g$$

Table 5-10. Summary of Ground Control Aircraft Flow (1 of 12)

Run No. 15

Date 2-8-73 Start Time 9:05LR TO End Time 10:05LR TO Primary Arrival Runways 9R, 14L Arrival Mode from W (E or W)

Runway I. D.	Number of		Avg Taxi Time		Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays			Delay Time - seconds	
	Arr N_a	Dept Nd	Arr. $\bar{T}_{gat}$ sec.	Dept $\bar{T}_{gdt}$ sec.		# of Arrival "Waits"	#of all "Holds"	# of P.B. "Holds"	Total P B. ΣT_{caw}	All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area 4L										
32R										
9L		20		230	4,594	-	12	-	-	540
27R										
14L	26		286		7,428	-	13	-	-	1,040
22R										
18										
36										
Subtotal	26	20			12,022	-	25	-	-	1,580
South Area 4R										
32L										
9R	26	1	203	210	D 210 A 5285	- 1	1 12	- 3	- 561	D 665 A 459
27L										
14R										
22L		28		241	6,761	-	4	-	-	385
Subtotal	26	29			12,256	1	17	3	561	1,509
Airport Total	52	49			24,278 (a)	1	42	3	561 (b)	3,089 (c)
Averages	---	---	244	236	------	---	---	---	187 (1)	73.5 (2)

Avg. Time in System ($\bar{T}g$) = $\frac{a+b+c}{Na+Nd}$ = 276sec. - Aircraft Density Q = $\lambda\bar{T}g$ = $\frac{(Na+Nd)}{3600}\bar{T}g$ = 7.7

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

Run No. 20

Table 5-10. Summary of Ground Control Aircraft Flow (2 of 12)

Date 3-1-73 Start Time 8:40TQ LR End Time 9:40TQ LR Primary Arrival Runways 27L, 22R Arrival Mode from E (E or W)

Runway I. D.	Number of		Avg Taxi Time		Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays			Delay Time - seconds	
	Arr N_a	Dept Nd	Arr. T_{gat} sec.	Dept T_{gdt} sec.		# of Arrival "Waits"	#of all "Holds"	# of P.B. "Holds"	Total P B. ΣT_{caw}	All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area										
4L										
32R		23		205	4,704	-	6	-	-	574
9L										
27R	2	15	111	194	A 222 D 2,917	-	3 D	-	-	A - D - 254
14L										
22R	29		190		5,489	-	13	2	336	867
18										
36										
Subtotal	31	38			13,332	-	22	2	336	1,695
South Area										
4R										
32L										
9R										
27L	33	36	152	230	A 5,017 D 8,266	-	20 A 11 D	6	1,456	A 624 D 980
14R										
22L										
Subtotal	33	36			13,283	-	31	6	1,456	1,604
Airport Total	64	74			26,615 (a)	-	53	8	1,792 (b)	3,299 (c)
Averages	---	---	168	215	------	---	---	---	224 (1)	73 (2)

Avg. Time in System ($\bar{T}g$) = $\frac{a + b + c}{Na+Nd}$ = 230 sec. - Aircraft Density Q = $\lambda\bar{T}g = \frac{(Na + Nd)}{3600}\bar{T}g$ = 8.8

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

Table 5-10. Summary of Ground Control Aircraft Flow (3 of 12)

Run No. 29

Date 3-6-73 Start Time 18:02 End Time 19:02 Primary Arrival Runways 14L/9R Arrival Mode from W (E or W)

Runway I. D.	Number of		Avg Taxi Time		Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays			Delay Time - seconds	
	Arr N_a	Dept Nd	Arr. T_{gat} sec.	Dept T_{gdt} sec.		# of Arrival "Waits"	#of all "Holds"	# of P.B. "Holds"	Total P B. ΣT_{caw}	All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area										
4L		21		236	4,949	-	9	-	-	668
32R										
9L										
27R										
14L	27		271		7,319	0	11	6	1203	242
22R										
18										
36										
Subtotal	27	21			12,268	0	20	6	1203	910
South Area										
4R {(Adj from (1800/1845 data)		31		342	10,602	-	27	-	-	1500
32L										
9R	32		242		7,445	2	25	9	1896	746
27L										
14R		3		360E	1,080 E		0		-	-
22L										
Subtotal	32	34			19,127	2	52	9	1896	2246
Airport Total	59	55			31,395 (a)	2	72	15	3099 (b)	3156 (c)
Averages	---	---	250	302	275	---	---	---	206.6 (1)	55.4 (2)

Avg. Time in System ($\bar{T}g$) = $\frac{a+b+c}{Na+Nd}$ = 330 sec. - Aircraft Density Q = $\lambda\bar{T}g = \frac{(Na + Nd)}{3600}\bar{T}g$ = 10.5

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

Table 5-10. Summary of Ground Control Aircraft Flow (4 of 12)

Run No. 33

Date 3-7-73 Start Time 16:45 End Time 17:45 Primary Arrival Runways 27R, 27L Arrival Mode from E (E or W)

Runway I. D.	Number of		Avg Taxi Time		Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays			Delay Time - seconds	
	Arr N_a	Dept Nd	Arr. T_{gat} sec.	Dept T_{gdt} sec.		# of Arrival "Waits"	#of all "Holds"	# of P.B. "Holds"	Total P B. ΣT_{caw}	All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area										
4L										
32R		30		218	6,530	-	5	-	-	379
9L										
27R	32		170		5,453	1	14	3	769	419
14L										
22R	8		104		830	1	4	2	306	128
18										
36										
Subtotal	40	30			12,813	2	23	5	1,075	923
South Area										
4R										
32L		8		161	1,288	-	3	-	-	164
9R										
27L	34	3	176	414	5,994 A 1,241 D	0 -	16 A 2 D	5 A -	1,305	621 A 471 D
14R										
22L		27		273	7,383	-	5	-	-	208
Subtotal	34	38			15,906	-	26	5	1,305	1,464
Airport Total	74	68			28,719 (a)	2	49	10	2,380 (b)	2,387 (c)
Averages	---	---	165	242	202	---	---	---	238 (1)	61.5 (2)

Avg. Time in System ($\bar{T}g$) = $\frac{a+b+c}{Na+Nd}$ = 236 sec. - Aircraft Density Q = $\lambda\bar{T}g = \frac{(Na+Nd)}{3600}\bar{T}g$ = 9.3

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

Table 5-10. Summary of Ground Control Aircraft Flow (5 of 12)

Run No. 35

Date 3-8-73 Start Time 10:07 End Time 11:07 Primary Arrival Runways 27R, 32L Arrival Mode from E (E or W)

Runway I. D.	Number of Arr N_a	Number of Dept Nd	Avg Taxi Time (Based on TO and LR Times) Arr. T_{gat} sec.	Avg Taxi Time (Based on TO and LR Times) Dept T_{gdt} sec.	Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays # of Arrival "Waits"	Delays #of all "Holds"	Delays # of P.B. "Holds"	Delay Time - seconds Total P B. ΣT_{caw}	Delay Time - seconds All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area										
4L										
32R		29		222	6,440		1			150
9L										
27R	22	1	137	57	57 D 3,003 A	-	- D 1 A			19 A
14L										
22R	2		114		228	-	-	-	-	-
18										
36										
Subtotal	24	30			9,728	-	2	-	-	169
South Area										
4R										
32L	25	1	190	193	193 D 4,760 A	-	1 D 5 A	4	496	49 D 140 A
9R										
27L		26		235	6,097		-			
14R										
22L										
Subtotal	25	27			11,050	-	6	4	496	189
Airport Total	49	57			20,778 (a)	-	8	4	496 (b)	358 (c)
Averages	---	---	163	224	197	---	---	---	124 (1)	90 (2)

Avg. Time in System ($\bar{T}g$) = $\frac{a+b+c}{Na+Nd}$ = 202 sec. - Aircraft Density Q = $\lambda\bar{T}g = \frac{(Na + Nd)}{3600} \bar{T}g$ = 5.9

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

Run No. 37

Table 5-10. Summary of Ground Control Aircraft Flow (6 of 12)

Date 3-8-73 Start Time 3:36TO LR End Time 4:36TO LR Primary Arrival Runways 14R,14L Arrival Mode from W (E or W)

Runway I. D.	Number of		Avg Taxi Time		Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays			Delay Time - seconds	
	Arr N_a	Dept N_d	Arr. T_{gat} sec.	Dept T_{gdt} sec.		# of Arrival "Waits"	#of all "Holds"	# of P.B. "Holds"	Total P B. ΣT_{caw}	All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area										
4L										
32R										
9L		27		209	5,633		7			345
27R										
14L	32		247		7,894	0	22	7	1,180	516
22R	2		96		192	0	2	0	0	50
18										
36										
Subtotal	34	27			13,719	-	31	7	1,180	911
South Area										
4R										
32L										
9R		34		209	7,121		39			4,702
27L										
14R	37		176		6,524	3	19	3	809	668
22L										
Subtotal	37	34			13,645	3	58	3	809	5,370
Airport Total	71	61			27,364 (a)	3	89	10	1,989 (b)	6,281 (c)
Averages	---	---	171	209	207	---	---	---	199 (1)	80 (2)

Avg. Time in System $(\bar{T}g) = \frac{a + b + c}{Na+Nd}$ = 272 sec. - Aircraft Density $Q = \lambda\bar{T}g = \frac{(Na + Nd)}{3600}\bar{T}g$ = 9.9

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

Run No. 39

Table 5-10. Summary of Ground Control Aircraft Flow (7 of 12)

Date 3-9-73 Start Time 8:29TO LR End Time 9:29TO LR Primary Arrival Runways 9R,14L . Arrival Mode from W (E or W)

Runway I. D.	Number of		Avg Taxi Time		Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays			Delay Time - seconds	
	Arr N_a	Dept N_d	Arr. T_{gat} sec.	Dept T_{gdt} sec.		# of Arrival "Waits"	#of all "Holds"	# of P.B. "Holds"	Total P B. ΣT_{caw}	All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area										
4L		22		189	4,157	-	1 D	-	-	24
32R										
9L	2		63		125	-	-	-	-	-
27R										
14L	33		301		9,929	-	23 A	5	1,202	2,329
22R										
18										
36										
Subtotal	35	22			14,211	-	24	5	1,202	2,353
South Area										
4R		51		457	23,292	-	39 D	-	-	6,201
32L										
9R	24		166		3,975	1	12 A	2	921	826
27L										
14R	5	3	235	117	D 699 A 1,177	- 1	1 D 3	- -	- -	D 228 A 210
22L										
Subtotal	29	54			29,143	2	55	2	921	7,467
Airport Total	64	76			43,354 (a)	2	79	7	2,123 (b)	9,820 (c)
Averages	---	---	238	370	------	---	---	---	303 (1)	124 (2)

Avg. Time in System ($\bar{T}g$) = $\frac{a+b+c}{Na+Nd}$ = 395 sec. - Aircraft Density Q = $\lambda\bar{T}g$ = $\frac{(Na+Nd)}{3600}\bar{T}g$ = 15.4

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

Run No. CSC 5

Table 5-10. Summary of Ground Control Aircraft Flow (8 of 12)

Date 1-16-74 Start Time 4:42TO LR End Time 5:42TO LR Primary Arrival Runways 27R, 32L Arrival Mode from E (E or W)

Runway I. D.	Number of		Avg Taxi Time		Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays			Delay Time - seconds	
	Arr N_a	Dept Nd	Arr. T_{gat} sec.	Dept T_{gdt} sec.		# of Arrival "Waits"	#of all "Holds"	# of P.B. "Holds"	Total P B. ΣT_{caw}	All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area										
4L										
32R		30		213	6,395		-	-	-	-
9L										
27R	32		173		5,524	-	16	1	241	980
14L										
22R										
18										
36		9		158	1,420		-	-	-	-
Subtotal	32	39			13,339		16	1	241	980
South Area										
4R										
32L	35	1	240	62	A 8,417 D 62	-	A 20 D -	A 5 D -	A 836	A 862
9R										
27L	3	28	110	271	A 329 D 7,593		A 2 D 1	-	-	A 49 D 18
14R										
22L										
Subtotal	38	29			16,401	-	23	5	836	935
Airport Total	70	68			29,740 (a)	-	39	6	1,077 (b)	1,915 (c)
Averages	---	---	204	228	------	---	---	---	180 (1)	49 (2)

Avg. Time in System ($\overline{T}g$) = $\frac{a + b + c}{Na+Nd}$ = 266 sec. - Aircraft Density Q = $\lambda\overline{T}g$ = $\frac{(Na + Nd)}{3600}$ $\overline{T}g$ = 10.6

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

Table 5-10. Summary of Ground Control Aircraft Flow (9 of 12)

Run No. CSC 7
Date 1-17-74 Start Time 2:45TQ LR End Time 3:45TQ LR Primary Arrival Runways 14L,14R Arrival Mode from W (E or W)

Runway I. D.	Number of Arr N_a	Number of Dept Nd	Avg Taxi Time Arr. $\bar{T}_{gat}$ sec.	Avg Taxi Time Dept $\bar{T}_{gdt}$ sec.	Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays # of Arrival "Waits"	Delays #of all "Holds"	Delays # of P.B. "Holds"	Delay Time - seconds Total P B. ΣT_{caw}	Delay Time - seconds All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area 4L										
32R										
9L		27		155	4,173	-	3	-	-	271
27R										
14L	26		271		7,056	-	9	-	-	472
22R										
18										
36										
Subtotal	26	27	271	155	11,229	-	12	-	-	713
South Area 4R										
32L										
9R		30		235	7,060	-	22	-	-	1,452
27L										
14R	27		220		5,936	-	17	1	200	1,106
22L										
Subtotal	27	30	220	235	12,996	-	39	1	200	2,558
Airport Total	53	57			24,225 (a)	-	51	1	200 (b)	3,271 (c)
Averages	---	---	245	197	------	---	---	---	200 (1)	64.1 (2)

Avg. Time in System ($\bar{T}g$) = $\frac{a + b + c}{Na+Nd}$ = 252 sec. - Aircraft Density Q = $\lambda\bar{T}g$ = $\frac{(Na + Nd)}{3600}\bar{T}g$ = 7.6

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

Table 5-10. Summary of Ground Control Aircraft Flow (10 of 12)

Run No. CSC 9

Date 1-18-74 Start Time 1:15LR TO End Time 2:15LR TO Primary Arrival Runways 14L, 14R Arrival Mode from W (E or W)

Runway I. D.	Number of		Avg Taxi Time		Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays			Delay Time - seconds	
	Arr N_a	Dept N_d	Arr. T_{gat} sec.	Dept T_{gdt} sec.		# of Arrival "Waits"	#of all "Holds"	# of P.B. "Holds"	Total P B. ΣT_{caw}	All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area										
4L										
32R										
9L		19		271	5,148	-	3	-	-	249
27R										
14L	31		275		8,525	1	28	5	2,535	1022
22R										
18										
36										
Subtotal	31	19			13,673	1	31	5	2,535	1326
South Area										
4R										
32L										
9R										
27L		35		263	9,191	-	2	-	-	191
14R	30		260		7,812	-	26	10	9,914	828
22L										
Subtotal	30	35			17,0003	-	28	10	9,914	1,019
Airport Total	61	54			30,676 (a)	1	59	15	12,449 (b)	2,345 (c)
Averages	---	---	267	267	------	---	---	---	830 (1)	53 (2)

Avg. Time in System ($\bar{T}g$) = $\frac{a + b + c}{Na+Nd}$ = 395 sec. - Aircraft Density Q = $\lambda\bar{T}g$ = $\frac{(Na + Nd)}{3600}$ $\bar{T}g$ = 11.9

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

Table 5-10. Summary of Ground Control Aircraft Flow (11 of 12)

Run No. CSC 10
Date 1-23-74 Start Time 6:34LR End Time 7:34LR Primary Arrival Runways 27R, 32L Arrival Mode from E (E or W)
TO TO

Runway I. D.	Number of		Avg Taxi Time		Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays			Delay Time - seconds	
	Arr N_a	Dept Nd	Arr. T_{gat} sec.	Dept T_{gdt} sec.		# of Arrival "Waits"	#of all "Holds"	# of P.B. "Holds"	Total P B. ΣT_{caw}	All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area										
4L										
32R		23		187	4,290	-	1	-	-	52
9L										
27R	33		226	-	7,451	-	3	1	496	85
14L										
22R										
18										
36										
Subtotal	33	23	-	-	11,741	-	4	1	496	137
South Area										
4R										
32L	33		212		7,003	-	10	3	954	356
9R										
27L	4	23	206	244	A 824 D5,619		A 1 D 1	-	-	A 161 D 67
14R										
22L										
Subtotal	37	23	-	-	13,446	-	12	3	954	584
Airport Total	70	46	-	-	25,187 (a)	-	16	4	1,450(b)	721 (c)
Averages	---	---	218	215	------	---	---	---	363(1)	45.6 (2)

Avg. Time in System ($\overline{T}g$) = $\frac{a+b+c}{Na+Nd}$ = 236 sec. - Aircraft Density Q = $\lambda\overline{T}g = \frac{(Na + Nd)}{3600}\overline{T}g$ = 7.6

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

Run No. CSC 8

Table 5-10. Summary of Ground Control Aircraft Flow (12 of 12)

Date 1-18-74 Start Time 8:50D / 8:54A End Time 9:50D / 9:54A Primary Arrival Runways 14R & 14L Arrival Mode from W (E or W)

Runway I. D.	Number of		Avg Taxi Time		Total Taxi Time-ΣT_{gat} and/or ΣT_{gdt} seconds	Delays			Delay Time - seconds	
	Arr N_a	Dept Nd	Arr. T_{gat} sec.	Dept T_{gdt} sec.		# of Arrival "Waits"	#of all "Holds"	# of P.B. "Holds"	Total P B. ΣT_{caw}	All excl. P.B. ΣT_{gah} and/or ΣT_{gdh}
North Area										
4L										
32R										
9L		27		249	6,721		7	0		240
27R										
14L	28		283		7,934	0	22	5	635	786
22R										
18										
36										
Subtotal	28	27	283	249	14,655	0	29	5	635	1,026
South Area										
4R										
32L										
9R										
27L										
14R	28	21	202	401	a) 5656/ d) 8427	2	A) 14 D) 1	4	616	A) 416/ D) 43
22L										
Subtotal	28	21	202	401	14,083	2	15	4	616	459
Airport Total	56	48			28,738 (a)	2	44	9	1,251 (b)	1,485 (c)
Averages	---	---	242	325	------	---	---	---	139.0 (1)	42 (2)

Avg. Time in System ($\bar{\bar{T}}g$) = $\frac{a + b + c}{Na+Nd}$ = 302.6 sec. - Aircraft Density Q = $\lambda \bar{\bar{T}}g$ = $\frac{(Na + Nd)}{3600} \bar{\bar{T}}g$ = 8.7

Notes: (1) Avg. Time in P.B. (2) Divided by number of non P.B. "Holds"

5.3.2.2 Summary of Results of Ground Control Analysis

Table 5-11 summarizes the results of the various runs which have been analyzed. These runs have been separated into either an "Arrival from the West" or "Arrival from the East" mode of runway operation. This table presents average taxi (movement) time for arrivals, departures, and all aircraft as well as delay statistics. The latter includes the number of arrival waits at runway turnoffs and the number of non-penalty box holds as well as penalty box holds. The average delay time associated with each of the last two delays is also presented.

Data compiled from the individual run sheets are presented in the summary table. Also included is the average time of an aircraft in the ground system (i.e., from ramp exit to departure queue entrance or from turnoff to ramp entrance) and the hourly average aircraft density (Q). The average delay times have been normalized to the number of operations per hour to permit addition of delays occurring in the several portions of the surface area (ramp, ground control, local). The data from the summary table have been used to develop a graphical presentation of the results of this analysis.

5.3.2.3 Penalty Box Delay

The normalized penalty box delay time per operation has been plotted vs operations level in Figure 5-9. There does not appear to be any difference between East and West mode of operation. There is a general upward trend with operations/hour. At 140 operations/hour an average of eight aircraft would be sent to the box (over 10 percent of the arrivals) for over three minutes each, a substantial delay. The delay does appear to depend upon the ratio of arrivals to departures. More arrivals than departures should tend to clog up the gates. In Figure 5-9 all the points above the curve have an excess of arrivals and all the points below the curve (except CSC #5 for which arrivals are about equal to departures) have an excess of departures.

Table 5-11. Summary - Aircraft Flow Statistics - Ground Control

Run No.	Ops/Hr		Avg Taxi Time (seconds)			Delays				Delay Time			Avg Time of A/C in Grd System			Q - A/C Density		Non PB Delay Time/ Oper. (secs)	PB Delay Time/ Oper. (secs)
	Arr	Dep				# of Arr. "Waits"	# of Non PB "Holds"		# of PB "Holds"	Avg PB Time	Avg Other "Holds"	Ratio (in %) $\frac{\Sigma\text{Hold}}{\Sigma\text{Taxi}}$[1]							
	N_a	N_d	$\overline{T}_{gat}$	$\overline{T}_{gdt}$	$\overline{T}_{gt}$		Arr	Dep					Arr	Dep	All	Arr	Dep		
ARRIVALS FROM EAST																			
TSC 20	64	74	168	215	193	-	25	20	8	224	73	10.4	219	239	230	3.9	4.9	24.0	12.9
TSC 33	74	68	165	242	202	2	24	15	10	238	61	8.2	214	260	236	4.4	4.9	16.7	16.8
TSC 35	49	57	163	224	197	0	2	2	4	124	90	1.7	176	227	202	2.4	3.6	3.4	4.7
CSC 5	70	68	204	228	215	0	32	1	6	180	49	6.4			266	10.6[6]		13.9	7.8
CSC 10	70	46	218	215	216	0	10	2	4	363	46	2.9			236	7.6[6]		6.2	12.5
ARRIVALS FROM WEST																			
CSC 7	53	57	245	197[4]	220	-	25	25	1	200	64.1	13.5			252	7.6[6]		29.8	1.8
CSC 8	56	48	242	313	276	2	27	8	9	139	42	5.2			303	8.7[6]		14.3	12.0
CSC 9	61	54	268	265	266	1	40	5	15	830	53	7.6			395	11.9[5,6]		20.3	109.0
TSC 15	52	45	244	236	239	1	22	17	3	187	73	12.6			276	7.7[6]		30.5	5.6
TSC 29	59	55	250	302	275	2	21	36	15	207	55	10.0	320	342	330	5.2	5.2	27.3	27.3
TSC 37	71	61	206	208	207	3	33	46	10	199	80	22.9[2]	251	292	272	5.0	5.0	47.7	15.0
TSC 39	64	76	238	370	309	2	31	41	7	303	124	22.5[3]			395	15.4[6]		70.0	6.6

NOTES

1. Not incl. PB Time.
2. Primarily due to A/C departure on 9R; RW change at 15:25
3. Primarily due to A/C departure on 4R.
4. Due to size of departure queue.
5. Due to Penalty Box Delays.
6. Total of these 2 columns.

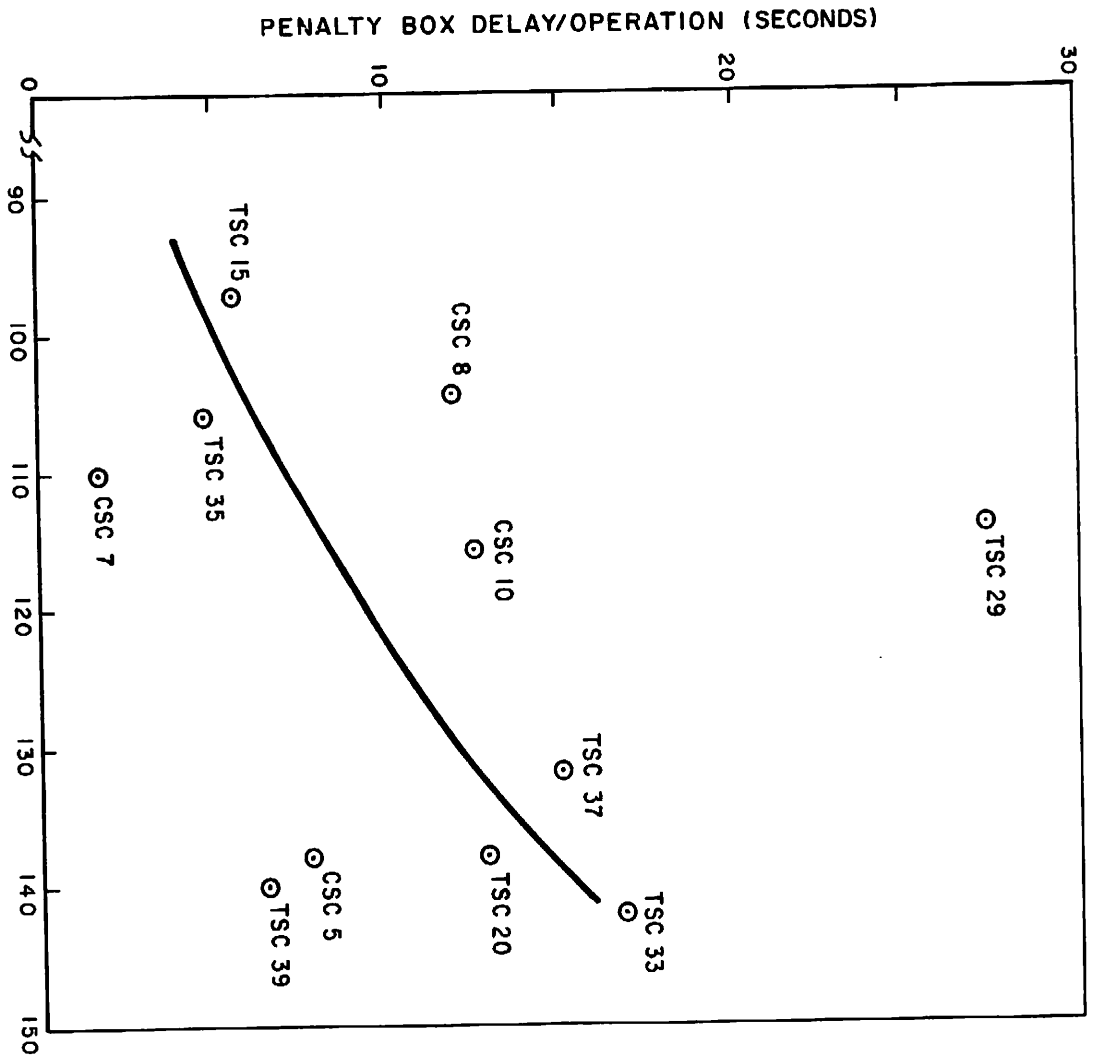


Figure 5-9. Penalty Box Delays

5.3.2.4 Non-Penalty Box Delay

The normalized non-penalty box delay time per operation has been plotted vs operations level in Figure 5-10. The substantial difference in the two runway configuration modes is readily apparent. The "Arrivals from the West" mode appears to have almost a minute longer taxi time. This is due simply to the longer taxi routes in this mode especially for the North side arrivals from 14L. In addition, the West mode has almost a minute more delay being experienced at high operations levels (135 operations/hour).

In examining the differences in delay each of the runs were analyzed in detail.

In all, twelve runs were analyzed, each consisting of one hour of airport operations. Table 5-12 summarizes the runs included in the analysis and gives the number of flights and number of holds observed in each.

Table 5-12. Summary of Analyzed Runs

Run	Direction	No. of Flights	No. of Holds
TSC			
15	West	100	40
20	East	136	50
29	West	110	62
33	East	142	44
35	East	106	8
37	West	130	82
39	West	140	83
CSC			
5	East	138	35
7	West	110	50
8	West	104	43
9	West	116	46
10	East	116	12

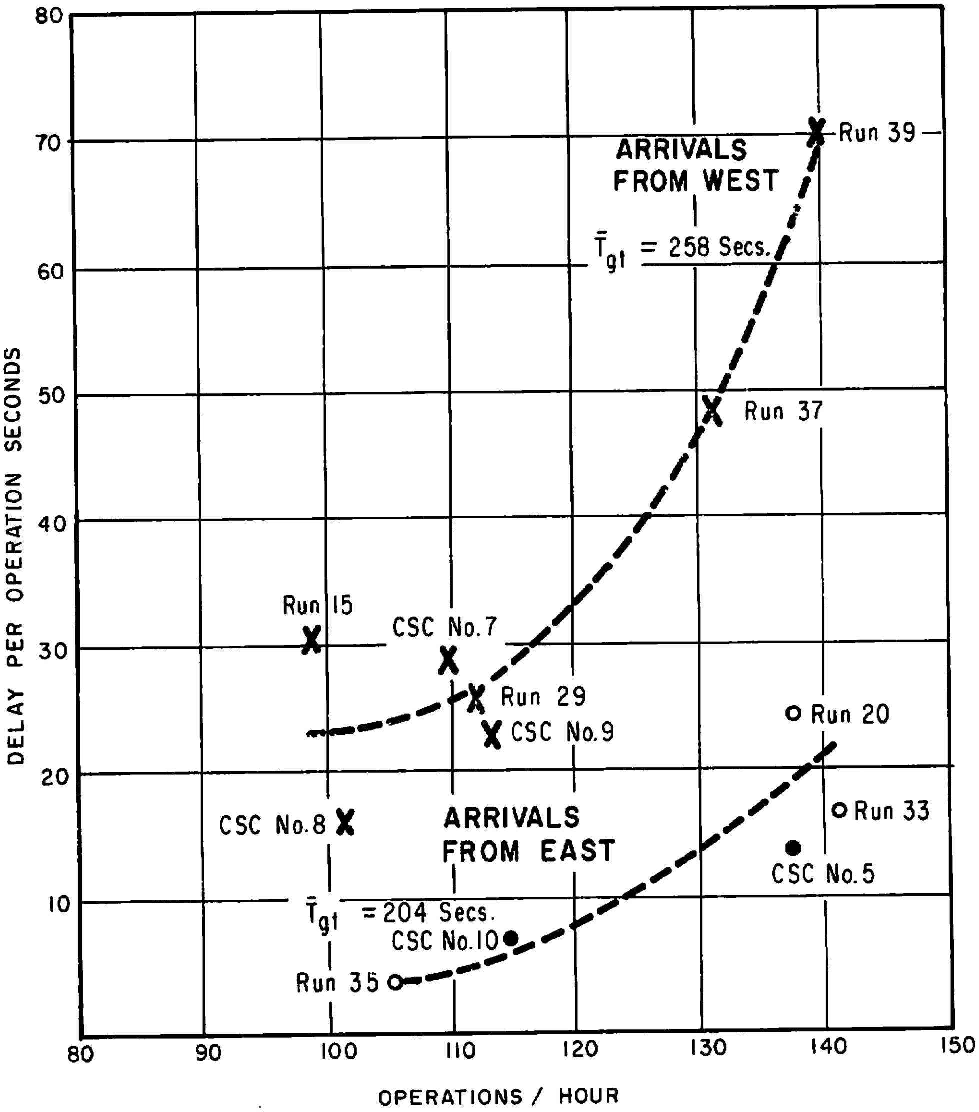


Figure 5-10. Aircraft Delay in Ground Control Area

For the purpose of the analysis a "hold" was defined as any stop while taxiing excluding penalty box and departure queues. Holds were categorized as follows based on observation of the traffic conditions apparent on the ASDE films:

1. Competing Traffic - Aircraft stops due to other traffic on taxiways such as another aircraft crossing its path, stopped traffic ahead, merging traffic, etc.

2. Runway Crossing - Aircraft stops prior to crossing a runway whether or not the runway is active.

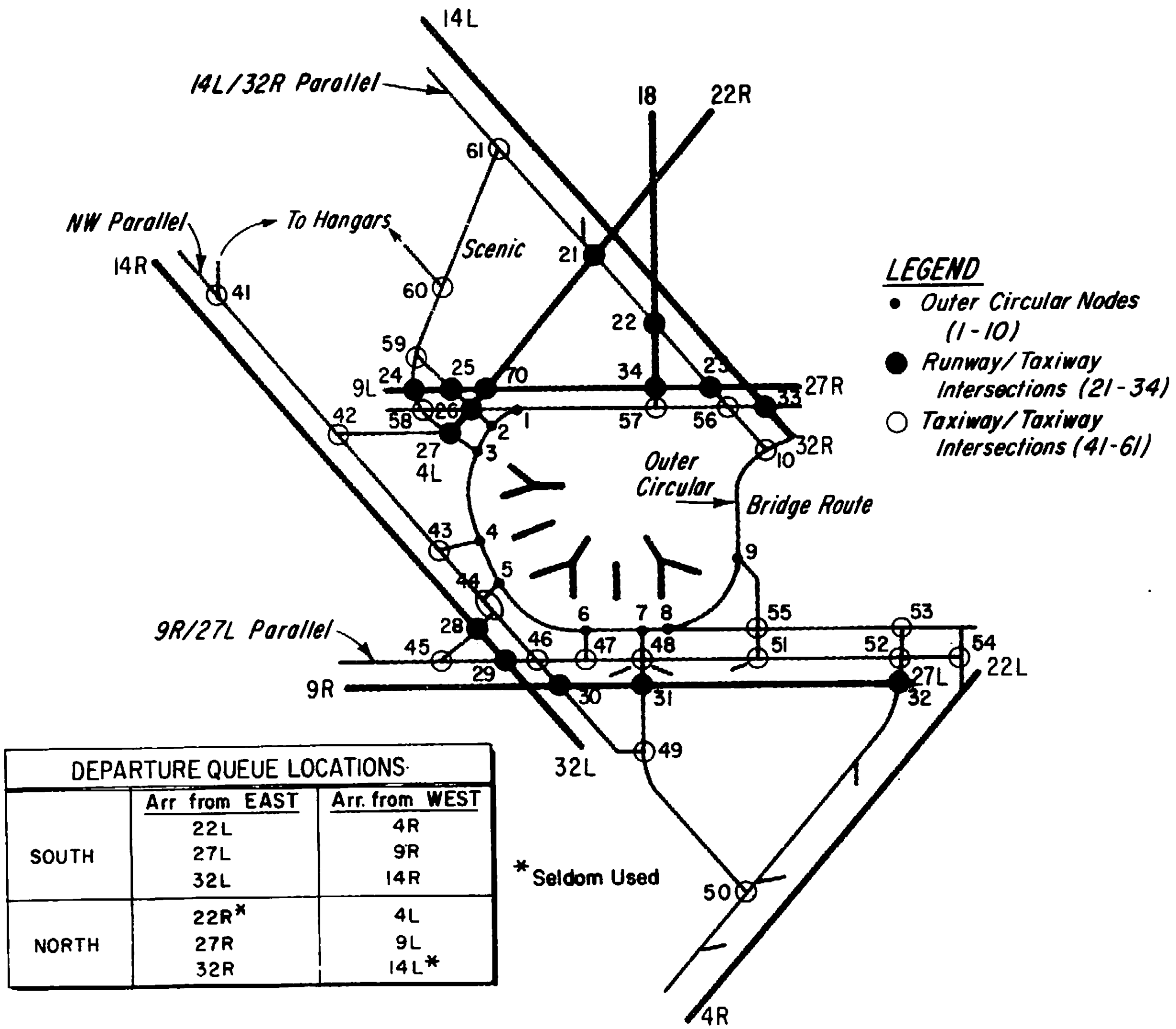
3. Ramp Congestion - Aircraft stops due to ramp operations or to await a gate. This does not include penalty box holds.

4. Unknown - Stops for which no reason is apparent.

5. Other - Any holds for reasons not included in the above categories.

In addition to ascertaining the reason for each hold, the location of each was also noted so that high incidence areas could be identified. For ease in indicating the location of holds, certain significant intersections in the taxiway system were assigned numbers as shown on the diagram in Figure 5-11. Numbers from 1 to 10 indicate intersections on the Outer Circular, 21 to 34 are intersections between runways and taxiways, 41 to 63 are taxiway/taxiway intersections, and 70 is the intersection of runways 4L/22R and 9L/27R. Locations along the Inner Circular and adjacent ramp entrances are indicated by the ramp letter designations (i. e., A to K).

The hold data from each of the twelve runs is given in Table 5-13. Arrival and departure runways in both north and south portions of the field are shown and the total number of flights related to each and the number of holds observed for those flights. In each column under specific hold reasons, the location of each hold is given by the appropriate designation from Figure 5-11. When holds were observed between designated intersections and/or ramp areas, two letters or numbers separated by a slash are used, e. g., if a hold occurred between intersections 3 and 4 on the Outer Circular the designation 3/4 is used. Similarly, holds in the area of the Inner between Ramps G and H are entered as G/H.



DEPARTURE QUEUE LOCATIONS		
	Arr from EAST	Arr. from WEST
SOUTH	22L 27L 32L	4R 9R 14R
NORTH	22R* 27R 32R	4L 9L 14L*

*Seldom Used

Figure 5-11. Intersection Numbering - O'Hare (CSC Assigned)

Table 5-13. Breakdown of Holds by Location and Cause (1 of 12)

Run	Runways				Total Flights	No. of Holds	Reason and Location of Holds				
	Departures		Arrivals				Competing Traffic	Runway Crossing	Ramp Congestion	Unknown	Other
	North	South	North	South							
15	9L				20	12	3/B 3/B E E 2/3 B H H			1 26 A 26	
		22L			28	4	55 H/K		D	55	
			14L		26	12	55 53 3/4 4	23 70 34	K C E 4	1	
				9R	26	12	4 5 4 7 7 7 48		4 H K F/G	7	
TOTAL					100	40	21	3	9	7	

Table 5-13. Breakdown of Holds by Location and Cause (2 of 12)

Run	Runways				Total Flights	No. of Holds	Reason and Location of Holds				
	Departures		Arrivals				Competing Traffic	Runway Crossing	Ramp Congestion	Unknown	Other
	North	South	North	South							
20	27R				15	3	8/63	56 25			
	32R				23	6				56 56 D/E A/B H/K H/K	
		27L			36	11	H/K 7 7 8/63 8/63 8/63 8/63 7			8/63 H/K H/K	
			22R		29	12	7 2 5	34 34	6 A 4 6	22	63 63
				27L	33	18	6 7 7 5 4 4 6 5/6 7 7		8 6 6 6	5 5 4 48	
TOTAL					136	50	22	4	8	14	2

Table 5-13. Breakdown of Holds by Location and Cause (3 of 12)

Run	Runways				Total Flights	No. of Holds	Reason and Location of Holds				
	Departures		Arrivals								
	North	South	North	South			Competing Traffic	Runway Crossing	Ramp Congestion	Unknown	Other
29	4L				25	9	53/55 63 7 3 5 6/7 5/6		H/K	2	
		4R			23	20	D/E D/E	13 AC at 30 5 AC at 46*			
		14R			3	0					
			14L		27	10	7/8 7/8 4/D 4/D	34	G F/G F/G H/K C		
				9R	32	23	8/63 5 8/63 7 7 7 55/63 6/7 6/7 2 7 6/7 5/6 5/6 6/7 5/6 5/6		H F G F H	2	
TOTAL					110	62	30	19	11	2	

*includes 1 AC which stopped at both 46 and 30.

Table 5-13. Breakdown of Holds by Location and Cause (4 of 12)

Run	Runways				Total Flights	No. of Holds	Reason and Location of Holds				
	Departures		Arrivals				Competing Traffic	Runway Crossing	Ramp Congestion	Unknown	Other
	North	South	North	South							
33	32R				30	5	B B/C B/C			57	8/9
		32L			8	3	E			4/43 44	
		22L			27	4	52/53 53 53 H/K				
		27L			3	0					
			22R		8	7	3/4 6 2	70 70 70	H/K		
			27R		32	11	4 1 4 5 5 53/55 7 4		G/H G	1	
				27L	34	14	6 7 48 5/44 6 7 7 7		4 4 F E D	46/47	
TOTAL					142	44	27	3	8	5	1

Table 5-13. Breakdown of Holds by Location and Cause (5 of 12)

Run	Runways				Total Flights	No. of Holds	Reason and Location of Holds				
	Departures		Arrivals				Competing Traffic	Runway Crossing	Ramp Congestion	Unknown	Other
	North	South	North	South							
35	32R				29	1					33
	27R				1	0					
		32L			1	1		31			
		27L			26	0					
			22R		2	0					
			27R		22	1	4				
				32L	25	5	48 7 48			6 48	
TOTAL					106	8	4	1	0	2	1

Table 5-13. Breakdown of Holds by Location and Cause (6 of 12)

Run	Runways				Total Flights	No. of Holds	Reason and Location of Holds				
	Departures		Arrivals				Competing Traffic	Runway Crossing	Ramp Congestion	Unknown	Other
	North	South	North	South							
37	9L				27	7	B D G 27 G 27				58
		9R			34	40	44 4 4/5 45	12 Stops at 28/44 /5. 24 Stops at 29/46/47/48			
			14L		32	19	9 8 8	23 70 34 34 23	D 9 5/6 F/G H C A/B	2 A/B	10 K
				14R	37	16	4 43 6 42/43 4 5/6 42/43 4 6 27		5/6 6 4 4 7	4/5	
TOTAL					130	82	23	41	12	3	3

Table 5-13. Breakdown of Holds by Location and Cause (7 of 12)

Run	Runways				Total Flights	No. of Holds	Reason and Location of Holds				
	Departures		Arrivals				Competing Traffic	Runway Crossing	Ramp Congestion	Unknown	Other
	North	South	North	South							
39	4L				22	1	H/K				
		4R			51	51	D 50 H D 50 2/3 50 48 8 K	16 AC at 32 21 AC at 30		H/K H/K H/K	4R Pad
		14R			3	1					44
			14L		33	18	9 9/10 6 B	34	9 9/10 9/10 G/H 7 7 G/H H 7 H/K 6	B/C 8	
				14R	5	3	43		8	43	
				9R	24	9	5 7 48 D 6 7 6		7 G/H		
				9L	2	0					
TOTAL					140	83	23	38	14	6	2

Table 5-13. Breakdown of Holds by Location and Cause (8 of 12)

Run	Runways				Total Flights	No. of Holds	Reason and Location of Holds				
	Departures		Arrivals								
	North	South	North	South			Competing Traffic	Runway Crossing	Ramp Congestion	Unknown	Other
CSC 5	32R				30	0					
	36				9	0					
		27L			28	3	5 7 7				
		32L			1	0					
			27R		32	15	4 5 A/B 4 4 2 F/G		A/B H/K C/D A/B 5/6 F/G F/G G/H		
				32L	35	15	42/43 43 5 4/5 4 6 6		7/8 G/H 7/8 C/D F/G 6 7/8	42	
				27L	3	2	48 7				
TOTAL					138	35	19		15	1	

Table 5-13. Breakdown of Holds by Location and Cause (9 of 12)

Run	Runways				Total Flights	No. of Holds	Reason and Location of Holds				
	Departures		Arrivals				Competing Traffic	Runway Crossing	Ramp Congestion	Unknown	Other
	North	South	North	South							
CSC 7	9L				27	3	4			58 58	
		9R			30	22	47/48 6	28 28 18 holds at 29*			
			14L		26	9		34 23 23	H/K B B G F C		
				14R	27	16	4 43/4 43/4 4 4/3 4/3 2/1 27 27 44 27 42**	33	D K	56	
TOTAL					110	50	15	24	8	3	

*4 AC had 2 HOLDS each.

**These 12 HOLDS due to 9L Departure Queue

Table 5-13. Breakdown of Holds by Location and Cause (10 of 12)

	Runways						Reason and Location of Holds				
	Departures		Arrivals		Total	No. of	Competing	Runway	Ramp		
Run	North	South	North	South	Flights	Holds	Traffic	Crossing	Congestion	Unknown	Other
CSC 8	9L				27	7	3 B E/F 4 D/E			3 3	
		14R			21	1	4				
			14L		28	21	26 2 26	70 34 70 23 23 23 34 34 34 23 70	7 7 C/D 6/7	8/9 10 26	
				14R	28	14	2 7 4 4 G/H 41/42 41/42		7 6/7 F F/G C/D	47 43	
TOTAL					104	43	16	11	9	7	

Table 5-13. Breakdown of Holds by Location and Cause (11 of 12)

Run	Runways				Total Flights	No. of Holds	Reason and Location of Holds				
	Departures		Arrivals				Competing Traffic	Runway Crossing	Ramp Congestion	Unknown	Other
	North	South	North	South							
CSC 9	9L				19	3	3 3 3/B				
		27L			35	2	5/6 5/6				
			14L		31	24	55/53 H/K 3 H	70 34 34 70	9/63 H/K 7 H/7 D D 7 H/7 C 9 H/K H	56/10 23/56 56	1
				14R	31	17	6 46 26 4 6 6 43 4		6 F/G 8	43/44 29/46 43 47/6 43 24*	
TOTAL					116	46	17	4	15	9	1

*Some of these HOLDS may be due to lack of space in the Penalty Box.

Table 5-13. Breakdown by Holds by Location and Cause (12 of 12)

Run	Runways				Total Flights	No. of Holds	Reason and Location of Holds				
	Departures		Arrivals				Competing Traffic	Runway Crossing	Ramp Congestion	Unknown	Other
	North	South	North	South							
CSC 10	32R				23	1				33	
		27L			23	1	6				
			27R		33	2	6/7 4				
				32L	33	7	4 4 4 6/7 4		E 7		
				27L	4	1			H/K		
TOTAL					116	12	8		3	1	

Table 5-14 presents a summary breakdown of holds observed for arrival and departure flights by East and West Arrival modes. Of the 1448 flights observed, 810 were in the west mode of operations and these had 406 holds, or a .50 hold-per-flight ratio. The 638 flights in the east mode had 149 holds or a .23 hold-per-flight ratio which is approximately half that for the west. The higher ratio for the west mode is directly attributed to the higher incidence of runway crossing holds. These were caused by the use of Runway 4R for departures with 9R for arrivals (55 holds), 9R for departures with 14R for arrivals (56 holds), and the use of 9L for departures with 14L for arrivals (29 holds). To examine the impact of the runway crossings on the delay curve in Figure 5-10, the two high delay points (TSC #39 and TSC #37) are broken down by category of delay in Table 5-15. As expected, the major element is due to runway crossing.

If the runway crossing is subtracted from the total for the two cases and the adjusted points plotted on Figure 5-10, they fall close to the curve for the East arrival mode. It is presumed that a similar adjustment to all the West mode points would produce a common delay curve showing 10 seconds to 30 seconds of delay per aircraft at the higher operations rates (135 operations/hour). The total delay is similar to that for penalty box holds; however, its impact is not as dramatic since it is distributed over more aircraft (i.e., an average of 48 non-penalty box holds vs 8 penalty box holds).

In considering why the runway crossing delays increase sharply at 130 to 140 operations/hour, it is necessary to consider runway capacity. Paragraph 5.3.3 will show that the current quota (135 operations/hour) is quite consistent with the capacity of the runways. Operations (e.g., TSC #37 and TSC #39) for which departures must cross an active arrival runway and which are near capacity building a queue, should tend to experience increased crossing delays as the controller (Ground Control) loses the incentive to be prompt in his crossing command. In this case, runway crossing delay is simply more runway delay in a two segment queue (i.e., one on each side of the active runway). In addition,

Table 5-14. Summary of Holds by Reason

	West		East		Combined	
	Number of Holds	% of Holds	Number of Holds	% of Holds	Number of Holds	% of Holds
Competing Traffic	145	36	80	54	225	40
Runway Crossing	140	35	8	5	148	27
Ramp Congestion	78	19	34	23	112	20
Unknown	37	9	23	15	60	11
Other	6	1	4	3	10	2
Total	406	100	149	100	555	100

Table 5-15. Delay Time by Category

		Percent Traffic Held	Delay Per Operation (seconds)
TSC 37	Runway Crossing	32	35
	Competition	18	7
	Ramps	9	5
	Not Identified	4	3
	TOTAL	63	50
TSC 39	Runway Crossing	27	36
	Competition	16	11
	Ramps	10	15
	Not Identified	6	8
	TOTAL	59	70

creating two queues on the terminal side of the arrival runway can facilitate moving aircraft into the departure queue in an advantageous sequence.

5.3.2.5 Review of Individual Runs

The following brief summaries present some salient features observed in each of the runs analyzed.

TSC Run 15

Although this is an "Arrivals from the West" run, the departure runway in the south part of the field is 22L rather than 4R which is more often used in this configuration. This results in the elimination of the runway crossing holds normally encountered for flights departing on 4R when 9R is used for arrivals (e.g., Runs 29 and 39). Several runway crossing holds were observed in the north side of the field for flights arriving on 14L and having to cross departure runway 9L. About half of the holds (21 out of 40) were due to competing traffic with arrivals on 9R stopping mostly on the Outer and departures on 9L encountering stops on the Inner or in crossing the Outer. Ramp congestion holds occurred throughout the terminal area and several holds were observed along the cargo taxiway for flights arriving on 14L and going to the cargo area and for departures going to 22L.

TSC Run 20

In this run both arrivals and departures in the south use 27L. Most of the holds recorded for flights using this runway occur on or crossing the outer taxiway between the penalty box area and the junction of the Outer with the cargo taxiway. It is not clear that any relationship exists between these two observations. Ramp congestion in the FG area caused holds on or crossing the Outer while some flights exiting between H and K were held at the Inner for reasons which are not obvious but which may be associated with departure sequencing.

TSC Run 29

The use of 4R for departures in this run causes most flights using that runway to hold before crossing Runway 9R which is used for arrivals. These holds occur at the intersections of the 14R/32L parallel with the 9R/27L parallel or 9R. Many other holds are due to competing traffic on or crossing the Outer from the area of the penalty box to the junction of the Outer with the cargo taxiway. Most ramp congestion holds occurred in the area of Ramps F, G, and H.

TSC Run 33

The 142 flights in this run were observed to have 44 holds. Approximately 60 percent of these were attributed to competing traffic. No definite pattern to these holds was apparent although several flights arriving on 27L encountered traffic at the south side of the terminal area at Outer opposite the FG and GH ramps and the intersection of the north-south and 9R/27L parallel taxiways. About one-third of the holds were in the categories of "Ramp Congestion", "Unknown", or "Other" and these too had no significant pattern. No runway crossing holds occurred in the southern part of the field where 22L was the major departure runway and 27L was used for arrivals. In the north, the primary runways were 32R for departures and 27R for arrivals. Several flights landed on 22R resulting in three runway crossing holds at the intersection of 22R and 27R.

TSC Run 35

Only 8 holds were observed in the 106 flights in this run. Five of these occurred south of the terminal area for flights arriving on runway 32L, at the same points noted for 27L arrivals in Run 33. The lower number of holds in this run as compared to Run 33 which also involved "Arrivals from the East" may have been due to fewer operations (106 in Run 35 to 142 in Run 33) and/or to a difference in the runway usage in the southern portion of the airport. In Run 33, 22L was the major departure runway in the South and 27L was the arrival runway while in Run 35 the major departure runway was 27L and the arrival runway was 32L. Operations in the North were similar for both runs.

TSC Run 37

Most flights departing on 9R had to hold one or more times before crossing 14R which was being used for arrivals. These holds occurred in the area of the intersection of taxiway T-1 with the Outer, 14R/32L parallel, and 14R, and on the 9R/27L parallel at intersection with the north-south, 14R/32L parallel, and 14R. Although arrivals on 14L had to cross departure Runway 9L to get to the terminal area, relatively few (5 out of 32) had to hold before crossing 9L. This may be due to the spacing of these flights relative to the time intervals associated with runway operations in contrast to the more random distribution of departure flights leaving the terminal and having to cross a runway to get to the departure runway. Ramp congestion and competing traffic holds were distributed throughout the terminal area on both the Inner and Outer during this run.

TSC Run 39

With 83 holds for 140 flights this run had considerably more holds than Run 33 which had slightly more operations (142 flights with 44 holds). The difference may be directly attributed to the 37 flights which had to stop prior to crossing arrival Runway 9R in order to use Runway 4R for departure. Many holds in this run were caused by Ramp Congestion and heavy traffic in the southeast portion of the terminal area in the vicinity of Ramps H and K. This resulted in delays inside the Bridge for flights arriving on 14L. Several holds were observed for flights arriving on 9R in the same areas noted for 27L arrivals in Run 33 and 32L arrivals in Run 35.

CSC Run 5

This run had a similar runway configuration as Run 35 but substantially more flights (138 to 106). While Run 35 had only 8 holds, this run had 35 holds, most of which were attributed to Ramp Congestion and competing traffic on the Outer Circular. Ramp Congestion holds occurred throughout the terminal area.

Most of the holds on the Outer Circular were observed between T-3 and the north-south taxiway. Almost all holds in these categories involved arrival flights and were about equally divided between aircraft landing on runways 27R in the north and 32L in the south.

CSC Run 7

The runways used in this run were the same as in TSC Run 37. Although there were fewer flights (110 in Run 7 and 130 in Run 37) and fewer holds (50 to 82) there are several similarities in the occurrence of holds. In both runs most departures on 9R experienced one or more holds in crossing 14R which was used for arrivals while only a few flights arriving on 14L stopped before crossing departure runway 9L. In this run most of the competing traffic holds were due to an extremely long departure queue for runway 9L. At times during the run this queue extended down the Outer past the penalty box causing congestion along the Outer and at T-1 and T-3.

CSC Run 8

This run is similar in runway usage to Runs 37 and 7; the significant difference is that, instead of using 9R for the departure runway in the south, 14R was used for both departures and arrivals. This, of course, eliminated the runway crossing holds experienced by 9R departures. Another difference was that in Run 8 a far greater number of arrival flights on 14L had runway crossing holds at 9L. The number of Ramp Congestion and Competing Traffic holds in this run was comparable to Runs 37 and 7; however, 14R arrivals were not affected by the 9L departure queue as in Run 7. The 104 flights in Run 8 were observed to have 43 holds.

CSC Run 9

The runway configuration in this run is similar to Runs 37, 7, and 8 except that the departure runway in the south was 27L instead of 9R or 14R. The number of Ramp Congestion and Competing Traffic holds were comparable in all these runs. However, in Run 9 most Ramp Congestion holds were observed on both the Inner and Outer in the area of Ramps H and K while most competing traffic holds were on the Outer in the western half of the terminal area. In this run only a few flights landing on 14L stopped before crossing 9L. The penalty box was heavily used in this run and several holds, whose reasons could not be definitely determined, may have been caused by the use of other areas in lieu of the penalty box.

CSC Run 10

The runway usage in this run was similar to Runs 35 and 5. As in Run 35 a fairly low number of holds was observed (12 holds for 116 flights). Most of the holds were due to competing traffic on the Outer both at the intersection with T-3 and opposite Ramp H.

5.3.2.6 Ground Control Area Summary

1. Penalty box delay time does tend to increase with operations/hour. The mean curve (Figure 5-9) passed through the 150 operations/hour point at 18 seconds per aircraft. This appears very low compared with the runway delays; however, at this operations rate about 10 arrivals (see Table 5-11, TSC #33) comprise the delay. This amounts to over 4 minutes/aircraft held. On this basis, the 150 operations/hour capacity estimate appears reasonable.

2. Non-penalty box delay time tends to increase with operations/hour. Delays in the West Arrival mode are much higher (mean delay of a minute at 140 operations/hour) due to runway crossing delays in that mode. Excluding runway crossing delays, the average delay per operation in either mode is about 20 seconds per aircraft. This is similar to the penalty box delay but remains distributed over a much larger number of aircraft. In addition, of the 20 seconds delay in the taxiway, as much delay is associated with ramp congestion (again gate related problems) as competing taxiway traffic (see Table 5-15). On this basis, it does not appear that the basic taxiways are operating near saturation--but rather quite smoothly.

3. Only 9 Arrival aircraft of the approximately 700 observed experienced entrance waits before taxiing after runway turnoff. This may be an indication of the small percentage of time that conflicts arise between aircraft at turnoffs and other taxiing aircraft. Thus, although during peak hours the Ground channels can reach saturation (see paragraph 5.4.1.6), its impact on aircraft delay is not currently showing up as substantial. Pilot interviews indicate they tend to taxi while waiting for clearance from Ground. This may be why so few waits were detected.

4. Excessive runway crossing hold times (about a minute/aircraft) in the West mode in the 130 to 140 operations/hour region can be attributed to runway saturation with long departure queues on the outside of the arrival runway. There is no overall delay reduction in hastening to cross the aircraft into a queue. In addition, creating two departure queues on the inside of the arrival runway can facilitate moving aircraft into the departure queue in an advantageous sequence.

5. The average time of other "holds" ranges from 60 to 90 seconds.

6. With the exception of Run #35, the number of holds (including penalty box holds) ranged from 42 to almost 80. Since each hold will probably require two control instructions, this would represent 80-160 control instructions per hour or almost one per minute per controller.

7. While most hourly surface density values (aircraft only) ranged from 6 to 10.4, Run #39 had a value of 15.4. We attribute this to the large departure Q for runway 4R in the south, and the delays associated with moving aircraft into the departure Q in the proper order.

8. The total non-penalty box delay time ranged from about 2 percent to 10 percent of non-delay taxi (movement) time for the east mode of operation but from 10 percent to 23 percent for the west mode of operation.

5.3.3 Local Controllers' Area

Two Local Controllers are on duty during most of the day at O'Hare. The split is between the North side and South side. This section describes the controllers operation in a quantitative way beginning with his capacity to handle traffic (paragraph 5.3.3.1), then correlating that capacity with observed delays (paragraph 5.3.3.2).

5.3.3.1 Local Control Area Capacity

The local control area capacity is dependent on many external factors. These factors include weather, visibility conditions, terminal ATC procedures, runway configurations, traffic demand, demand mix (i.e., arrivals versus departures), aircraft type mix, aircraft weight mix and aircraft service mix (i.e., IFR versus VFR). This analysis does not examine all of these factors and those considered are done so with a limited amount of data. Its purpose is to derive some understanding of what the Local Controller is faced with for typical O'Hare conditions and to estimate the potential capacity increase which new local controller aids might provide. Any generalization to other airports or even to O'Hare operating in a mode not examined here (e.g., high VFR operations in a low air carrier demand period) requires careful examination of the impact of each factor. That examination is not made here. The factors which were in effect for this analysis are

1. Good braking action,
2. Winds varying from 0 to 15 knots with gusts to 25 knots,
3. Visibility either excellent, permitting visual approaches, or very poor such that the cab could not see the entire airport,
4. O'Hare, a Group I TCA airport,
5. Aircraft type mix as given in Table 6-1, and
6. Aircraft service mix with IFR representing over 90 percent of all aircraft.

Each Local Controller at O'Hare controls a mixed arrival/departure operation, either a single runway with mixed operations or intersecting runways. His job is basically (1) to assure a clear arrival runway for the next arrival, and (2) to clear departures out between arrivals. His ability to do this depends on the runway configuration, his visibility of the operation and the distributions of various parameters over which he has little control. To illustrate the nature of these parameters consider Figures 5-12 and 5-13.

5.3.3.1.1 Parameter Distributions

Figure 5-12 illustrates an ideal single runway operation. Every 90 seconds an arrival sets down on the runway, rolls out and clears off in 45 seconds. Every 90 seconds, just following the arrivals setting down, a departure gets on, waits for the arrival to clear and takes off, becoming airborne in 45 seconds. Figure 5-13 illustrates an actual single runway operation. The slopes of the arrival time lines are not uniform. The arrival runway on time is dependent on the aircraft type, exit ramp type and location, touchdown (velocity, rate of descent, crab angle, roll angle, and position) and roll out deceleration. The slopes of the departure time lines are not uniform. Departure on time is dependent on aircraft type and load. The inter-arrival spaces are not uniform. The spaces depend on the ability of the Approach Controller to deliver perfectly spaced arrivals to the outer marker and the final approach velocity profile. The non-uniformity of these parameters and the controller's ability to estimate these parameters

1. Can result in aborted departures (i.e., departure cleared on and then directed off) as for departure 2,
2. Cause unused inter-arrival spaces (i.e., space too small so a departure is held) as for inter-arrival space 11-12,
3. Permit double departures as for departures 3 and 4.

The actual operations rate observed is 64 operations/hour versus the ideal of 80 operations/hour, a substantial reduction due to the distributions of the parameters.

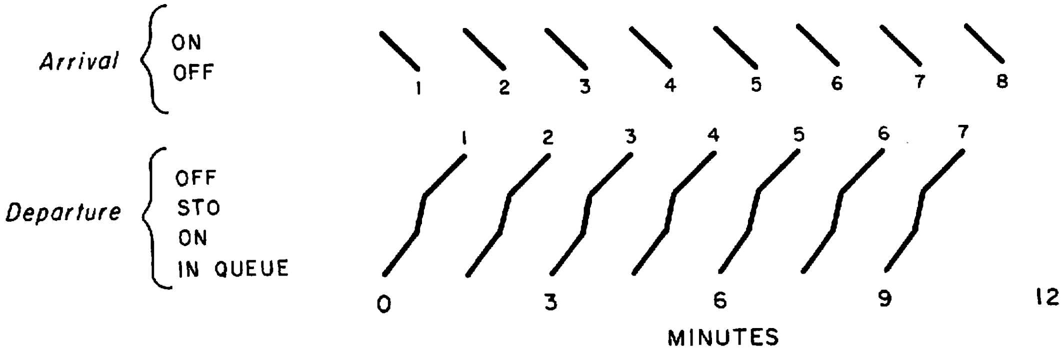


Figure 5-12. Time Line Plot of Ideal Single Runway Operation Saturated In Arrival and Departure Demand (80 Operations/Hour)

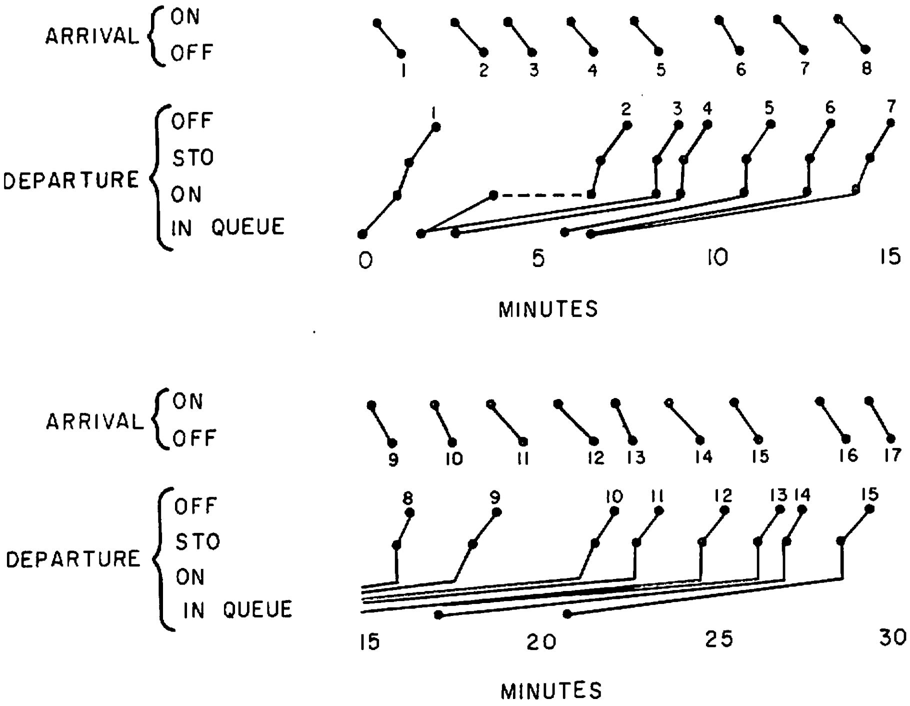


Figure 5-13. Time Line Plot of Actual Single Runway Operation Saturated In Arrival and Departure Demand in Good Visibility Conditions (64 Operations/Hour) (R/W - 27L)

Figure 5-14 illustrates the distribution of arrival "on" times for two one-hour periods. The total distribution is also shown and will be used as a general arrival on time distribution for the subsequent capacity estimates. It should be noted that this distribution is for good braking conditions.

Figure 5-15 illustrates the distribution of departure "on" times for two one-hour periods. Again they are very similar and display a smaller variance than do the arrivals. The on times only involve the roll out time. Delays prior to initiating takeoff are not included. As with the arrivals, the total distribution will be used as a general departure on time distribution for subsequent capacity estimates.

Figure 5-16 illustrates the distribution of inter-arrival time as arrival demand increases. The times are taken over the runway threshold. With a modest number of arrivals (TSC #35N) the distribution is not sharply peaked and only one space falls in the 70-second bin. At a common approach speed of 160 knots at the outer marker (Approach Control to Local hand-off) 67 seconds is 3 nautical miles, the minimum separation standard. At a common touchdown speed of 130 knots, the 70-second bin represents 2.5 nautical miles separation at the threshold. As the demand increases the distribution's mean (shown by the solid triangle) shifts to the left, while the 60-second bin remains empty (i.e., the 3 nautical mile separation is adhered to at the outer marker) until at 37 arrivals the leading edge of the distribution slips into the 60-second bin (2.7 nautical miles at the outer marker and 2.2 nautical miles at the threshold). At this point the probability of double runway occupancy begins to increase (see Figure 5-14) as the main body of the arrival on time distribution begins to overlap the inter-arrival distribution. For the purposes of capacity estimation the sum of the two runs prior to TSC #37S (i.e., TSC #20S and CSC #5S) will be used to represent a general saturated demand inter-arrival distribution. The total is shown in Figure 5-17.

The inter-arrival spacings in Figure 5-17 depict a distribution which peaks at about 95 seconds and is evenly distributed about the peak with a standard

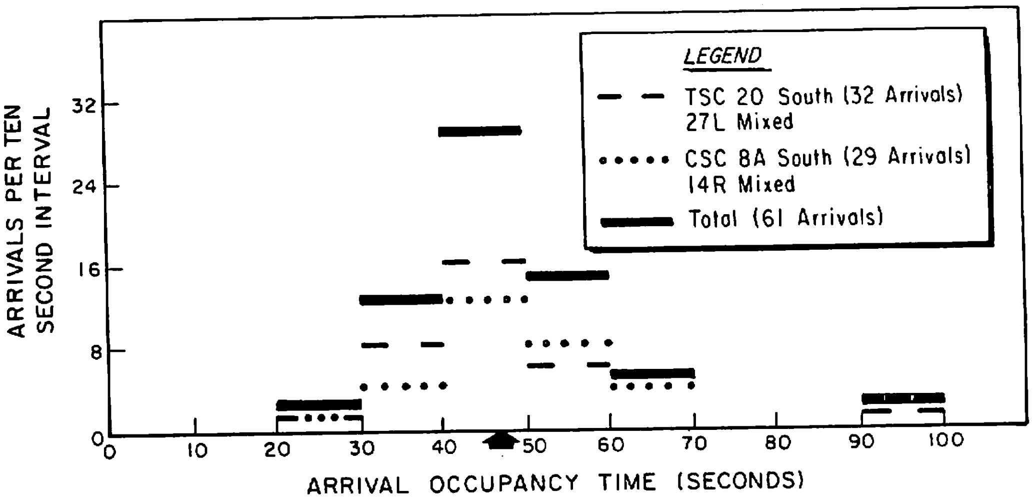


Figure 5-14. Arrival Runway Occupancy Time for Two One-Hour Periods (Total Mean 46 Seconds)

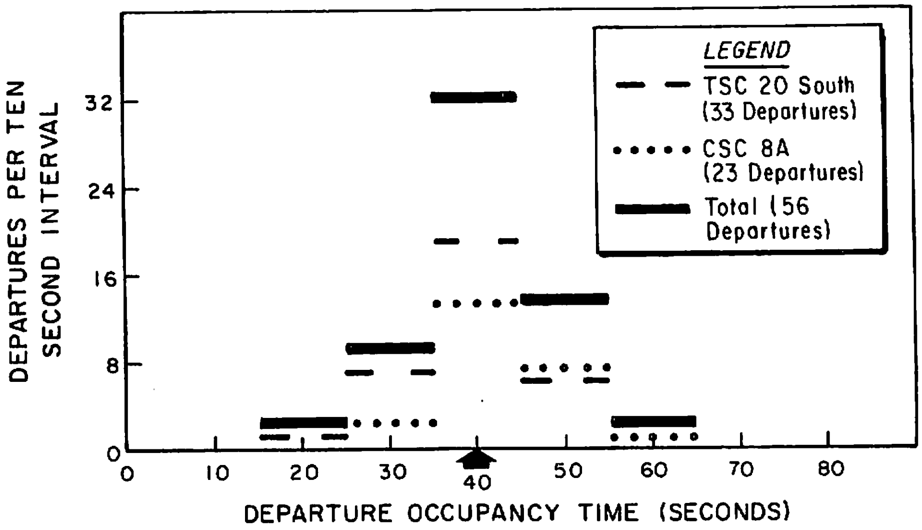


Figure 5-15. Departure Runway Occupancy Time for Two One-Hour Periods (Total Mean 40 Seconds)

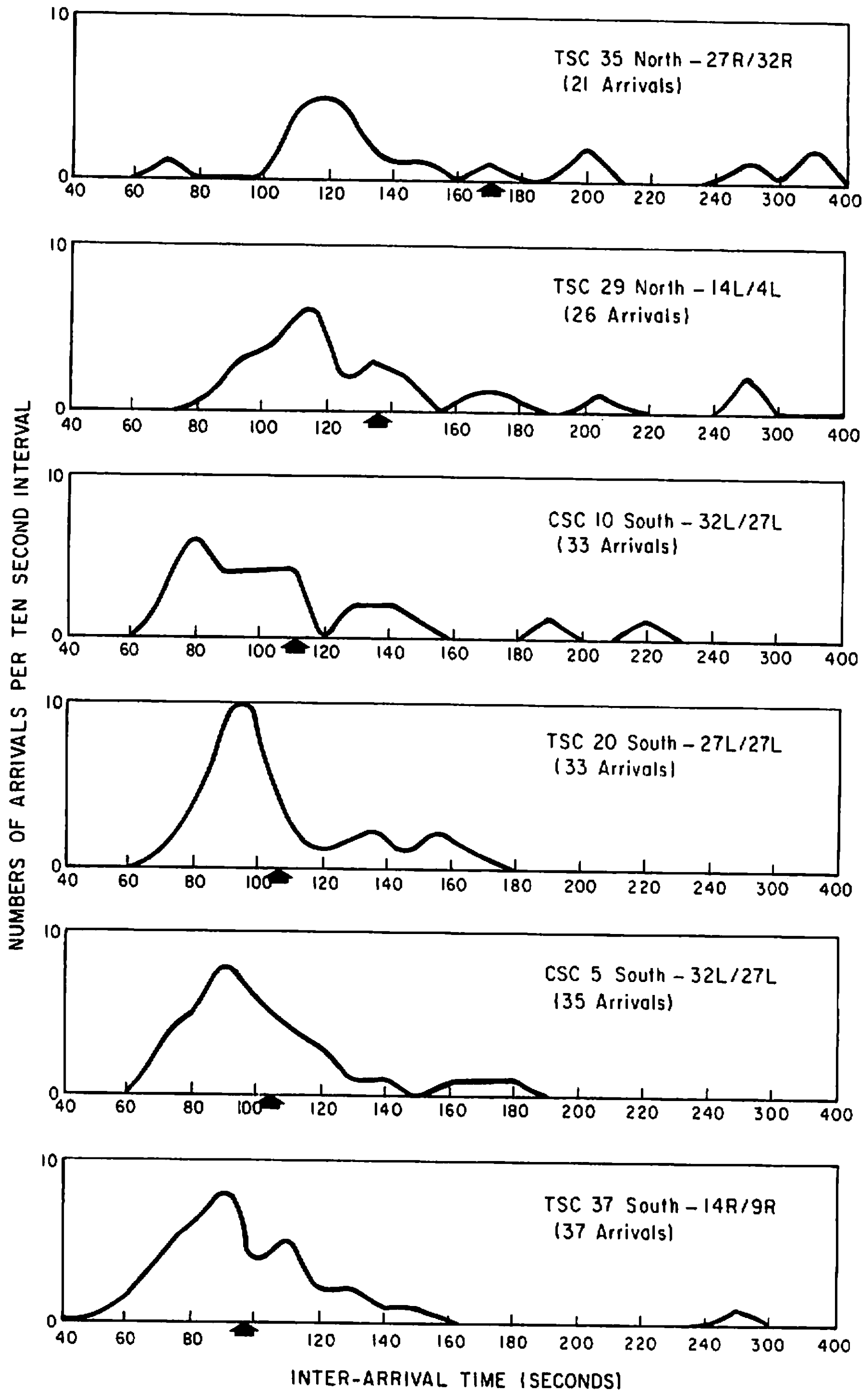


Figure 5-16. Interarrival Spacing for Six One-Hour Periods of Varying Demand

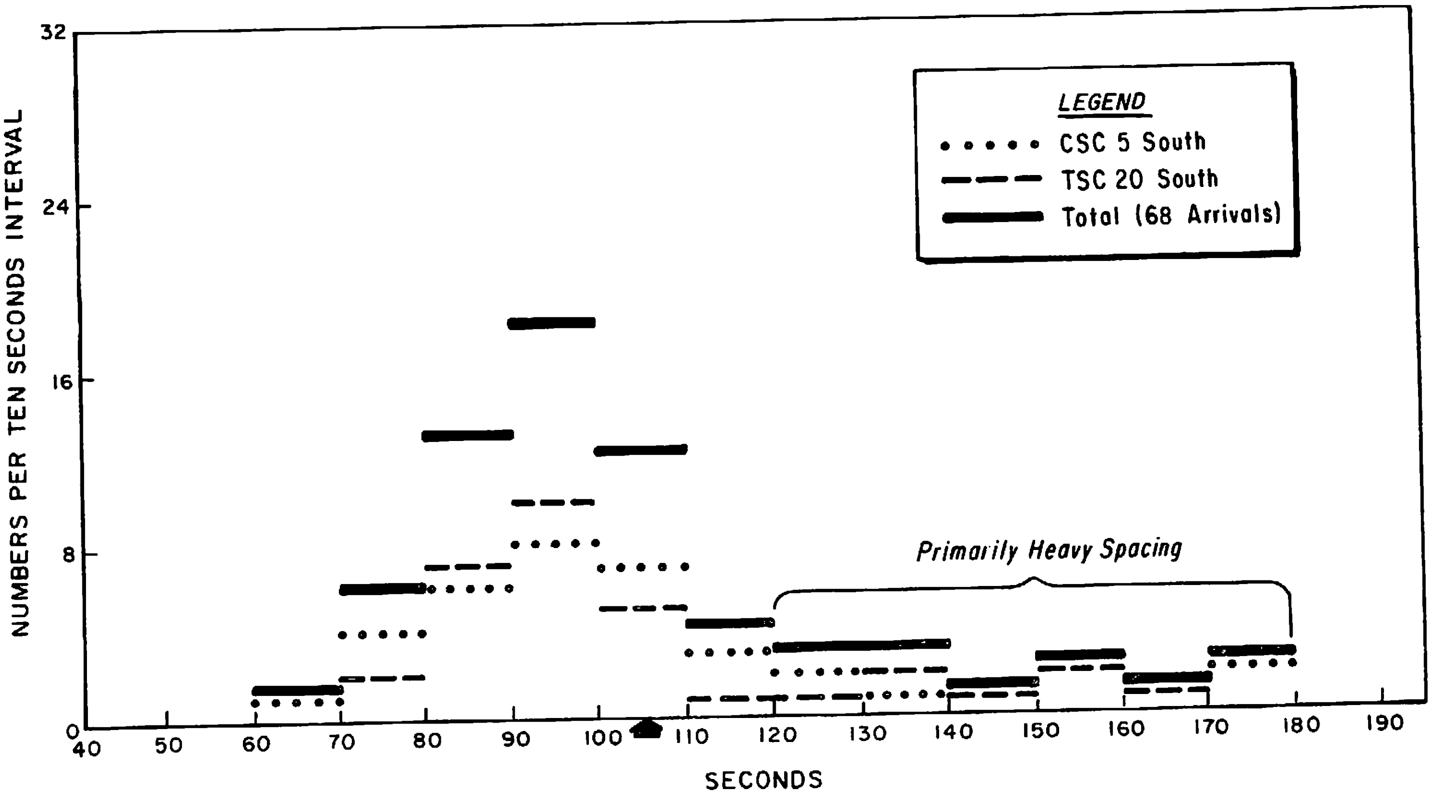


Figure 5-17. Interarrival Spacing for Two One-Hour Busy Periods

deviation of 10 seconds except for a set of trailing inter-arrivals beginning at 2 minutes. By listening to voice communication tape recordings these trailing spaces have been determined as primarily heavy spacings. These trailers represent 17 percent of the spaces which is consistent with the percent of the heavies operated in general at O'Hare.

5.3.3.1.2 Predicted Capacity (Theoretical)

Given the three distributions and a single runway operating strategy, an operations rate can be predicted. The single runway operating strategy used here is as follows:

To clear a departure following an arrival the previous arrival should be initiating his turnoff (not necessarily clear) and the next arrival should be at least 40 seconds from threshold (about 2 miles).

For mixed operations on a single runway the runway entrance time (i.e., the time needed for the aircraft to move from the Local Control Departure Q to "in-place" on the runway) becomes a significant parameter in developing an operating strategy. This factor, however, has not been treated in this analysis since it is not significant in multiple runway operations.

To clear a departure following a departure the previous departure should be off the runway and the next arrival should be at least 40 seconds from threshold (about 2 miles).

The rationale for the strategy is that (1) except for predictable circumstances (e.g., a heavy on a reverse high speed) the maximum clear time from turn initiation observed was 15 seconds and the minimum time for a departure to pass the common turnoffs was 30 seconds, leaving 15 seconds of margin following an arrival; (2) an arrival 15 seconds out at departure release will catch the departure so that using 40 seconds leaves 5 seconds pilot delay and 20 seconds of margin; (3) an arrival 40 seconds out will minimize (not eliminate) double runway occupancy; and (4) a previous departure off will permit an immediate turn clearing the runway for the next departure.

The resulting operations rate may be estimated graphically with Figure 5-18. The dotted curve represents the probability of a controller being unable to successfully release a single departure as a function of inter-arrival spacing. The curve is obtained by taking the arrival on-time distribution, which represents the minimum time that the departure must wait to be released after the arrival has touched down, and adding 40 seconds (the minimum time the next arrival must be from the threshold to permit a release) to obtain the distribution of minimum inter-arrival spaces required for a departure, and taking the inverse accumulation (i.e., integration) of that distribution. Similarly, the dashed line represents the probability that a controller would be unable to release two departures as a function of inter-arrival spacing. The curve, in this case, is obtained by taking the convolution of the arrival on-time distribution with the departure on-time distribution, which represents minimum time that the second departure must wait to be released after the arrival has touched down, and adding 40 seconds (again, the minimum time the next arrival must be from threshold to permit a release) to obtain the distribution of minimum inter-arrival spaces required for double departures, and taking the inverse accumulation of that distribution.

The departure rate estimate is obtained by "playing" these strategy curves against the saturated demand inter-arrival distribution (e.g., 30 percent of the 20 percent inter-arrival spaces between 80 and 90 seconds will not permit a departure--70 percent will). The results are 34 arrivals/hour, 27 single departures/hour and 6 extra departures for a total of 67 operations/hour.

With rationale similar to that used for single runway operations, operating strategies were developed for dependent intersecting runways. All strategies used are summarized in Table 5-16. The resulting strategy curves are shown in Figure 5-19; and the resulting capacity estimates are shown in Table 5-17. As evidenced by Figure 5-19, all crossing runways are predicted to clear at least one

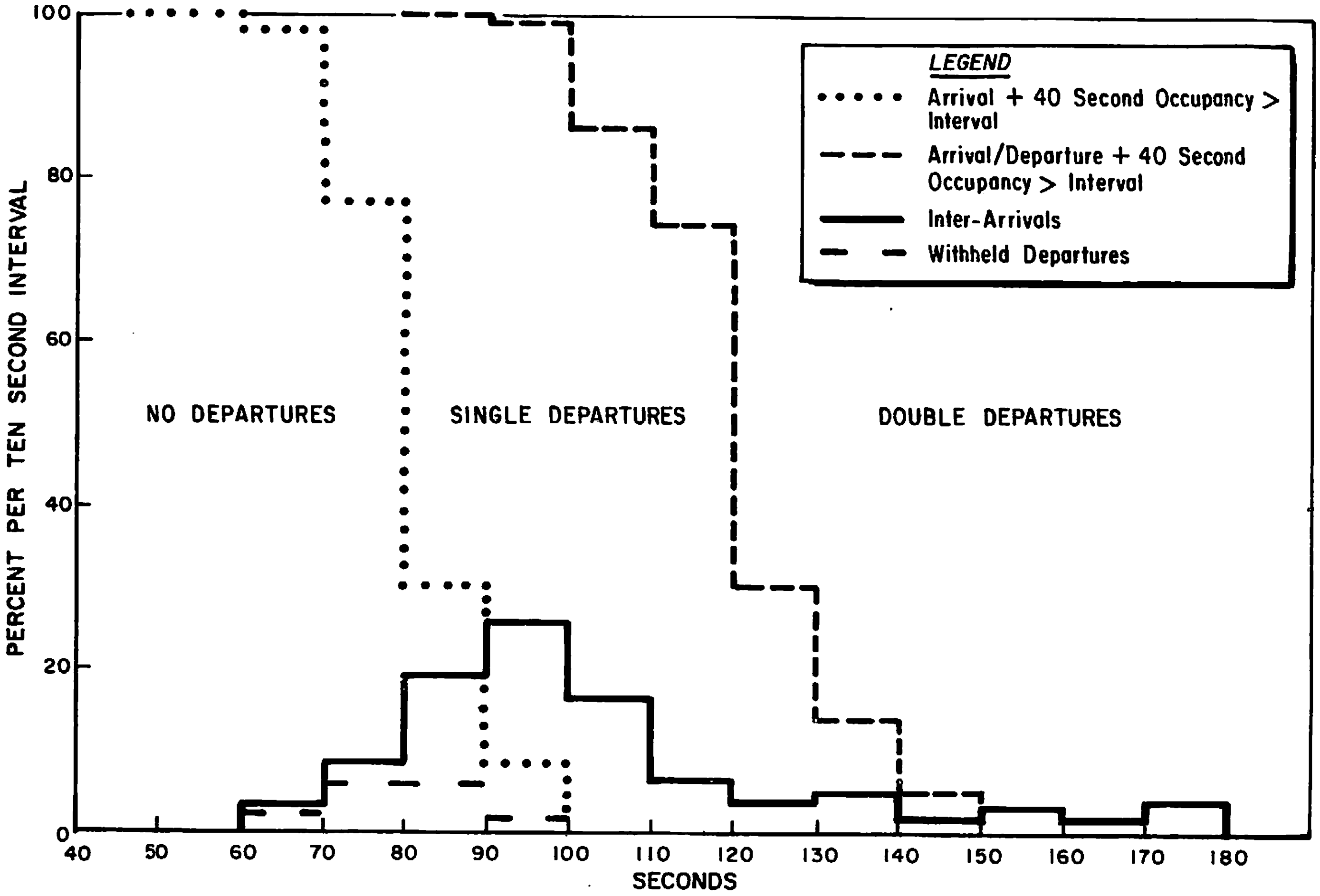


Figure 5-18. Departure Capacity Estimate for Single Runway Operation (34 Arrivals/Hour; 27 Single Departures/Hour; and 6 Double Departures for a Total of 67 Operations/Hour)

Table 5-16. Operating Strategies for Capacity Estimation

Configuration	Previous Arrival	Next Arrival	Previous Departure
Single (Mixed)	Initiating turn-off	40 seconds out from threshold (2 miles)	Off and turning
Near-Near Crossing	Clear through intersection	40 seconds out from threshold (2 miles)	Off and turning
Near-Far Crossing	15 seconds out from intersection (at threshold)	65 seconds out from threshold (2-1/2 miles)	Off and turning
Far-Far Crossing	10 seconds out from intersection (1000 feet)	45 seconds out from threshold (2-1/2 miles)	Off and turning

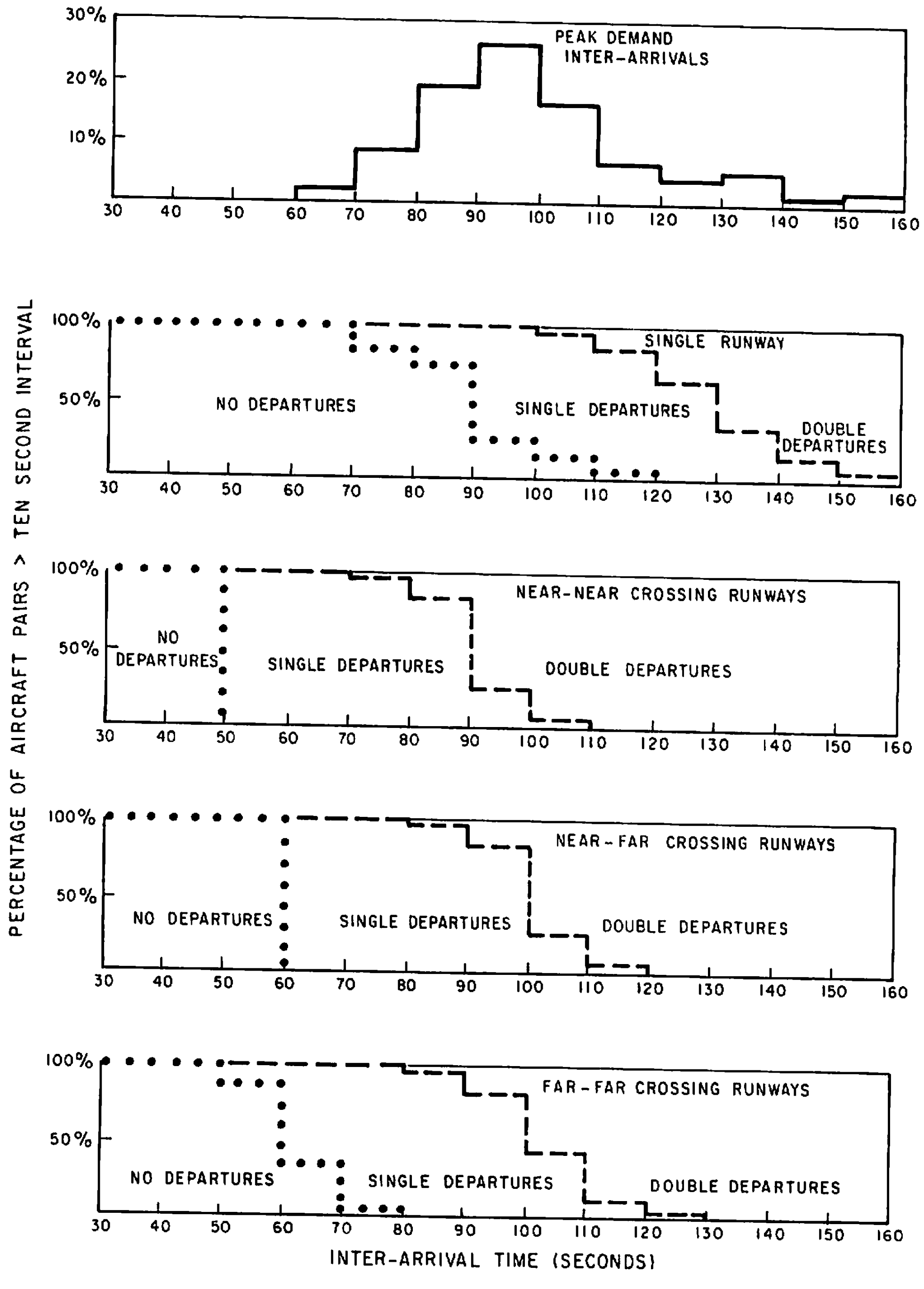


Figure 5-19. Strategy Curves for Various Runway Configurations

Table 5-17. Predicted Capacity of Various Runway Configurations

2 One Hour Periods		60/ 70	70/ 80	80/ 90	90/ 100	100/ 110	110/ 120	120/ 130	130/ 140	140/ 150	150/ 160	160/ 170	170/ 180	Total (60/ 180)	Equivalent Hourly Rates	Total Hourly Rate
Interarrivals (Refer to Fig. 5-17)		1	6	13	18	12	4	3	3	1	2	1	2	66	34 Arrivals	
Single	Single Departures	0	1	9	16	12	4	3	3	1	2	1	2	54	27	67
	Extra Departures	0	0	0	0	1	1	2	2	1	2	1	2	12	6	
Near-Near Crossing	Single Departures	1	6	13	18	12	4	3	3	1	2	1	2	66	33	88
	Extra Departures	0	0	2	13	12	4	3	3	1	2	1	2	43	21	
Near-Far Crossing	Single Departures	1	6	13	18	12	4	3	3	1	2	1	2	66	33	81
	Extra Departures	0	0	0	3	9	4	3	3	1	2	1	2	28	14	
Far-Far Crossing	Single Departures	0	6	13	18	12	4	3	3	1	2	1	2	65	33	79
	Extra Departures	0	0	0	3	6	3	3	3	1	2	1	2	24	12	

departure for every inter-arrival space. The ability to get double departures varies. Near-Near crossing runways do best since the second departure clears the critical intersection quickly. The Near-Far crossing runways do poorer since the second departure takes longer to clear the critical intersection. The Far-Far crossing runways do poorest since a large variance in first arrivals clearing the intersection plus the longer time to clear the critical intersection impact on the operation. It may also be noted that the data presented to the Local Controller gives him no predictive capabilities for either arrivals or departures.

5.3.3.1.3 Predicted Capacity (Actual)

The actual operation at O'Hare is compared with the predicted capacity in Tables 5-18 to 5-21. The single runway operation is rare at O'Hare and O'Hare traffic volumes place a good deal of strain on the operation. In this instance (Table 5-18) the controller got off 27 single departures versus 30 theoretically predicted (for this inter-arrival distribution) and all six predicted extra departures. Measured against the operating strategy previously given, the controller did nearly perfect. That he was straining his capabilities to do this, however, is also evident from Table 5-18. Of the 20 single departures released for spaces between 70 and 110 seconds, 10 were released perfectly (within 5 seconds) according to the strategy, two were released more than 5 seconds early (one of them 16 seconds before the preceding departure committed to clear) and one was released more than 5 seconds late (the next arrival only 32 seconds out). This resulted in five cases where the runway was occupied by two aircraft for more than 5 seconds. In addition, in one instance an aircraft was cleared on and then directed off due to the proximity of the next arrival. It would appear that the theoretical capacity should not be expected or demanded of the controller. As mentioned previously, this is a rare operation at O'Hare.

The Near-Near operation is shown in Table 5-19. Although the departure queue exceeded 10 aircraft for much of the hour, at one point it was only one aircraft and hence a double departure demand did not exist. To account for this

Table 5-18. Single Runway Mixed Operations in Good Visibility With Continuous Double Departure Demand

	Operations Per Time Interval										
TSC 20 South	70/ 80	80/ 90	90/ 100	100/ 110	110/ 120	120/ 130	130/ 140	140/ 150	150/ 160	160/ 170	170/ 180
Predicted Percent Single Departures	23	70	92	100	100	100	100	100	100	100	100
Predicted Percent Double Departures	0	0	2	14	26	70	86	95	100	100	100
Interarrivals	2	7	10	5	1	1	2	1	2	1	0
Single Departures	2	5	8	5	0	1	2	1	2	1	0
Extra Departures	0	0	0	0	0	1	2	1	1	1	0
Withheld Departures	0	1	2	0	1	0	0	0	0	0	0
Departure Late by Over 5 Secs	0	0	1	0	0	0	0	0	0	0	0
Departure Early by Over 5 Secs	1	1	0	0	0	0	0	0	0	0	0
Runway Double Occupancy Over 5 Secs	1	2	2	0	0	0	0	0	0	0	0
Departures/Arrival Aborted	0	1	0	0	0	0	0	0	0	0	0
Perfect Departure ±5 Secs Early/Late	1/2	3/1	5/3	1/0	0	0	0	0	0	0	0

Table 5-19. Near-Near Runway Configuration in Good Visibility

TSC 33 North (40 minutes)	Operations Per Time Interval						
	80/90	90/100	100/110	110/120	120/130	130/140	140/150
Predicted Percent Single Departures	100	100	100	100	100	100	100
Predicted Percent Double Departures	18	75	98	100	100	100	100
Interarrivals	4	3	5	4	2	1	3
Single Departure Demand	4	3	5	4	2	1	3
Single Departures	4	3	5	4	2	1	3
Double Departure Demand	4	3	5	3	2	1	3
Double Departures	0	0	0	0	1	0	2
Withheld Departures	0	0	0	0	0	0	0
Departure Release Late by Over 5 Secs	0	0	0	0	0	0	0
Departure Release Early by Over 5 Secs	0	0	0	0	0	0	0
Double Runway Occupancy by Arrivals	0	0	0	0	0	0	0
Perfect Release ±5 Secs Early/Late	1/0	0/0	1/0	0/0	2/0	0/0	1/0

the two rows, Single Departure Demand and Double Departure Demand, are added to the table format. These represent inter-arrival spaces for which the departure queue was at least 1 and 2, respectively. Predicted percent departures must be "played" against these demand rows instead of the inter-arrival row as for the single runway case.

The Near-Near operation results in 100 percent of all predicted singles but only 3 of 16 predicted (for its inter-arrival distribution) extra departures. As with the previous case (single runway case), the departure queue exceeded 10 aircraft so the loss of extra departures was not due to low demand. The high degree of success for single departures would be expected due to the simple strategy. The loss of extra departures remains to be explained.

The Near-Far operation (Table 5-20) results in 90 percent of all predicted single departures and as with the Near-Near only 20 percent of all double departures. The 10 percent loss of singles is explained by some reluctance on the controller's part to put in the 15 seconds "lead" (i. e., clear departure 15 seconds prior to the arrivals clearing the intersection) hypothesized in the strategy. However, the perfect releases on the early side indicate that the lead is inserted for the most part.

The Far-Far operation (Table 5-21) results in only 75 percent of the predicted single departures and none of the double departures. This 25 percent loss in singles is due to even more reluctance on the controllers' part to put in the 10 seconds lead especially for the tight inter-arrival spaces. The complete loss of double departures combined with the 80 percent loss for the other two cases prompts the special examination of Quasi-Independent intersecting runways (an effective departure only independent runway.)

Figure 5-20 depicts the relative position of the two arrivals at the time a departure is released between them. In accordance with the Near-Near strategy, at the time of departure all first arrivals are clear of the intersection and all second arrivals are more than 40 seconds out. However, for the

Table 5-20. Near-Far Runway Configuration in Good Visibility

	Operations Per Time Interval											
CSC 5 South	60/ 70	70/ 80	80/ 90	90/ 100	100/ 110	110/ 120	120/ 130	130/ 140	140/ 150	150/ 160	160/ 170	170/ 180
Predicted Percent Single Departures	100	100	100	100	100	100	100	100	100	100	100	100
Predicted Percent Double Departures	0	0	2	18	76	98	100	100	100	100	100	100
Interarrivals	1	4	6	8	7	3	2	1	0	0	1	2
Single Departure Demand	1	2	6	7	4	3	2	1	0	0	1	2
Single Departures	1	2	4	7	4	3	1	1	0	0	1	2
Double Departure Demand	1	2	5	4	3	2	2	1	0	0	1	1
Double Departures	0	0	0	0	1	0	0	0	0	0	0	1
Withheld Departures	0	0	2	0	0	0	1	0	0	0	0	0
Departure Release Late by Over 5 Secs	0	0	0	0	0	0	0	0	0	0	0	0
Departure Release Early by Over 5 Secs	0	0	0	0	0	0	0	0	0	0	0	0
Double Runway Occupancy by Arrivals	0	0	0	0	0	0	0	0	0	0	0	0
Perfect Release ±5 Secs Early/Late	0/0	1/0	0/0	3/0	1/0	1/0	0/0	0/0	0/0	0/0	0/0	0/0

Table 5-21. Far-Far Runway Configuration (1 of 2 Cases)

TSC 39 North (50 minutes)	Operations Per Time Interval												
	60/ 70	70/ 80	80/ 90	90/ 100	100/ 110	110/ 120	120/ 130	130/ 140	140/ 150	150/ 160	160/ 170	170/ 180	Over 180
Predicted Percent Single Departures	63	96	100	100	100	100	100	100	100	100	100	100	100
Predicted Percent Double Departures	0	0	3	18	56	88	99	100	100	100	100	100	100
Interarrivals	4	1	2	6	2	4	6	2	1	0	0	0	0
Single Departure Demand	4	1	2	6	2	4	6	2	1	-	-	-	-
Single Departures	1	1	1	4	2	3	5	1	1	-	-	-	-
Double Departure Demand	3	1	2	4	2	2	6	1	1	-	-	-	-
Double Departures	0	0	0	0	0	0	0	0	0	-	-	-	-
Withheld Departures	3	0	1	2	0	1	1	1	0	-	-	-	-
Departure Release Late by Over 5 Secs	1	0	0	0	0	0	0	0	0	-	-	-	-
Departure Release Early by Over 5 Secs	1	0	0	0	0	0	0	0	0	-	-	-	-
Double Runway Occupancy by Arrivals Over 5 Secs	1	0	0	0	0	0	0	0	0	-	-	-	-
Perfect Release ±5 Secs Early/Late	0/0	1/0	1/0	1/0	0/0	1/0	1/0	0/0	0/0	-	-	-	-

NOTE: 19 single departures versus 26 predicted (75%) and no double departures versus 10 predicted (0%). Mean 10 minute peak queue = 3.

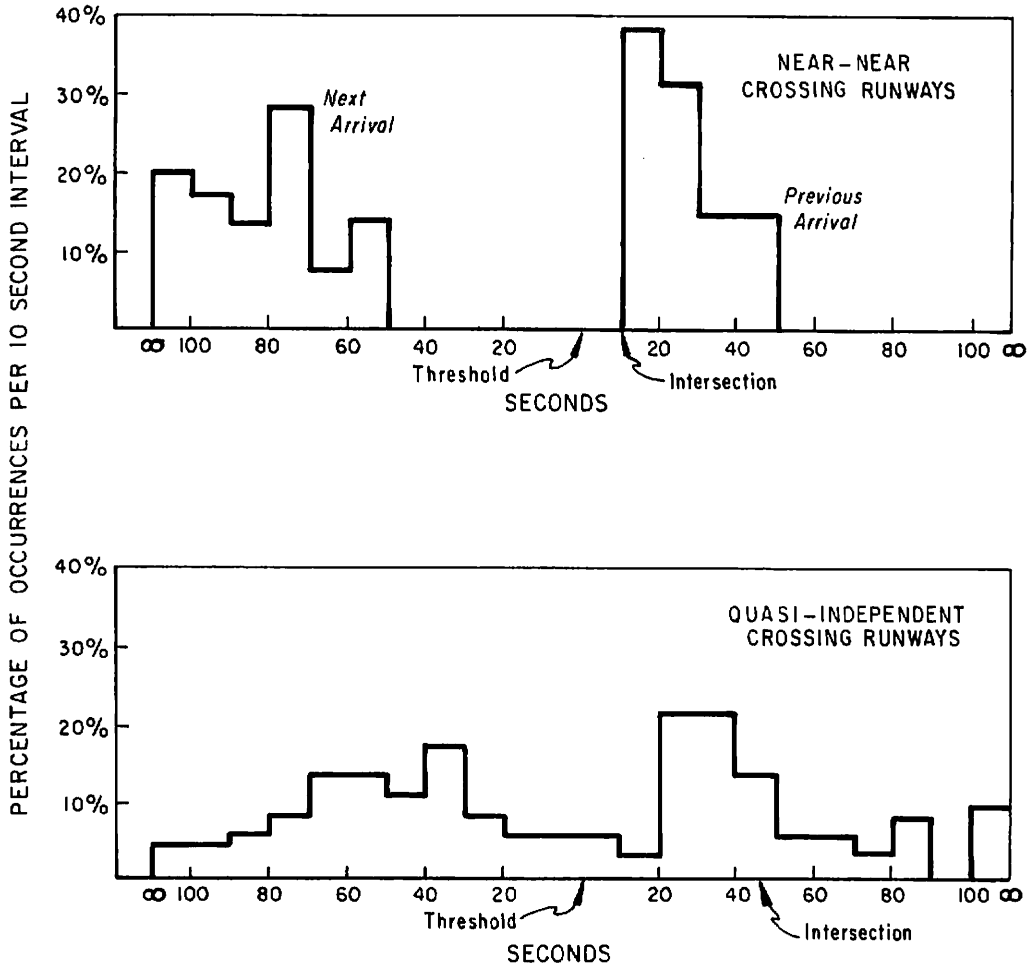


Figure 5-20. Position of Arrival Pairs at the Time of Departure Release for Two Runway Configurations

Quasi-Independent configuration, no such clear strategy is evident. Departures are released with arrival pairs in any position although the preference is to guarantee that the first arrival is down all right (i. e., between 20 and 40 seconds into roll out) and the second arrival is over 30 seconds out. Thus, departures should represent a nearly independent departure only runway.

In accordance with the strategies thus far, a departure only runway sould be capable of a departure every 45 seconds or so (a capacity of 80 departures/hour!). The Quasi-Independent example ran 44 departures/hour. The missing factor is departure separation standards. The local controller must time successive departures such that on hand-off to departure control, the radar separations (vertical, lateral, and/or longitudinal) are adequate. If successive departures will follow the same initial flight path, longitudinal separation must be assured and interdeparture timing can be affected (i.e., the second departure can be delayed). However, when the initial headings of departures immediately diverge (by more than 45 degrees) lateral separation can be employed and interdeparture timing is less critical. Thus, the departure rate depends on the mix of initial headings for the departures which depends on where those departures are bound and how they have been sequenced by Local Control with the help of Departure Ground Control.

Figure 5-21 shows the initial heading mix for the Quasi-Independent example. Out of 37 departures, only 11 favorable heading differences existed. The heading mix was such that longitudinal separation considerations were required of 70% of the departures. It would be natural to assume that this would affect the number of close-spaced departures to be observed in the quasi-independent configuration and in the double departures (i.e., one right after the other) of the other more dependent arrival-departure configurations. If the actual double departures of the cases cited herein are compared with the double departure demand, it is found that on the average only 20% of the possible double departures were realized and therefore (1) the 100% double departures of the single runway case will be considered exceptional due to the high pressure situation it

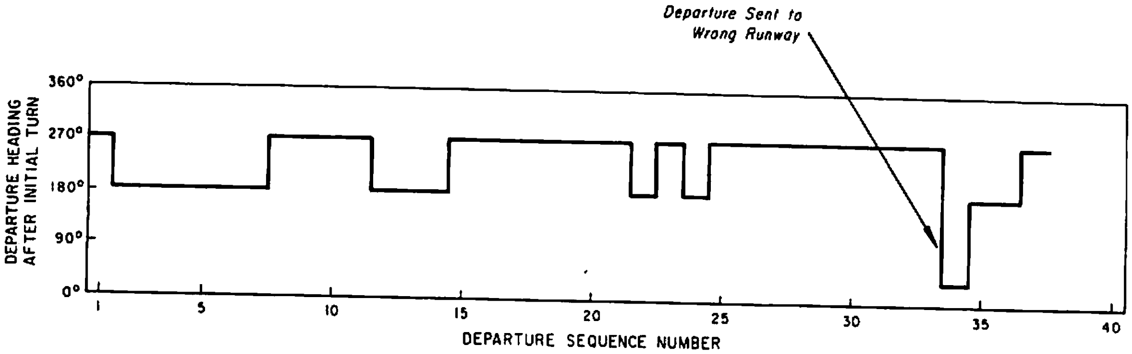


Figure 5-21. Initial Heading Mix of Departures for Quasi-Independent Runway Operation Over 50 Minutes of Heavy Demand

represents; and (2) for capacity prediction 20 percent of theoretical double departures will be used.

Table 5-22 shows the effect of using 20 percent of possible doubles on the capacity estimates. In addition, the Practical column represents the added loss in capacity that either occurred (departures withheld) or should have occurred (departures in violation of strategy) in practice when applied to the peak interarrival distribution.

5. 3. 3. 1. 4 Bad Cab Visibility Effects

When the cab loses visibility of the runways the Local Controller uses pilot position reports and ASDE-2 radar, when functioning. Even when using ASDE-2, the controller does not have complete coverage of the flight path. ASDE covers only the airport surface and the ARTS BRITE display blanks out arrivals prior to reaching the runway and departures until they are well off the runway (see Figure 4-5). The result is that initial turn position reports from departures are required and the position of arrivals in the final seconds of their approach must be estimated. These factors influence runway capacity.

Table 5-23 shows a single runway mixed operation in Category II conditions. Demand is high with the departure queue always exceeding five aircraft and averaging 16 for 20 minutes. The arrival demand was fairly high, 21 in 40

Table 5-22. Practical Estimated Runway Capacity

		Perfect Split (Table 5-17)	20 Percent Split	Practical
Single Mixed	Departures	33	28	23
	Operations	67	62	57
Near-Near Crossing	Departures	54	37	37
	Operations	88	71	71
Near-Far Crossing	Departures	47	36	31
	Operations	81	70	65
Far-Far Crossing	Departures	45	35	27
	Operations	79	69	61
Quasi-Independent	Departures	60	36	36
	Operations	94	70	70

Table 5-23. Single Runway Mixed Operations in Bad Cab Visibility Conditions With Continuous Double Departure Demand and ASDE-2 in Use

TSC 24 (Cat II) (40 Minute Period)	Operations Per Time Interval											
	70/ 80	80/ 90	90/ 100	100/ 110	110/ 120	120/ 130	130/ 140	140/ 150	150/ 160	160/ 170	230/ 240	300/ 310
Predicted Percent Single Departures	23	70	92	100	100	100	100	100	100	100	100	100
Predicted Percent Double Departures	0	0	2	14	26	70	86	95	100	100	100	100
Interarrivals Before Missed Approaches	0	1	2	7	5	2	0	0	2	1	0	0
Interarrivals After Missed Approaches	0	1	2	4	3	2	0	0	2	1	1	1
Single Departures	0	1	1	2	3	2	0	0	2	1	1	0
Double Departures	0	0	0	0	0	0	0	0	1	0	1	0
Withheld Departures	0	0	1	1	0	0	0	0	0	0	0	1
Departure Late by Over 5 Secs	0	1	0	0	0	0	0	0	0	0	0	0
Departure Early by Over 5 Secs	0	0	0	0	0	0	0	0	0	0	0	0
Departure/Arrival Aborted	0	0	0	1	0	0	0	0	0	0	0	0
Perfect Departure ±5 Secs Early/Late	0	0	1/1	0	1/0	1/0	0	0	0	0	0	0

minutes or 31 arrivals/hour. In this case, it is evident from voice communication recordings that ASDE-2 is being used. Missed approaches (pilot initiated) broke up the arrival stream as indicated from the inter-arrival spaces before and after the three missed approaches. The controller did pretty well in the operation suffering a 25 percent loss over predicted for singles but getting 40 percent of all possible doubles. The high percent of doubles might be explained by the fact that this was the only runway in operation at O'Hare at the time and a favorable initial heading split was more likely than normal.

Table 5-24 shows a single runway mixed operation in which voice communication recordings indicate the controller cannot see the runway and is not using ASDE-2. In place of ASDE-2 he uses reports from the number 1 departure in the runup pad to determine arrival on time (and so to clear the next departure on) and reports from the arrival aircraft on runway turnoff initiation (to permit clearing the departure for takeoff). The impact of the completely blind operation is evident. Practically no inter-arrival spaces less than two minutes in duration were used in release of departures. The three that were used had the departure cleared early (before the arrival began its turn but after the pilot said he would) to leave a very safe margin between it and the next arrival. In this instance, the inter-arrival distribution did not peak sharply in the 90-110 second period as is normally the case and so 65 percent of the predicted single operations were achieved. Had the more normal peak occurred, this would have dropped to about 30 percent. The more normal 15 percent extra departures were released during the long inter-arrival spaces. Unlike the Category II case, both sides of the airport were running. As in the Category II case, departure demand was high with a queue averaging 11 for 20 minutes.

The effect of bad visibility is estimated in Table 5-25 by applying the strategies of the two bad visibility cases to the peak hour inter-arrival spacing. This essentially normalizes all the capacity estimates to a peak arrival demand. Case CSC #8, however, is an example of how arrivals can be traded (in some fashion) for departures. For this case, only 28 arrivals were taken permitting

Table 5-24. Single Runway Mixed Operations in Bad Cab Visibility Conditions With Continuous Double Departure Demand Without ASDE-2 In Use

CSC 8A (West) No Cab Visibility	Operations Per Time Interval											
	70/ 80	80/ 90	90/ 100	100/ 110	110/ 120	120/ 130	130/ 140	140/ 150	150/ 160	160/ 170	170/ 180	180/ 190
Predicted Percent Single Departures	23	70	92	100	100	100	100	100	100	100	100	100
Predicted Percent Double Departures	0	0	2	14	26	70	86	95	100	100	100	100
Interarrivals	2	3	1	4	3	3	3	2	2	1	1	2
Single Departures	0	0	0	1	2	2	3	2	2	1	1	2
Double Departures	0	0	0	0	0	0	0	0	1	0	0	1
Withheld Departures	2	3	1	3	1	1	0	0	0	0	0	0
Departure Late by Over 5 Secs	0	0	0	0	0	0	0	0	0	0	0	0
Departure Early by Over 5 Secs	0	0	0	1	0	0	1	0	0	0	0	0
Perfect Departure ±5 Secs Early/Late	0	0	0	0	2/0	0	0	0	0	0	0	0

Table 5-25. Effect of Bad Visibility on Single Runway Mixed Operations

		Theoretical	Good Visibility	Bad Visibility With ASDE	Bad Visibility Without ASDE
Current Analysis	Arrivals	34	34	34	34
	Departures	28	23	20	9
	Total	62	57	54	43
	Percent of Ideal	-	92	87	69
Preliminary Analysis	Total	60	54	43	40
	Percent of Ideal	-	90	72	67

19 valid departures for a total of 47 versus the 43 predicted for the unbalanced operation. Therefore, the arrival/departure mix juggling between the cab and Approach Control can have a beneficial effect on total operations and (1) the departure capacity estimates should be considered as problem indicators rather than exact estimates and (2) the total capacity estimates should be considered conservative.

Also included in Table 5-25 are the results of the preliminary analysis done in Reference 8. The comparison with the current results is fairly good in good visibility conditions and bad visibility conditions without ASDE-2. However, the Category II case indicates that a controller can do better with an ASDE than originally thought, adding increased weight to the ASDE deployment recommended in Reference 8.

5.3.3.1.5 Capacity Improvements

The first area of potential improvement concerns the distributions of the three basic parameters: arrival on time, departure on time, and inter-arrival spacing. Of the three, the only one which impacts each configuration is inter-arrival spacing. The potential payoffs associated with narrowing the spacing distributions are substantial and are the driving force behind the current Metering and Spacing program. If the current distribution could be converted to one more nearly like that shown in Figure 5-22, the arrival rate would rise from 34 per hour to 45 per hour (with 20 percent heavies). In addition, if the arrivals on time could be shortened and the distribution narrowed, the inter-arrival distribution could be moved to the left (i.e., separation standards could be reduced), further increasing capacity.

The next area of potential improvement concerns lost single departure release opportunities, particularly in the 60 to 100 second inter-arrival bins. The potential improvement is runway configuration dependent, ranging (in good visibility) from none for the Near-Near crossing runways to 25 percent for the Far-Far crossing runways. In addition, when Metering and Spacing is deployed, it will

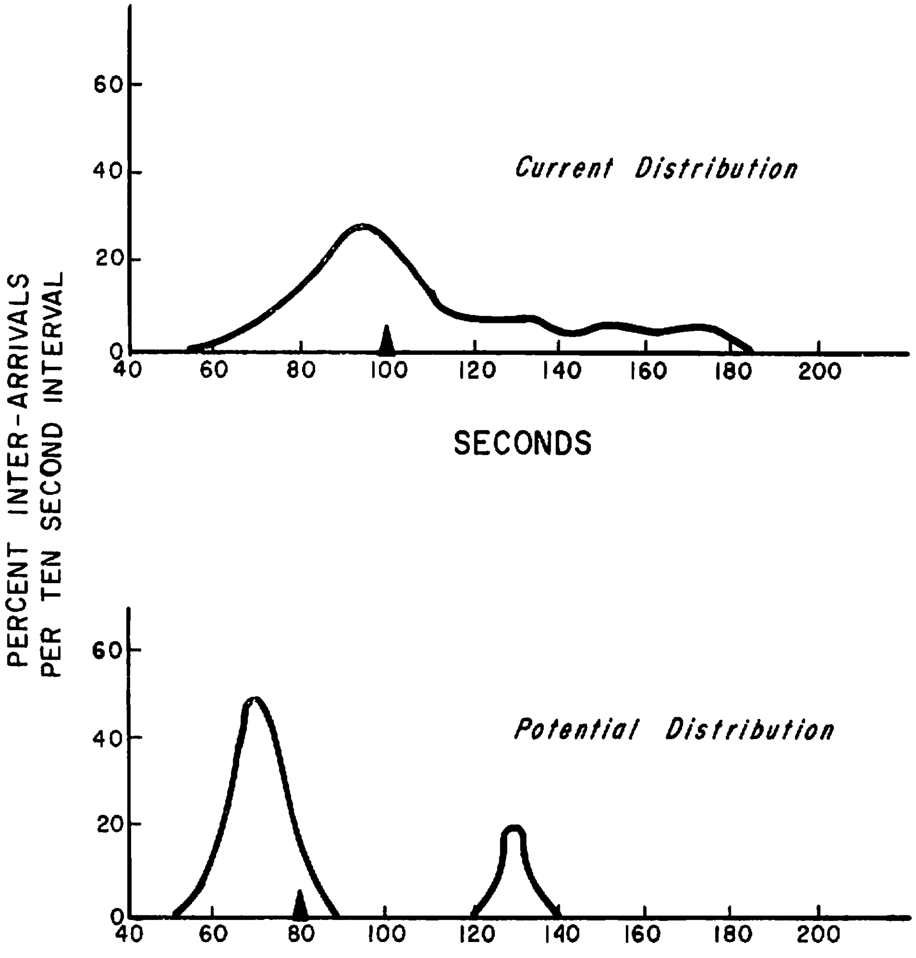


Figure 5-22. Potential Payoffs for Metering and Spacing

place most of the traffic in the critical 60 to 100 second bins where Local Control currently has the most problems. Its effect will be to increase arrival capacity while choking off departures unless some assistance is provided to Local Control.

A third area of potential improvement concerns the lost single departure releases under poor cab visibility conditions. The single runway mixed operation cases herein indicate that the critical 60 to 100 second inter-arrival spaces are largely ignored when cab visibility is lost and only position reporting is used (i.e., no ASDE). In this instance Metering and Spacing improvements could not be used to their full potential. ASDE does help the situation but falls short of good visibility capacity and will not permit Metering and Spacing to realize its full potential. At hard pressed airports such as O'Hare, something more is required.

The last area of potential improvement concerns lost double departures due to unfavorable mixing of initial departure directions of flight. It is possible that some assistance to Departure Ground Control, who initially sets up the departure sequence, might tap some of this potential improvement.

5.3.3.2 Local Control Area Delays

For arrival aircraft, no queueing or delay time was defined from the ASDE film. Any arrival delays prior to landing would occur while the aircraft was being handled by Approach Control in the TRACON. Delays associated with aircraft movements after clearing the runway were treated in the previous Ground Controllers' Area analysis. This is not completely in agreement with the operational procedures described in Section 4.2 for Local Control to retain aircraft until clear of the last active runway for which he is responsible. However, this division significantly eased the ASDE film analysis in that it was not necessary to make the distinction as to whether the aircraft was or was not under Ground Control for the various configurations.

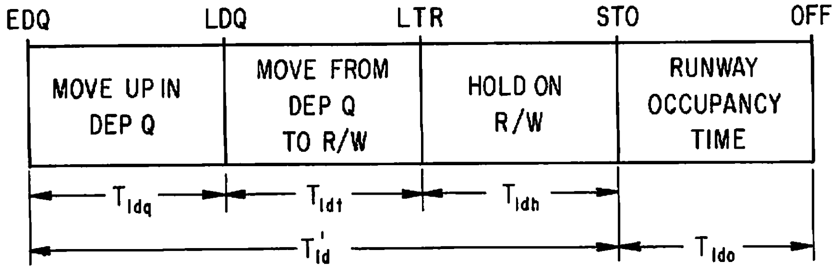
Departure aircraft, for the purposes of this analysis, have been considered to be in the Local Controller's area of responsibility from the time of entrance into the Departure Queue (EDQ) until they leave the runway. The timing relationships for departures are shown in Figure 5-23. Initial data reduction efforts separated the departure delays into the two components of departure queue delay and runway "Hold" time. In the remainder of the runs the difference between STO and EDQ time was used to obtain a total delay value, i.e., $T_{ldq} + T_{ldh}$, based upon the assumption (as verified in the initial runs) that the movement time from ldq to the runway was approximately 30 seconds.

Runway occupancy time, as measured from "over threshold" to "turnoff" was determined for 210 arrival aircraft. The data samples included all runways except those requiring a taxi phase because of the absence of turnoffs. The average of this parameter varied from 38-52 seconds depending on the runway; the standard deviation ranged from 6-19 seconds. This parameter appears sensitive to both runway and aircraft navigation effects and will influence the operating strategies used by the Local Controller(s).

The basic data for analysis was derived from the departure history forms discussed earlier in paragraph 5.3.2 (Table 5-8). A sample of the data reduction sheet for Local Control is given in Table 5-26; the remaining data reduction sheets for the various runs are given in the Operations Analysis Data Supplement. The flights treated as occurring within the sample hour are those whose STO (takeoff) time was within the observation period. The compilation of data on each runway sheet permitted the following parameters to be obtained for departures:

N_d - Number of Takeoffs in Observation Period

$\overline{T}_{ldt}$ and $\sum T_{ldt}$ - Average and total taxi (movement) time (only for some runs)



where

$T_{ldq} + T_{ldh}$ - Total "Hold" Time

T_{ldq} - Delay in Departure Queue

T_{ldh} - Delay on Runway

T_{ldt} - Local Control Taxi (Movement) Time

$T_{ld}' = T_{ldt} + T_{ldq} + T_{ldh}$ - Local Control Service Time

T_{ldo} - Runway Occupancy Time

Code:

l = Local Controller

d = Departures

t = Taxiing

h = Runway "Holds"

q = Departure Queue "Holds"

o = R/W Occupancy

Figure 5-23. Timing Relationships - Local Controllers' Area (Departures)

Table 5-26. Sample Data Reduction Sheet

LOCAL CONTROL - DEPARTURES

Run # 20 Date 8-1-73 Runway 27 R

Start Time 8:40 STO End Time 9:40 STO

AC #	Time in Dept. Q LDQ-EDQ(1) T_{ldq}	Runway Hold Time STO-RTR(2) T_{ldh}	Local Control Taxi +Delay Time STO-EDQ(3)=T'_{ld}	Local Control Taxi (Movement) Time $T_{ldt=3-(2+1)}$
1	385	84	583	114
2	451	239	746	56
3	406	61	499	32
4	639	165	833	39
5	691	48	780	41
6	675	165	883	43
7	825	180	1039	34
8	362	218	604	24
9	954	154	1180	72
10	1277	111	1469	81

	6665	1425	8616	536
(Nd)	ΣT_{ldq}	ΣT_{ldh}	$\Sigma T'_{ld}$	ΣT_{ldt}
	667	143	862	54
	$\bar{T}_{ldq}$	$\bar{T}_{ldh}$	$\bar{T}'_{ld}$	$\bar{T}_{ldt}$

Number of aircraft with

Departure Q delays $\geq$ 10 sec

Runway holds

Total Delay Times

a) $\sum T_{1dq}$, b) T_{1dh}, and c) the sum of the two delays

The data for the individual runway data reduction sheets was next summarized for each run to show the delays in the north and south areas respectively. This data is presented in Table 5-27. The number of arrival aircraft within the observation hour was based on "OL" time.

The summary data sheets for each run present the total Local Control delays [in some cases broken down into Departure Queue and runway hold component(s)] as well as the average delay per departure for both the north and south areas. While average delay per departure for the total airport is also presented in these summary sheets, these values are not as meaningful as those for each Local area.

The data from the individual runs have been summarized in Table 5-28 which presents the runway configuration used, the total number of arrivals and departures in the sample hour, the departure queue which existed at the start of the hour, the total delay to departing aircraft and the normalized parameters of average delay/departure and average delay/operation. Runs CSC #7 and CSC #8 represent bad cab visibility conditions.

Table 5-29 presents the average delay for the two modes of operation. The delay associated with the West Arrival Mode is higher than the East Arrival Mode (8.5 minutes versus 6.2). This is largely due to the two poor cab visibility cases included in this set. The good visibility delay differences are examined in Table 5-30.

Table 5-27. Summary of Local Control Aircraft Flow (1 of 12)

Date 2-8-73 Start Time 9:17 STD End Time 10:17 STD Primary Arrival Runways 9R, 14L

Arrival Mode From W (E or W) Run #15

Runway ID	Number of		Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	Delays		Delay Time-secs	
	Arrivals N_a	Departures N_d			# of A/C with $T_{ldq} > 10$ sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold)** ΣT_{ldh}
North Area 4L								
32R								
9L		19			17		7,726	
27R								
14L	28							
22R								
18								
36								
Subtotal	28	19			17		7,726	
Average							407	
South Area 4R								
32L								
9R	21	2			2		1,299	
27L								
14R								
22L		38			35		25,945	
Subtotal	21	40			37		27,244	
Average							681	
Airport Totals	49	59			56		34,970	
Average							593	

*Average over all A/C Depts.

** Runway Hold included in Departure Q Time.

Table 5-27. Summary of Local Control Aircraft Flow (2 of 12)

Date 3-9-73 Start Time 8:29 STD OL End Time 9:29 STD OL Primary Arrival Runways 9R, 14L

Arrival Mode From W (E or W) Run #39

Runway ID	Number of		Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	Delays		Delay Time-secs	
	Arrivals N_a	Departures N_d			# of A/C with $T_{ldq} > 10$ sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold)** ΣT_{ldh}
North Area								
4L		22	30 Assumed		19		5618	
32R								
9L	2							
27R								
14L	33							
22R								
18								
36								
Subtotal	35	22			19		5618	
Average							255	
South Area								
4R		34	30 Assumed		32		8169	
32L								
9R	23							
27L								
14R	5	3			0		0	
22L								
Subtotal	28	37			32		8169	
Average			*				220	
Airport Totals	63	59			51		13,787	
Average							234	

*Average over all A/C Depts.

** Runway Hold included in Departure Q Time.

Table 5-27. Summary of Local Control Aircraft Flow (3 of 12)

Date 3-1-73 Start Time 8:40 STD End Time 9:40 STD Primary Arrival Runways 27L, 22R

Arrival Mode From E (E or W) Run #20

Runway ID	Number of		Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	Delays		Delay Time-secs	
	Arrivals N_a	Departures N_d			# of A/C with $T_{ldq} > 10$ sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold) ΣT_{ldh}
North Area								
4L								
32R		20	32	648	16	16	7081	1547
9L								
27R	2	10	54	536	10	10	6665	1425
14L								
22R	28							
18								
36								
Subtotal	30	30	-	1,184	26	26	13,746	2,972
Average	--	---	39*	---	--	--	458*	99*
South Area								
4R								
32L								
9R								
27L	34	34	38	1,306	34	14	24,968	250
14R								
22L								
Subtotal	34	34	-	1,306	34	14	24,968	250
Average								
Airport Totals	64	64	-	2,490	60	40	38,714	3,222
Average	--	--	39	---	---	---	605	50.3

*Average over all A/C Depts.

Table 5-27. Summary of Local Control Aircraft Flow (4 of 12)

Date 3-6-73 Start Time 18:08 End Time 19:08 Primary Arrival Runways 14L, 9R

Arrival Mode From W (E or W) Run #29

	Number of				Delays		Delay Time-secs	
Runway ID	Arrivals N_a	Departures N_d	Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	# of A/C with $T_{ldq} > 10$ sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold) ΣT_{ldh}
North Area								
4L		19	36	693	19	17	7122	2055
32R								
9L								
27R								
14L	27							
22R								
18								
36								
Subtotal	27	19		693	19	17	7122	2055
Average	--	--	36 *	---	--	--	375*	108*
South Area								
4R		32	32	1,012	32	30	37,716	2,330
32L								
9R	32							
27L								
14R		3	35	104	2	3	593	852
22L								
Subtotal	32	35		1,129	34	33	38,309	3,182
Average	--	---	32*	---	--	--	1,095 *	90.9 *
Airport Totals	59	54		1,822	53	50	45,431	5,237
Average	--	---	34 *	---	---	---	841 *	96.9 *

*Average over all A/C Depts.

Table 5-27. Summary of Local Control Aircraft Flow (5 of 12)

Date 3-7-73 Start Time 16:52 End Time 17:52 Primary Arrival Runways 27R/27L

Arrival Mode From E (E or W) Run #33

	Number of				Delays		Delay Time-secs	
Runway ID	Arrivals N_a	Departures N_d	Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	# of A/C with $T_{ldq} > 10$ sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold) ΣT_{ldh}
North Area 4L								
32R		30	30	903	26	25	16,417	1,995
9L								
27R	33							
14L								
22R	6							
18								
36								
Subtotal	39	30		903	26	25	16,417	1,995
Average	--	---	30 *	---	--	---	547*	66*
South Area 4R								
32L		9	30E	270 E	0	1	0	194
9R								
27L	33	3	27	80	0	3	0	53
14R								
22L		26	27	696	26	0	3,585	0
Subtotal	33	38		1,046	26	4	3,585	
Average	--	---	27.6 *	---	---	---	94.5 *	6.5 *
Airport Totals	72	68		1,949	52	29	20,002	2,242
Average	--	--	29 *	---	---	---	295 *	33 *

*Average over all A/C Depts.

Table 5-27. Summary of Local Control Aircraft Flow (6 of 12

Date 3-8-73 Start Time 10:07 End Time 11:07 Primary Arrival Runways 27R/32L

Arrival Mode From E (E or W) Run #35

Runway ID	Number of		Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	Delays		Delay Time-secs	
	Arrivals N_a	Departures N_d			# of A/C with $T_{ldq} > 10$ sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold) ΣT_{ldh}
North Area								
4L								
32R		30	53	1579	23	23	14,287	1,374
9L								
27R	21	1	30 E	30	-	-	-	-
14L								
22R	2							
18								
36								
Subtotal	23	31		1609	23	23	14,287	1,374
Average	--	---	52 *	---	--	--	460*	44*
South Area								
4R								
32L	26	1	30E	30		-	-	
9R								
27L		19	34	775	7	11	430	450
14R								
22L								
Subtotal	26	20		805	7	11	430	450
Average	--	---	40 *	---	---	--	21.5 *	22.5*
Airport Totals	49	51		2414	30	34	14,717	1,824
Average	--	---	47 *	---	---	---	278 *	355 *

*Average over all A/C Depts.

Table 5-27. Summary of Local Control Aircraft Flow (7 of 12)

Date 3-8-73 Start Time 3:36STD End Time 4:36STD Primary Arrival Runways 14R, 14L

Arrival Mode From W (E or W) Run #37

Runway ID	Number of		Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	Delays		Delay Time-secs	
	Arrivals N_a	Departures N_d			# of A/C with T_{ldq} > 10 sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold) ΣT_{ldh}
North Area 4L								
32R								
9L		24	29	699	10	11	1274	877
27R								
14L	32							
22R	2							
18								
36								
Subtotal	34	24		699	10	11	1274	877
Average	--	---	29 *	---	--	--	53 *	37 *
South Area 4R								
32L								
9R		37	34	1245	32	28	7349	1407
27L								
14R	37							
22L								
Subtotal	37	37		1245	32	28	7349	1407
Average	--	--	34 *	---	--	--	199 *	38 *
Airport Totals	71	61		1944	42	39	8623	2284
Average	--	--	32 *	---	--	--	141 *	37 *

*Average over all A/C Depts.

Table 5-27. Summary of Local Control Aircraft Flow (8 of 12)

Date 1-17-74 Start Time 2:45STD End Time 3:45STD Primary Arrival Runways 14R, 14L

Arrival Mode From W (E or W) Run #CSC 7

Runway ID	Number of		Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	Delays		Delay Time-secs	
	Arrivals N_a	Departures N_d			# of A/C with $T_{ldq} > 10$ sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold)** ΣT_{ldh}
North Area								
4L								
32R								
9L		36			35		39,424	
27R								
14L	26							
22R								
18								
36								
Subtotal	26	36			36		39,424	
Average	--	---		---			1,095	
South Area								
4R								
32L								
9R		34			34		18,792	
27L								
14R	27							
22L								
Subtotal	27	34			34		18,792	
Average							553	
Airport Totals					34		58,216	
Average	53	70			70		832	

*Average over all A/C Depts.
** Runway Hold included in Departure Q Time.

Table 5-27. Summary of Local Control Aircraft Flow (9 of 12)

Date 1-16-74 Start Time 4:42STD End Time 5:42STD Primary Arrival Runways 27R,32L

Arrival Mode From E (E or W) Run #CSC 5

Runway ID	Number of		Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	Delays		Delay Time-secs	
	Arrivals N_a	Departures N_d			# of A/C with T_{ldq} > 10 sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold)** ΣT_{ldh}
North Area								
4L								
32R		27			26		8,512	
9L								
27R	32							
14L								
22R								
18								
36		9			0		0	
Subtotal	32	36			26		8,512	
Average	--	---		---	---		226	
South Area								
4R								
32L	35	1			0		0	
9R								
27L	3	28			22		4,592	
14R								
22L								
Subtotal	38	29			22		4,592	
Average	--	--	---	---	--		158	
Airport Totals	70	65			48		13,104	
Average	--	---		---	--		201.6	

*Average over all A/C Depts.

** Runway Hold included in Departure Q Time.

Table 5-27. Summary of Local Control Aircraft Flow (10 of 12)

Date 1-18-74 Start Time 1:15 STD End Time 2:15 STD Primary Arrival Runways 14L, 14R

Arrival Mode From W (E or W) Run #CSC 9

Runway ID	Number of		Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	Delays		Delay Time-secs	
	Arrivals N_a	Departures N_d			# of A/C with $T_{ldq} > 10$ sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold)** ΣT_{ldh}
North Area								
4L								
32R								
9L		19			12		2314	
27R								
14L	31							
22R								
18								
36								
Subtotal	31	19			19		2314	
Average	--	---			--		122	
South Area								
4R								
32L								
9R								
27L		37			37		9481	
14R	30							
22L								
Subtotal	30	37			37		9481	
Average	--	--		---	---	---	256	
Airport Totals	61	56			56		11,795	
Average	--	--	--	---	---	---	211	

*Average over all A/C Depts.

** Runway Hold included in Departure Q Time.

Table 5-27. Summary of Local Control Aircraft Flow (11 of 12)

Date 1-23-74 Start Time 6:34 STD End Time 7:34 STD Primary Arrival Runways 27R, 32L

Arrival Mode From E (E or W) Run #CSC 10

Runway ID	Number of		Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	Delays		Delay Time-secs	
	Arrivals N_a	Departures N_d			# of A/C with $T_{ldq} > 10$ sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold)** ΣT_{ldh}
North Area								
4L								
32R		25			14		3399	
9L								
27R	33							
14L								
22R								
18								
36								
Subtotal	33	25			14		3399	
Average							136	
South Area								
4R								
32L	33							
9R								
27L	4	28			17		3942	
14R								
22L								
Subtotal	37	28			17		3942	
Average							141	
Airport Totals	70	53			31		7341	
Average							139	

*Average over all A/C Depts.

** Runway Hold included in Departure Q Time.

Table 5-27. Summary of Local Control Aircraft Flow (12 of 12)

Date 1-18-74 Start Time 8:54 STD End Time 9:54 STD Primary Arrival Runways 14R, 14L

Arrival Mode From W (E or W) Run #CSC 8

Runway ID	Number of		Avg. LC Taxi Time $\overline{T}_{ldt}$	Total Taxi Time ΣT_{ldt}	Delays		Delay Time-secs	
	Arrivals N_a	Departures N_d			# of A/C with $T_{ldq} > 10$ sec	# of A/C with Runway Hold	ΣT_{ldq} (Departure Q)	(R/W Hold)** ΣT_{ldh}
North Area								
4L								
32R								
9L		25						
27R								
14L	28				20		6333	
22R								
18								
36								
Subtotal	28	25			20		6333	
Average							253	
South Area								
4R								
32L								
9R								
27L								
14R	28	21			21		16,250	
22L								
Subtotal	28	21					773	
Average								
Airport Totals	56	46					22,580	
Average							481	

*Average over all A/C Depts.

** Runway Hold included in Departure Q Time.

Table 5-28. Summary - Aircraft Flow Statistics - Local Control

Run No.	Runway Configuration				North Area						South Area						Total Airport				
	North		South		Ops/Hr		Initial Queue	Total Delay Sec^1	Delay/Dep.	Delay/Oper.	Ops/Hr		Initial Queue	Total Delay Sec^1	Delay/Dep.	Delay/Oper.	Ops/Hr		Total Delay Sec^1	Delay/Dep.	Delay/Oper.
	A	D	A	D	A	D					A	D					A	D			
ARRIVALS FROM EAST																					
TSC 20	22R	27R 32R	27L	27L	30	30	3	16,718	557	279	34	34	0	25,218 Mixed A/D	740	370	64	64	41,936	656	328
TSC 33	27R	32R	27L	22L	39	30	0	18,412	614	267	33	38	0	3,585	94.5	50.5	72	68	22,244	327	157
TSC 35	27R	32R	32L	27L	23	32	0	15,661	506	291	26	20	0	880	44	19.2	49	51	16,541	325	165
CSC 5	27R	32R	32L	27L	32	36	0	8,512	237	125	38	29	0	4,592	159	68	70	65	13,104	202	97
CSC 10	27R	32R	32L	27L	33	25	2	3,399	136	59	37	28	0	3,942	141	61	70	53	7,341	139	60
ARRIVALS FROM WEST																					
CSC 7	14L	9L	14R	9R	26	36	14	39,424	1070	622	27	34	2	18,792	552	308	53	70	58,216	830	472
CSC 8	14L	9L	14R	14R	28	25	0	6,333^2	253	119	28	21	0	16,250	773	332	56	46	22,580	481	222
CSC 9	14L	9L	14R	27L	31	19	0	2,314	122	46	30	37	3	9,481	256	141	61	56	11,795	211	101
TSC 15	14L	9L	9R	22L	28	19	6	7,726	407	165	21	40	9	27,244	682	446	49	59	34,970	593	323
TSC 29	14L	4L	9R	4R	27	19	0	9,177	482	200	32	35	14	41,491	1180	620	59	54	50,668	936	448
TSC 37	14L	9L	14R	9R	34	24	0	2,151	90	37	37	37	0	8,756	236	118	71	61	10,907	179	83
TSC 39	14L	4L	9R	4R	35	22	0	5,618	256	98	28	37	0	8,169	220	125	63	59	13,787	234	113

NOTES

1. Sum of $\Sigma T_{ldq} + \Sigma T_{ldh}$

2. Large Departure Q running back from 9L into Outer Circular and T3

Table 5-29. Average Delay for the Primary Arrival Modes

	Average Departures/Hour	Average Delay/ Departure (Minutes)
East Arrival Mode	55.2	6.2
West Arrival Mode	57.8	8.5
Good Visibility (from Cab)	57.8	7.0
Bad Visibility (from Cab)	58.0	11.6

From Table 5-30 it is apparent that the East mode of operation balances its operations between the North and South side very well, each running at about 85 percent of capacity (using paragraph 5.3.3.1 capacity estimates). However, when the Arrivals are coming from the West there appears to be substantial differences in delay between North and South side operations (8.5 minutes/departure in the South and 4.4 minutes/departure in the North). Since O'Hare is located in the North Central part of the country its traffic tends to be departing primarily to the East, South and West. Therefore, the natural split would favor departures from the South side (to the South and West or the South and East). Balancing of the operation involves the use of "secondary departure runways" (e.g., South bound traffic departs the North side) which does not appear to have been done for the selected West mode cases.

In order to correlate the delay with runway configuration and its associated capacity estimate, the average delay/departure and percent of predicted capacity represented by the departures are computed for each case, presented in Table 5-31 and plotted in Figure 5-24. For the most part the data falls about a curve whose asymptote is slightly over 100 percent. The three circled exceptions are TSC #15N which has an inflated delay due to an initial departure queue (i.e., some of the delay is associated with the previous hour), TSC#20S which represents the exceptionally fine performance shown previously on a single runway with mixed

Table 5-30. North Side/South Side Delays for the Primary Arrival Modes in Good Cab Visibility Conditions

		East Arrivals Mode	West Arrivals Mode
North Side	Average Observed Departures/Hour	30.4	20.6
	Percent of Total Departures	55.0	36.0
	Average Capacity (Departures/Hour)	35.0	32.4
	Percent of Capacity	87.0	64.0
	Average Delay (minutes)	6.9	4.4
South Side	Average Observed Departures/Hour	24.8	37.2
	Percent of Total Departures	45.0	64.0
	Average Capacity (Departures/Hour)	29.4	36.0
	Percent of Capacity	84.0	10.3
	Average Delay (minutes)	4.3	8.5
Total	Average Observed Departures/Hour	55.2	57.8
	Average Capacity (Departures/Hour)	64.4	68.4
	Percent of Capacity	86.0	85.0
	Average Delay (minutes)	6.2	7.0

Table 5-31. Delay and Percent Predicted Capacity for Good Cab Visibility Conditions

Run Identity	Configuration	Capacity Estimate	Departures	Delay (secs)	Percent Capacity	Delay Per Departure (mins)	
TSC 20N	F-F	27	30	16718	130	9.3	East Arrivals Mode
TSC 20S	S	23	34	25218	148	12.4	
TSC 33N	N-N	37	30	18412	81	10.2	
TSC 33S	N-N	37	38	3585	100	1.6	
TSC 35N	N-N	37	31	15661	84	8.4	
TSC 35S	N-F	29	20	880	69	0.7	
CSC 5N	N-N	37	36	8512	97	3.9	
CSC 5S	N-F	29	29	4592	100	2.6	
CSC 10N	N-N	37	25	3399	68	2.3	
CSC 10S	N-F	29	28	3942	100	2.3	
TSC 15N	QI	36	19	7726	53	6.8	West Arrivals Mode
TSC 15S	QI	36	40	27244	111	11.4	
TSC 29N	F-F	27	19	9177	70	8.0	
TSC 29S	QI	36	35	41491	97	19.8	
TSC 37N	QI	36	24	2151	67	1.5	
TSC 37S	QI	36	37	8756	100	3.9	
TSC 39N	F-F	27	22	5618	81	4.3	
TSC 39S	QI	36	37	8169	100	3.7	
CSC 9N	QI	36	19	2314	53	2.0	
CSC 9S	QI	36	37	9481	103	4.2	

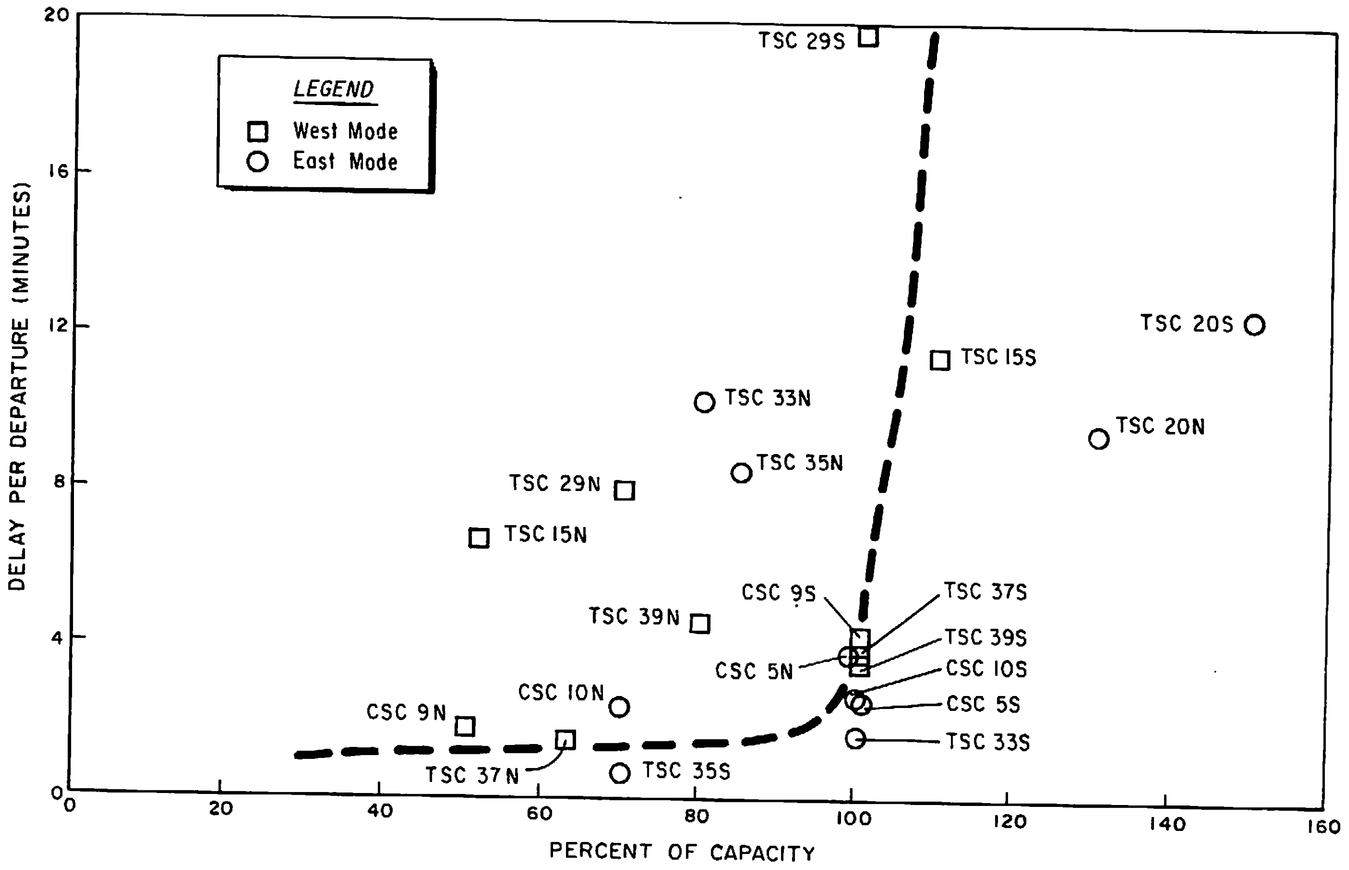


Figure 5-24. Correlation of Delay and Capacity Estimates

operations, and TSC#29N which represents an extremely conservative operation of a far-far end crossing runway (the most difficult to tolerate). In general, the data tends to confirm the capacity estimates.

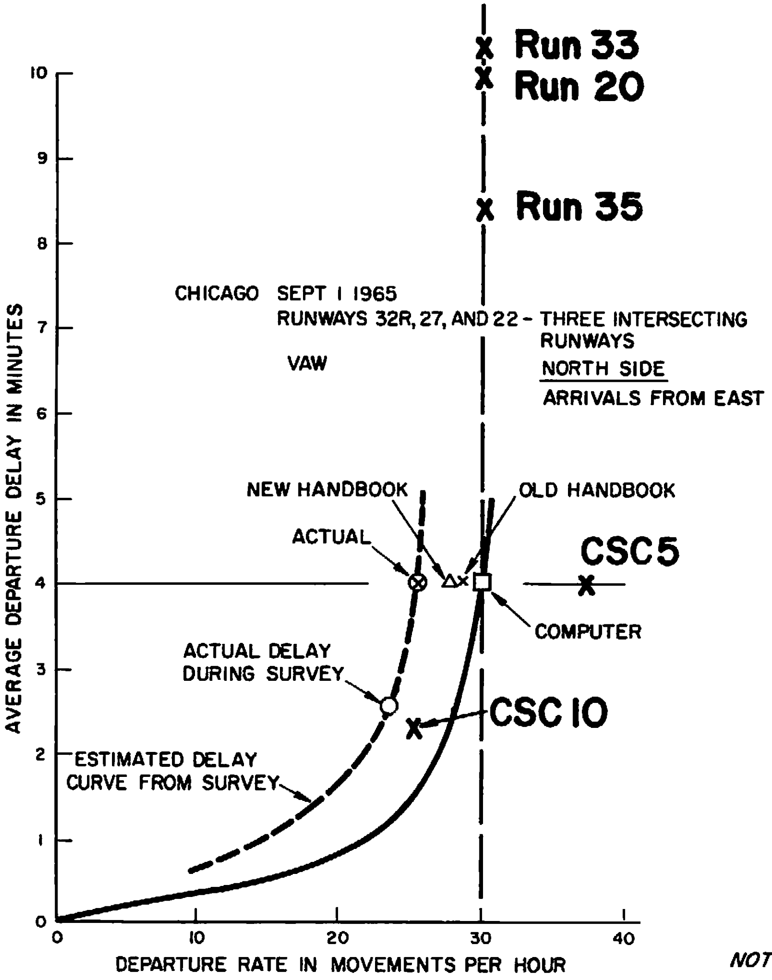
5.3.3.2 Summary of Results of Local Control Analysis

The values shown in Table 5-28 have been used to plot delay vs operations for the north and south areas for both the Arrival from West and Arrival from East modes (Figures 5-25 through 5-28). The format used represents data taken from the reference (indicated on the figure) on which the 1973/1974 data results have been superimposed (with the exception of southside-west arrivals for which no previous survey was performed).

Considering first the Arrival from the East curves, reasonably good agreement exists between the two sets of data which indicate apparent northside saturation near 30 departures/hr and southside saturation at between 35 and 40 departures/hr. The southside appears also capable of operating at the 35-40 departures/hr in the Arrival from the West mode. However, the northside appears to be appreciably less efficient when operating in the Arrival from the West mode. Saturation levels appear to be between 20-25 departures/hr, based on the proposed saturation level of 4-minute average departure delay proposed by the FAA Airport Capacity Manual developed some years ago.

5.3.3.3 Delay Analysis

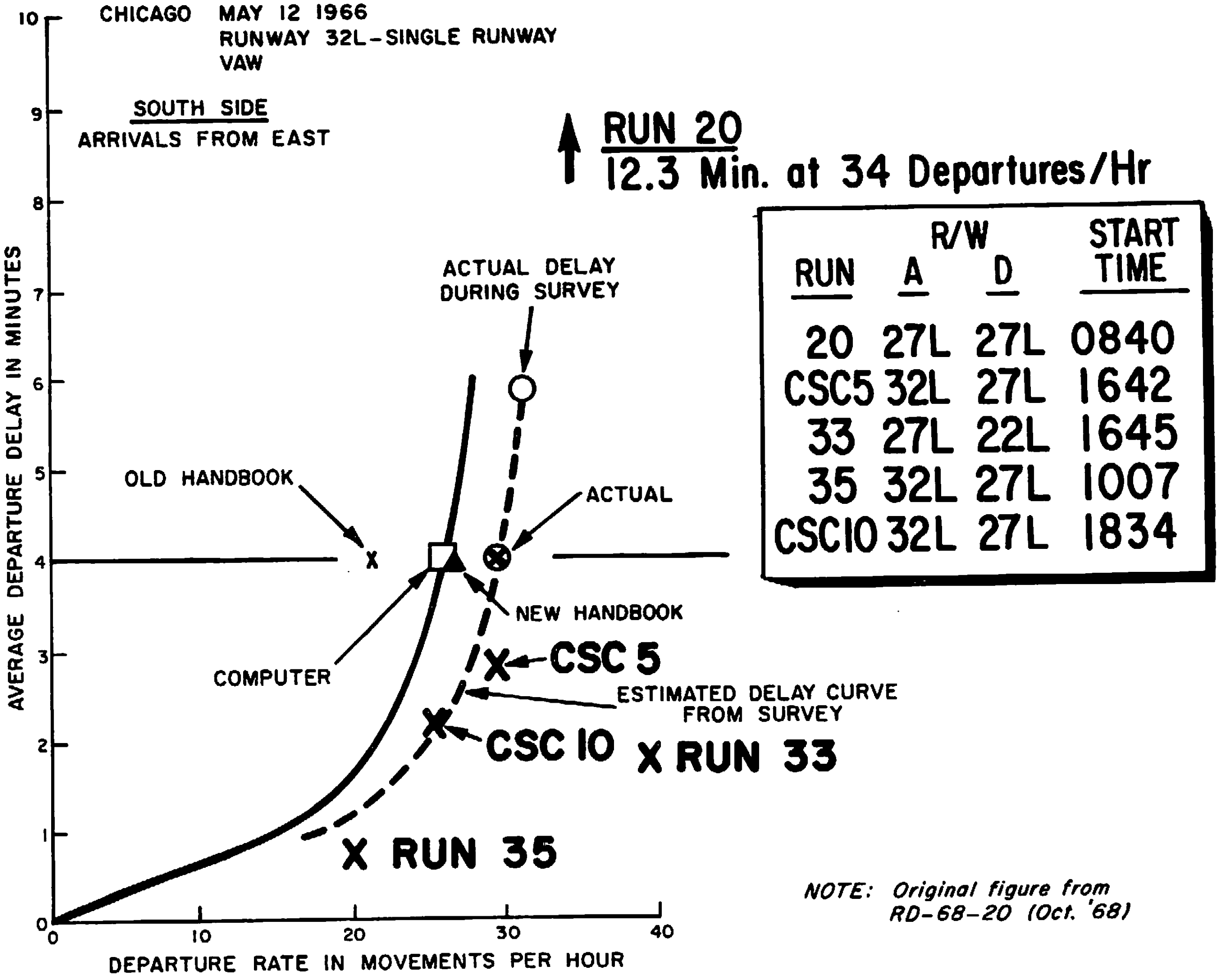
Official FAA NASCOM delay statistics count only those aircraft experiencing delays greater than 30 minutes. For operational reasons, statistics on delays to Departure aircraft are developed at the tower facilities (ATCT) while delays to "Arrivals" are kept at Centers (ARTCCs). A recent study ("FAA Report on Airport Capacity"; FAA-EM-74-5, I and II dated Jan 1974) examined delays at eight major airports associated with aircraft meeting the above 30-minute criteria. This analysis indicated a 2:1 ratio in the number of Arrival aircraft experiencing these delays as contrasted to Departure aircraft. It was further concluded that



RUN	R/W		START TIME
	A	D	
20	22R	27R/32R	0840
CSC5	27R	32R	1642
33	27R	32R	1645
35	27R	32R	1007
CSC10	27R	32R	1834

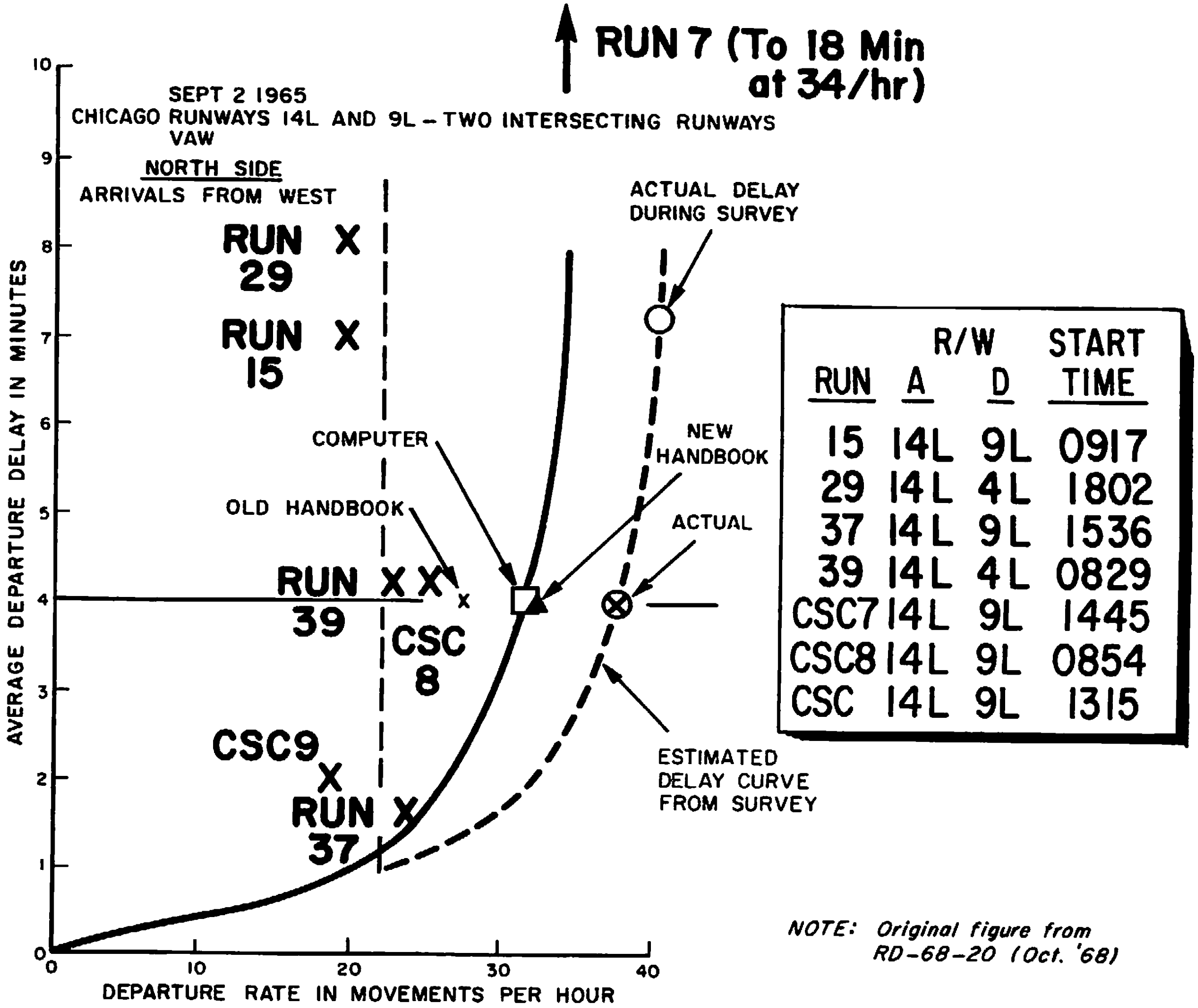
NOTE· Original Figure from RD-68-20 (Oct '68)

Figure 5-25. Local Control Delay - North Side (East Arrivals)



NOTE: Original figure from RD-68-20 (Oct. '68)

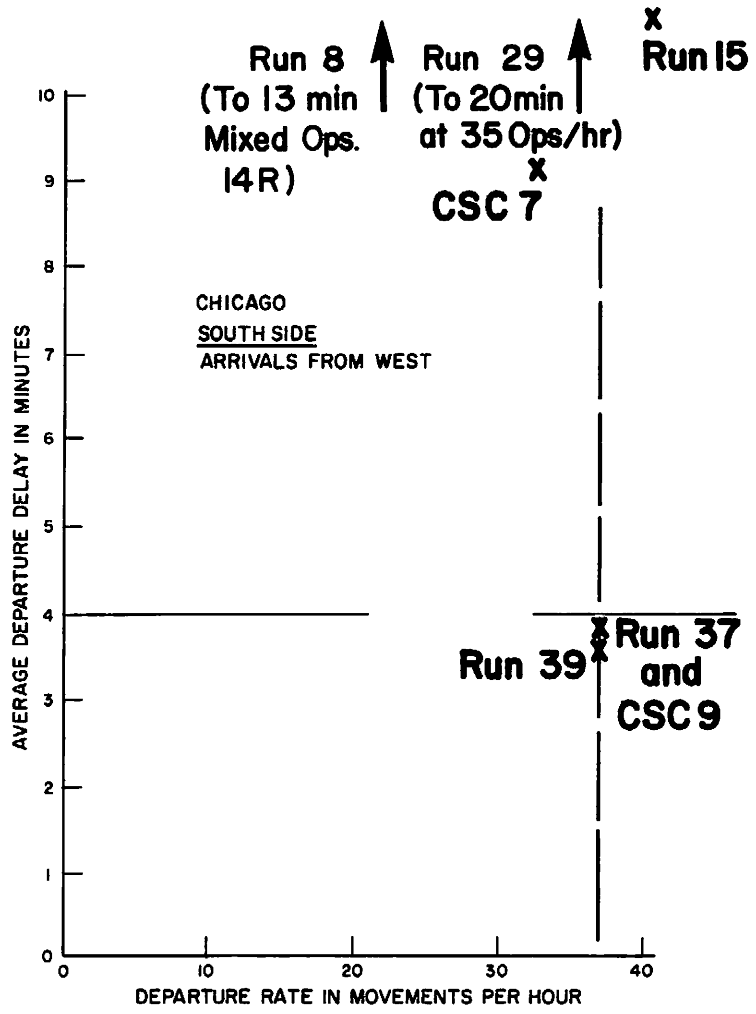
Figure 5-26. Local Control Delay - South Side (East Arrivals)



	R/W		START
RUN	A	D	TIME
15	14L	9L	0917
29	14L	4L	1802
37	14L	9L	1536
39	14L	4L	0829
CSC7	14L	9L	1445
CSC8	14L	9L	0854
CSC	14L	9L	1315

NOTE: Original figure from RD-68-20 (Oct. '68)

Figure 5-27. Local Control Delay - North Side (West Arrivals)



RUN	R/W		START TIME
	A	D	
15	9R	22L	0917
29	9R	4R	1802
37	14R	9R	1536
39	9R	4R	0829
CSC7	14R	9R	1445
CSC8	14R	14R	0854
CSC9	14R	27R	1315

Figure 5-28. Local Control Delay - South (West Arrivals)

weather is the major reason for these extensive delays. This reference states that at O'Hare approximately 20, 000 aircraft were delayed more than 30 minutes in 1973. Assuming an average delay of 45 minutes (no exact value is available) the total yearly delay for these aircraft would amount to 900, 000 minutes. If the average delay per aircraft is the same for both Departure and Arrivals the above values would indicate 6, 000 Departures experiencing total delay time of 300, 000 minutes per year; Arrival delay values would be twice those for Departures.

These delay statistics, as reported by NASCOM, may be compared with those experienced by aircraft not included in the NASCOM figures since they do not meet the 30-minute criteria. These "other" aircraft, representing the large majority of operations as well as primarily good weather conditions, experience delays for a wide variety of reasons. These include:

Aircraft Equipment Type (Sequencing and Separation Rules)
Mix of Arrivals/Departure Loads
Data Inadequacy for Sequencing Purposes
Controller Differences
Runway Configurations
Pilot/Aircraft Differences
Runway Occupancy Times

The sensitivity of aircraft delays to these multiple factors during "normal" operations has not been determined, although individual studies have shown the effects of varying some of the individual parameters, i. e., the effect of "heavies", for example.

It is in this area of operations that improved data for the controller can result in significant delay reductions. The total delay, of course, includes both Arrivals and Departures. Since this operations analysis effort is directed solely at tower cab operations, only Departures delays (and potential improvements in this area) can be estimated.

At O'Hare during the 13-hour busy period from 0800-2100, approximately 750 "Departures" will be handled. The distribution of Local Control delays during the 12 sample hours is presented in Tables 5-32 and 5-33 for the two different arrival modes. The average delay per departure is seen to be 6. 2 minutes for the Arrival from the East mode and 8. 48 minutes for the West mode.

These values include departure aircraft which would be cited in NASCOM statistics as well as those which would not be included. Since the 750 "busy hour" departures translate into about 225, 000 departures in a year (300 busy days per year with Saturdays and Sundays each treated as a half day), it can be seen that only 2. 6 percent (6000 ÷ 225, 000) of the Departures are actually counted in the NASCOM statistics. From the distribution shown in the tables it appears that the aircraft included in NASCOM data would be those falling into the 25-30 minute "bin". We may therefore adjust the average delay time to exclude these aircraft so that the average delay under normal busy conditions and good weather becomes 7. 93 (8. 48-0. 55) and 5. 75 (6. 2-0. 45) minutes for the two cases. Using a conservative average delay of 6. 75 minutes for the 97. 4 percent of departures not counted in NASCOM data gives rise to a total estimated yearly delay of (. 974 x 225, 000 x 6. 75 = 1. 48 (10^6) minutes. This value may be contrasted with the 300, 000 minutes of delay as reported by NASCOM. A reduction of only 20 percent in delays during normal operations would be comparable to <u>all</u> the Departure delays reported by NASCOM for O'Hare. At an average aircraft cost of $10. 00 per minute this 20 percent reduction would translate to $3, 000, 000 per year savings for the carriers. Moreover, the potential exists for greater reductions in Departure delays than the 20 percent assumed above. Delay reductions for Arrival aircraft during "normal" operations are a further potential benefit if Metering and Spacing techniques can be developed and applied on an integrated basis for the several control positions involved, namely the "transitional" sector controller(s) at the center, approach control, and local control.

Table 5-32. Distribution Statistics of Local Control Delays (Arrivals from West)

Run No.	Runway	No. of Occurrences with Delays of						Total
		0-5 min.	5-10 min.	10-15 min.	15-20 min.	20-25 min.	25-30 min.	
TSC								
15	9R			2	-	-		
	22L	13	2	8	11	4		
	9L	9	4	4	2	-		
		22	6	14	13	4		
29	4R				10	17		
	14R		3					
	4L	4	8	7				
		4	11	7	10	17		
37	9R	25	12					
	9L	22	2					
		47	14					
39	14R	3	-	-				
	4L	14	7	1				
	4R	24	7	3				
		41	14	4				
CSC								
7	9R	9	10	11	4	-	-	
	9L	6	-	-	11	11	8	
		15	10	11	15	11	8	
8	9L	16	9					
	14R	5	3					
		21	12	1	5	6		
9	9L	16	3					
	27L	24	13					
		40	16					
Subtotal - North		100	35	20	24	15	8	(202)
Subtotal - South		90	48	17	19	23	-	(197)
Total		190	83	37	43	38	8	(399)
Percent		47.5	20.7	9.3	10.8	9.5	2	

Avg Delay = .475(2.5)+.207(7.5)+.093(12.5)+.108(17.5)+.095(22.5)+.02(27.5)
= 1.18 + 1.55 + 1.16 + 1.9 + 2.14 + .55
= 8.48 minutes

Table 5-33. Distribution Statistics of Local Control Delays (Arrivals from East)

Run No.	Runway	No. of Occurrences with Delays of					Total
		0-5 min.	5-10 min.	10-15 min.	15-20 min.	20-25 min.	
TSC							
20	27R(N)	–	3	4	2	1	
	27L	2	8	14	9	1	
	32R(N)	10	6	-	3	1	
		12	17	18	14	3	
33	22L	25	1	-	-		
	27L	3	-	-	-		
	32R(N)	5	6	15	4		
	32L	8	1	-	-		
		41	8	15	4		
35	32R(N)	12	4	7	4	3	
	27L	24					
	32L	1					
	27R(N)	1					
		38	4	7	4	3	
CSC							
5	32R(N)	15	12				
	27L	25	3				
	36(N)	9					
		49	15				
CSC							
10	27L	23	5				
	32R(N)	20	5				
		43	10				
Subtotal - North		72	36	26	13	5	(152)
Subtotal - South		111	18	14	9	1	(153)
Total		183	54	40	22	6	(305)
Percent		60	17.7	13.1	7.3	2	

Avg Delay = 0.6(2.5) + .177(7.5) + .131(12.5) + .073(17.5) + .02(22.5)

= 1.5 + 1.32 + 1.65 + 1.28 + .45

= 6.2 minutes

5.3.3.4 Summary of Local Control Area

1. The good visibility conditions capacity estimates are tabulated by configuration and percent utilization in Table 5-34 along with the average capacity as weighted by percent utilization. The estimates support a quota of 135 operations/hour evenly split between arrivals and departures, evenly split between the North and South sides and with a 20 percent mix of heavy aircraft. However, unbalanced operations (between North and South sides), such as those run in the West Arrival Mode cases herein, put a severe load on the Southside controller even with the 135 operations/hour quota.

2. The estimate for capacity improvements which could be achieved in good visibility conditions by assisting the controller in getting departures out in tight inter-arrival spaces is given in Table 5-35. The average departure rate increase is just over 10 percent. This amounts to about 5 percent of the total operations and would lead to a quota of about 140 operations/hour. All of the improvement lies in the Near-Far, Far-Far and single runway configurations, an average improvement of over 25 percent. This would be very important at other airports with less favorable runway configurations than O'Hare.

3. Although the potential for increasing departure capacity in the current system is significant (i. e., 10 percent at O'Hare and up to 25 percent at other airports), this potential will increase greatly with the deployment of Metering and Spacing. Metering and Spacing will be designed to create tight inter-arrival spacings to increase the arrival rate. These are precisely the spacings in which the unassisted Local Controller has trouble getting off departures.

4. Since current operations rates can often exceed the current runway capacity in good visibility conditions (i. e., mean capacity over all configurations is 132 operations/hour, the quota is 135 operations/hour) it would be expected that the departure delays would exceed the standard 4-minute delay criteria for acceptable (unsaturated) service. The average delay is 6. 2 minutes in the East Arrival mode and 7. 0 minutes in the West Arrival mode. These measurements are from periods of essentially "no delay" as would be reported by the ATCT.

5. When operating a single runway mixed mode in bad cab visibility conditions, a substantial reduction in capacity is experienced, (i. e., 25 percent in total operations). Thus, in Category II conditions at O'Hare with the two 14s operating an independent mixed

Table 5-34. Summary of Current O'Hare Capacity in Good Visibility

Runway Configurations		Departure Capacity		Total Capacity	Percent Use
South	North	South	North		
Near-Far	Near-Near	29	37	134	36
Quasi-Independent	Far-Far	36	27	131	24
Quasi-Independent	Quasi-Independent	36	36	140	13
Quasi-Independent	Near-Near	36	37	141	6
Far-Far	Quasi-Independent	27	36	131	2
Single	Far-Far	23	27	118	7
Near-Far	Far-Far	29	27	124	2
Near-Far	Single	29	23	120	2
Single	Single	23	23	114	4
Single	Near-Near	23	37	128	4
Weighted Mean		31	33	132	100

Table 5-35. Summary of ASTC Improved O'Hare Capacity in Good Visibility Without Metering and Spacing

Runway Configurations		Improved Departure Capacity		Improved Total Capacity	Percent Use
South	North	South	North		
Near-Far	Near-Near	36	37	141	36
Quasi-Independent	Far-Far	36	35	139	24
Quasi-Independent	Quasi-Independent	36	36	140	13
Quasi-Independent	Near-Near	36	37	141	6
Far-Far	Quasi-Independent	35	36	139	2
Single	Far-Far	28	35	131	7
Near-Far	Far-Far	36	35	139	2
Near-Far	Single	36	28	132	2
Single	Single	28	28	124	4
Single	Near-Near	28	37	133	4
Weighted Mean		35	36	139	100

operation, the capacity would be 86 operations/hour. The use of ASDE appears to provide substantial improvement. The two 14s would have a capacity of 108 operations/hour. This is still well below quota and will result in delays.

6. Most bad cab visibility operations are taken in the West Arrival Mode. For the two cases examined herein the delay/departure averaged 11.6 minutes reflecting the lost capacity in bad visibility.

7. When including the bad visibility cases in the West Arrival Mode, normalizing the delay per operation and ignoring the operation level variations between runs, the average delay per operation was 3.1 minutes (186 seconds) for east arrivals and 4.25 minutes (255 seconds) for west arrivals. These values will be used for comparison with delays at other portions of the system.

8. Departure delays at O'Hare during good weather are estimated at five times those reported by NASCOM using a 30 minute minimum delay criteria. Reduction of these delays by only 20 percent would benefit the airlines by more than $3, 000, 000.

5.4 CONTROLLER ACTIVITY (WORKLOAD) ANALYSIS

The second major area of investigation was related to the controller functional activity (workload) analysis. The results of the analysis of controller responsibilities and procedures were described in Section 4.2. The purpose of this section is to present the results of the quantitative analysis of controller activities. These activities fall into two general areas, communications and non-communications activities. The latter category may be further divided into four classes of activities: (1) visual observation and/or use of ARTS Brite or ASDE Brite displays; (2) recordkeeping on flight strips, logs, or scratch sheets; (3) handling of departure flight strips; and (4) coordination between controller positions. By virtue of the manner in which these activities were performed by controller personnel and could be observed by project analysts, it was not practically possible to obtain measurements of the time spent in the performance of visual monitoring and inter-controller coordination. However, these activities are discussed qualitatively later in this section.

Thus, the quantitative measurements of the activities of various controller positions presented in this section are limited to their communications activities and to their recordkeeping and strip handling activities.

Before proceeding further, it must be noted that communications activity represents the best measure of controller workload. Although recordkeeping and flight strip handling activities are performed for all aircraft, whether arrival or departure, they were observed to be performed almost totally in parallel with communications to the aircraft for which the activities were performed. Thus, computation of a total workload based upon addition of communications and these non-communications activities would result in a higher than true level of controller activity time.

Therefore, statistical analyses of controller recordkeeping and flight strip activities are presented in this report for the purpose of completeness and to serve as a reference in following program activities to develop functional designs for future ASTC systems. This is based on the premise that future system automation should, if anything, decrease the physical activity and should not increase it.

In addition to quantitatively describing this physical activity, this section presents examples of the handling of selected departure and arrival flights referenced to a chronological history of the movement of these aircraft through the ASTC system.

5.4.1 Controller Communications Activity Analysis

The communications activity data presented in the following paragraphs were derived from detailed analysis of controller communications recordings made by TSC and CSC for the various controller positions. The data presented for each position includes summaries of the message contents within the various communications transactions (CTs) examined, average number of CTs per aircraft, average CT duration, and channel occupancy (percent of time within the one-hour measurement periods spent in communications). For Ground Control and Local Control positions channel occupancy versus traffic volume is examined as well.

5.4.1.1 Clearance Delivery

The Clearance Delivery Controller is responsible for the issuance of flight clearance instructions to pilots and the handing over of aircraft ready to enter the ground control system to Ground Control, normally the Outbound Ground position.

A typical communication transaction sequence for an air carrier flight is:

1. Pilot contacts Clearance Delivery for his clearance.
   Controller transmits clearance from flight strip.

Pilot repeats clearance instructions.

Controller affirms that pilot has correctly received clearance and may request gate identification.

Pilot provides gate identification and signs off.

2. Pilot subsequently calls controller as "Ready to taxi."

   Controller instructs pilot to monitor the Outbound Ground frequency 121.75.

Transaction sequences vary due to the following typical causes:

1. Pilot calls for clearance which is not yet available to Controller; Controller puts flight "under request" status.
2. Pilot of flight "under request" may repeat request for clearance which is still not available to Controller.
3. Controller may attempt to contact flight which does not answer.
4. Pilot may challenge the validity of a provided clearance or seek a change.
5. At times of peak activity the Controller may broadcast "Anyone for taxi only?" or "Anyone for clearance only?" in order to sort a large number of flights attempting to contact him.
6. It is common for general aviation aircraft to call for flight clearance and be turned over to Outbound Ground in the same CT.

A transcripted example of communications for this controller position is provided in the Operations Analysis Data Supplement.

Analysis of the communication transactions indicated that Controller activity should be a nearly linear function of the number of aircraft seeking clearance. Upon traffic volume approaching saturation, abnormal delays will be encountered by flights requiring clearance. Based on two tape recordings, TSC #33 and CSC #7, a summary of transaction contents for typical one-hour periods is shown in Table 5-36.*

That the workload is a reasonably linear function of aircraft seeking clearance is demonstrated by the occupancy per aircraft contacted and the average number of CTs required per aircraft handled shown in the table. However, while remaining linear, the nature of the controllers service changed as the operations rate changed. In run CSC #7 at a total communication loading of 49 percent, the controller was able to initiate clearances prior to pilot request (i.e., 80 percent of clearances were not requested). In run TSC #33 at a total communication loading of 66 percent, the pilots were forced to get on the frequency and request their clearance (i.e., 75 percent of all clearances were requested). If it is assumed that 60 percent channel occupancy is a reasonable limit, then one controller could handle about 82 aircraft/hour or 66 departures/hour (based upon handovers/contacted aircraft of 0.8 from Table 5-36). This is consistent with the runway capacity estimates and the quota. It is also consistent with the fact that in December of 1973 the O'Hare ATCT had instituted a dual Clearance Delivery procedure for peak traffic periods. A "Pre-taxi" position was manned during this period and was responsible only for transmission of Center clearances to air carrier departures using the spare frequency 126.9. The Clearance Delivery position retained responsibility for handling air carriers as well as IFR and VFR general aviation traffic when ready to taxi. No data could be obtained on this dual position operation because it was terminated in January 1974 when the flight schedule reductions obviated the need for it. However, its existence tends to confirm that the current operation is near saturation.

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*Only two tape recordings were analyzed for this position. Clearance Delivery recordings were made for only a portion of the TSC runs; of the runs selected for analysis a tape was available only for TSC #33. Clearance Delivery recordings were available for nearly all CSC runs. However, after the completion of CSC #7 and comparison with the results of TSC #33, further analysis of this position was terminated.

Table 5-36. Summary of Clearance Delivery Communications Transactions

Run	TSC #33	CSC #7
Σ CTs	198	142
Message Elements*		
180A	58	11
180B	16	3
180	78	52
180S	1	0
150	3	1
210A	3	2
210B	5	1
230	64	58
310	52	29
420	60	58
500	17	13
Total Message Elements	297	228
No. of A/C Handled	89	68
Avg CT Duration (secs)	12.4	12.3
Avg No. of CTs/Aircraft (complete sequences)	2.5	2.3
Channel Time Occupancy (%)	66	49
Occupancy per A/C Handled (%)	0.75	0.72
CTs/Aircraft Handled	2.2	2.1

*Message element definitions were provided in Section 2.4 and are not repeated here.

5.4.1.2 Inbound Ground Control

Inbound Ground Control is responsible for the control of aircraft movements from the point of handover by Local Control to gate or other airport destination (i.e., Butler Aviation, cargo area, hangar area, military area). The point of handover is usually upon exit from the arrival runway or when the aircraft has crossed the last active runway under control of the Local Control for the south or north area in which it landed.

In discharging these responsibilities Inbound Ground is observed as attempting to exert some form of ramp control at times and appears to monitor gate status as far as he is able. When gate delay holds are reported by a pilot, he directs the aircraft to the penalty box or any other convenient holding area. He also directs aircraft out of these areas upon receiving notification from pilots that they have a gate. In addition to coordinating the movement of runway arrival aircraft, Inbound Ground coordinates the movement of aircraft between any two points on the airport (e.g., hangar to and from terminal, gate to gate, as well as the movement of all vehicles across runways and vehicles assisting aircraft.

Finally, he coordinates the initial departure of certain aircraft (mostly helicopters) and pushbacks for aircraft parked at the end of terminal fingers.

A typical communication transaction sequence for a particular arrival flight would be as follows:

1. Pilot contacts Controller and provides his flight identification, destination and his position. Controller provides taxi routing control instruction.

   Pilot acknowledges and repeats instruction.

2. Subsequently, the Controller may provide traffic advisory notice or call for a hold or yield to another aircraft.

   Pilot acknowledges and repeats instructions.

3. Controller clears aircraft to the gate.
   Pilot acknowledges.

Actual transaction sequences vary considerably depending on traffic volume, weather conditions, presence of aircraft with mechanical difficulties, etc. A transcripted example of communications for this controller position is provided in the Operations Analysis Data Supplement.

Inspection of the communications transactions indicated that controller activity was highly variable due to operating conditions but strongly dependent on traffic volume. In addition, the tape recordings indicated a fair amount of "human adaption" as operating conditions changed, in speed-up of talking rate, abbreviation of transactions, addressing multiple aircraft, etc. Due to adjacent channel interference, only one TSC recording, Run TSC #33, was analyzed together with six CSC-produced tapes--CSC #5, 7, 8A, 8B, 9 and 10. A summary of transaction contents for one-hour segments from these tapes is presented in Table 5-37.

Before exploring the ramifications of the above data, further explanation is required of the conditions under which tape runs TSC #33, CSC #8B and #9 were made. In the case of TSC #33, the data was difficult to analyze due to garbling through adjacent channel interference. Hence the data provided is to be judged as a "best estimate." In particular it is to be noted that the actual noted formal clearance of aircraft into the ground system was less than actual due to "lost" clearance messages. The number of aircraft handled, as posted, has been formed from the number of aircraft contacted and correlated with the ASDE data.

In the case of CSC #8B, the weather deteriorated rapidly from run CSC #8A and dense fog formed. Extremely long departure queues formed and departures were routed from runway 14R to runway 14L. The arrival Ground Controller assisted in the movement of some of these aircraft through the hangar

Table 5-37. Summary of Inbound Ground Communications Transactions

Run	TSC		CSC					
	#33A	#33B	#5	#7	#9	#10	#8A	#8B[2]
CTs	222	199	157	170	203	173	132	158
CTs Aircraft Only	220	197	156	165	196	173	132	153
Message Elements[1]								
110	82	57	41	37	63	46	23	43
111	18	15	20	12	12	16	11	3
112	1	0	7	1	18	6	0	0
120	31	8	27	15	28	8	18	23
140	24	25	7	8	32	22	3	8
150	56	75	62	49	62	75	48	12
160	7	0	6	7	1	2	3	3
230	0	0	3	1	0	1	1	4
310	11	9	2	54	14	7	79	77
311	20	36	49	42	53	66	39	24
410	20	20	24	16	12	12	11	22
420	7	1	5	10	3	6	14	10
470	37	34	3	5	28	8	2	6
500	13	7	3	20	19	9	14	20
Σ Message Elements	325	287	259	271	353	284	266	255
No. of A/C Handled	92	87	80	66	73	83	65	35
Avg CT Duration (secs)	8.0	9.6	9.2	8.3	11.5	9.2	10.2	8.5
Avg No. of CTs per Arrival A/C Handled	2.3	2.6	2.3	3.0	3.1	2.3	2.3	5.3
Time Occupancy (%)	49	53	40	39	64	44	38	38

NOTES

1. Message element definitions were given in Section 2.4.
2. Much of controller's time spent in moving aircraft from 14R to 14L and in assisting Outbound Ground.

area. Arrival runway operations virtually were halted during the period of the recording with the exception of a few flights early in the period and a few midway during the period when the fog lifted briefly. As determined from the tape, ASDE-2 was in use by Ground Control (not by Local).

In the case of CSC #9, the airport operating conditions under which this tape was made were abnormal. That morning (CSC #8B) dense fog virtually stopped operations, completely disrupting the system of terminal gate allocations upon restoration of "normal operations." This situation caused the penalty box and other holding areas to be completely filled with some aircraft required to undergo circular taxiing due to the lack of gates. In addition, a DC-10 had undercarriage trouble which required eight transactions to the flight, plus transactions to assistance vehicles and lengthy transactions to other aircraft circumventing the disabled aircraft.

The one single parameter that best describes controller communications activity is the time occupancy of communication transactions required to control aircraft movement. Figure 5-29 demonstrates the apparent relationship between the number of aircraft handled and occupancy for the data acquired. It appears that the percentage hourly occupancy for normal operations is approximately 0.55 N_H (where N_H is the number of aircraft handled per hour). Under abnormal conditions due to heavy fog, interruptions of normal aircraft traffic flow develop and the need for the aircraft position reports increases. Thus, communication transaction channel occupancy rises.

The requirement for aircraft position reports significantly increases under lower visibility conditions. Under normal operating conditions (TSC #33, CSC #5 and CSC #10) position reports (message category 310) comprised approximately 2.5 percent of all messages. However, under low Category I conditions (CSC #7 and #8A), position reports comprised approximately 16.5 percent of all messages. Under Category II conditions (CSC #8B), the situation worsened to where position reports comprised approximately 30 percent of all messages.

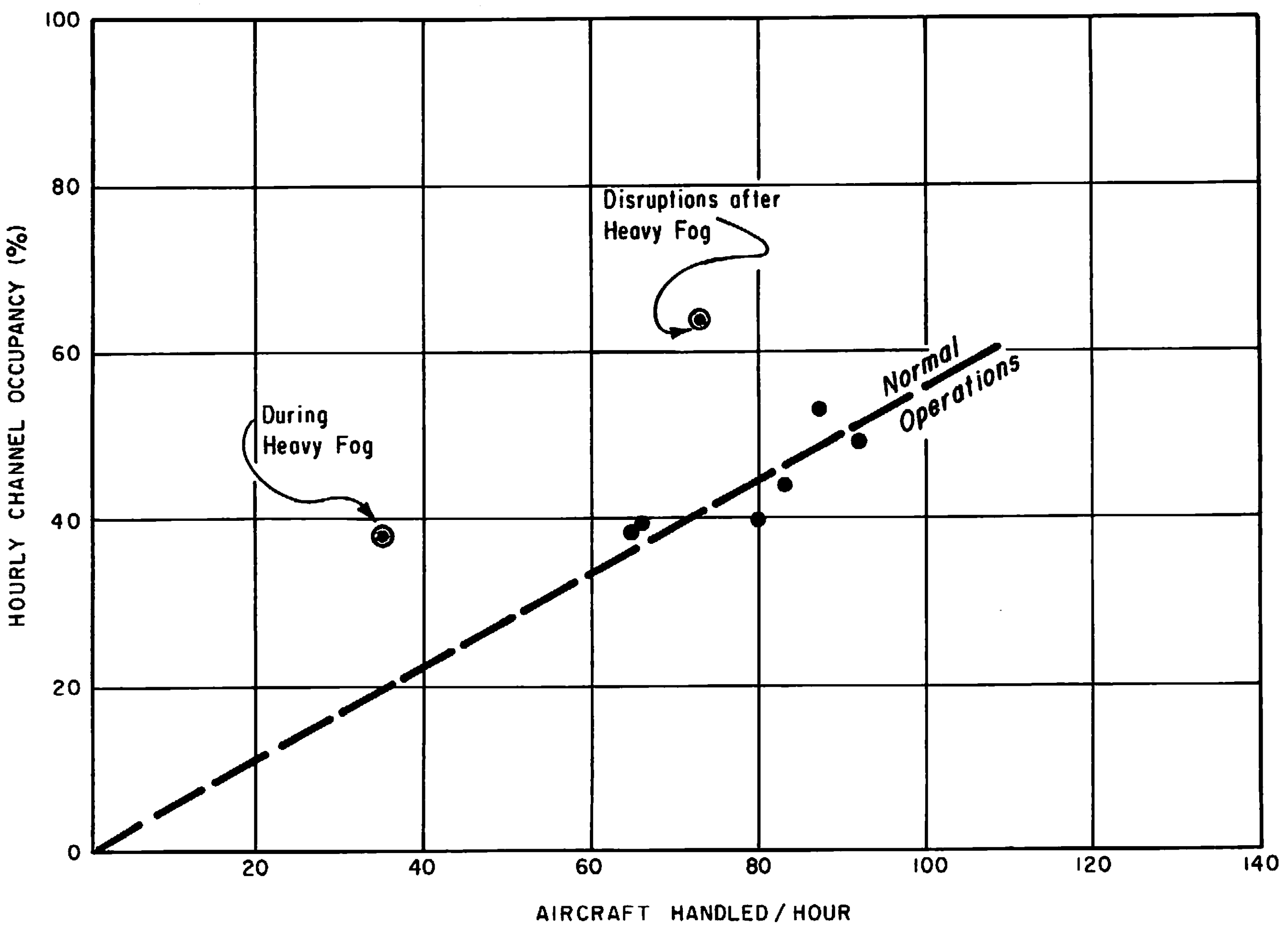

Figure 5-29. Hourly Channel Occupancy vs Aircraft Handled/Hour

As noted in Section 4.2, the Ground Controllers use both hold and yield instructions to accomplish intersection traffic control. Table 5-38 illustrates the relative usage of these types of control philosophy under good and low visibility conditions. The values shown are the percentage of all communications messages for the various runs under various conditions. It may be seen that the use of hold instructions tends to increase as visibility decreases, while the use of yield instructions tends to decrease as visibility decreases, but the percentage of communications devoted to intersection control is nearly the same for all conditions.

Table 5-38. Intersection Control Instruction Approach Vs Visibility Conditions - Inbound Ground

	Percentage of all Messages		
Visibility Conditions	Holds	Yields	Holds and Yields
Good visibility	6.4	6.8	13.2
Category I	6.9	4.8	11.7
Category II	9.0	3.1	12.1

In general the data indicates that as airport activity increases, so does occupancy. However, the mean CT duration is fairly independent and is probably more a function of individual controllers. In normal operations, the number of CTs per aircraft is fairly constant. Even in runs CSC #7 and CSC #8A where visibility was marginal (the cab could see almost to the runways) position reporting and CTs per aircraft were near normal. However, in run 8B when the cab could not see, reliance on position reporting doubled as did CTs per aircraft in general.

5.4.1.3 Outbound Ground Control

The Outbound Ground position is responsible for the coordination of airport departure aircraft movements from the terminal ramp to some convenient geographical point where the aircraft is handed over to the appropriate Local

Control. The geographical location of handover is one where the aircraft is removed from the taxi operations associated with terminal operations and has a clear taxiway to the runway run-up pad. These locations for various runways were identified in Section 4.2. Outbound Ground only handles aircraft that have received flight clearance from Clearance Delivery.

A typical communication transaction sequence for a departure flight under normal visual conditions would be as follows:

1. Controller contacts pilot and identifies his takeoff runway and provides routing instructions, as well as necessary sequencing and control instructions.

   Pilot acknowledges and repeats taxi clearance.

2. Subsequently the controller may provide traffic advisory information or call for a hold or yield to another aircraft.

   Pilot acknowledges and repeats instructions.

3(a). Controller contacts pilot and instructs him to monitor the appropriate Local Control frequency.

   Pilot acknowledges.

3(b). Controller clears aircraft across a runway and instructs pilot to monitor the appropriate Local Control frequency when across.

   Pilot acknowledges.

A transcripted example of communications for this controller position is provided in the Operations Analysis Data Supplement.

Examination of the communication transactions for this position indicated that controller activity was normally straightforward and strongly dependent on traffic volume. However, controller workload could increase remarkably upon the development of departure queues that extended backward across runways or into the Outer and Inner taxiway area. Under the latter circumstance a fair amount of "human adaption" occurred such as speed-up in talking rate, abbreviation of terms, or addressing multiple aircraft. Due to adjacent channel interference, no TSC recordings were utilized for analysis. Six CSC-produced recording tapes--CSC #5, 7, 8A and 8B, 9 and 10--were analyzed. A summary of transaction contents for one-hour segments from these tapes is presented in Table 5-39.

Table 5-39. Summary of Outbound Ground Communications Transactions

	CSC #5	CSC #7	CSC #8A	CSC #8B	CSC #9	CSC #10
Σ CTs	149	217	177	273	163	159
No. of A/C Handled	66	67	58	49	59	59
Message Elements*						
110	21	87	47	52	40	20
111	31	29	22	31	16	19
120	4	20	4	43	2	3
140	10	22	10	10	5	3
150	66	30	49	42	56	55
160	0	30	3	4	2	1
230	66	66	57	46	58	58
310	4	10	10	118	5	3
500	7	6	20	30	12	7
Misc	5	24	17	34	13	26
Σ Message Elements	216	324	239	410	209	195
Avg Ct Duration (secs)	8.7	7.8	7.2	10.1	6.3	7.5
Time Occupancy (%)	36	46	36	76	28	32
Avg No. of CTs per A/C Handled	2.3	3.2	3.1	5.6	2.8	2.7

*Message element definitions were previously given in Section 2.4.

It can be seen from the table that the results for CSC #8B exhibit the same expansion of communications activity noted for the Inbound Ground position. However, the results for the other runs are quite similar. The greater communications activity under CSC #7 was caused by a rather large queue for departures which extended some distance on the Outer. This caused some difficulties for Outbound in clearing departures out of the ramp areas blocked by the queue, including repeated requests to the waiting aircraft to avoid blocking the crossing taxiways between the Inner and Outer.

With the number of aircraft handled varying only from 58 to 67 for the sample hours, no meaningful relationships could be developed based on this data alone that could be used for interpolation, or limited extrapolation, to describe the various parameters on an hourly basis.

However, it was postulated that a similarity should exist between the nature of Outbound Ground and Inbound Ground data. To test this hypothesis, the Outbound Ground data (excluding the highly unusual data run CSC #8B) was plotted with the Inbound data. The results are shown in Figure 5-30 for the relationships between mean hourly channel occupancy vs aircraft handled/hour. It can be seen that for operations observed the Outbound Ground data fits well with the relationships developed for Inbound Ground data. The data for run CSC #7 which exhibited a long departure queue also appears to fit loosely with "abnormal operation" data of Inbound Ground.

The use of holds versus yields instructions for intersection control during various level of visibility as shown in Table 5-40 appears to follow the same pattern seen for Inbound Ground; that is, the use of holds tends to increase with reduced visibility while the use of yield instructions tends to decrease with reduced visibility (if the unusual CSC #7 run is not included for the Category I conditions). However, the total amount of intersection control appears to increase with reduced visibility for this position where it was approximately the same under the varying conditions for Inbound Ground.

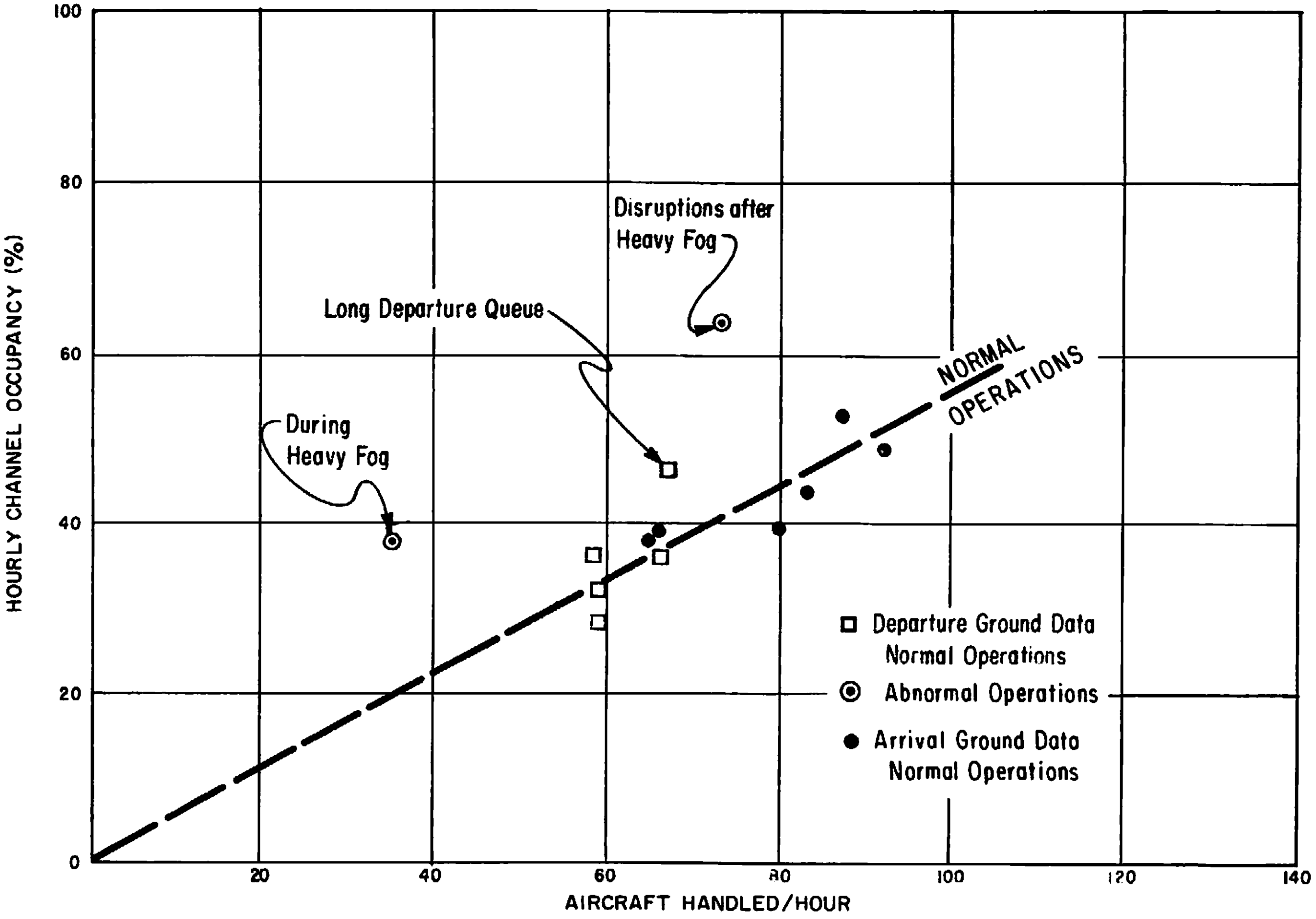

Figure 5-30. Channel Occupancy vs Aircraft Handled for Both Ground Control Positions

Table 5-40. Intersection Control Instruction Approach Vs Visibility Conditions - Outbound Ground

Visibility Conditions	Percentage of all Messages		
	Holds	Yields	Holds and Yields
Good visibility	1.7	3.2	4.9
Category I	3.3	3.3*	8.2
Category II	10.4	12.4	12.9

*This excludes the unusual conditions observed under CSC Run #9.

The effect of low visibility on Outbound Ground communications is also exhibited in the requirement for position reports from aircraft. Under good visibility conditions such reports occur for only 1.7 percent of all messages. In addition, unlike the Inbound Controller who required position reports for arrivals entering his control area out by the runways, the Outbound Controller in runs CSC #7 and CSC #8A handed off his aircraft before he lost visibility and needed little position reporting. In run #8B, however, he relied heavily on position reports as did the Inbound Controller (i.e., 28.8 percent).

5.4.1.4 Local Control

The two Local Controllers at O'Hare are responsible for controlling runway operations; Local Control #1 controls runway operations in the South and Local Control #2 controls runway operations in the North. Departure aircraft are handed over to the appropriate Local Control from the Outbound Ground at some convenient geographic point when the aircraft has departed the main Ground Control problem and has a clear taxiway to the runway run-up pad. From the communication tapes it may be determined that Local Control checks that his aircraft are in the right order in the departure queue, controls them onto the runway, clears them for takeoff, and provides turn headings after takeoff. When the departure aircraft has begun executing its turn after takeoff, the aircraft is handed over to Departure Control. In addition, it may be determined that Local Control time spaces successive takeoffs, taking into consideration wake turbulence problems when aircraft of vitally different sizes are attempting to take off and when a runway is used for mixed operations.

Arrival aircraft are handed over to Local Control from Approach Control from 3-6 miles off the end of the arrival runway. The identity and aircraft type are checked, the aircraft cleared to land on short final, and the aircraft handed over to Arrival Ground Control upon successfully exiting the runway in the South and after clearing all runways in the North.

The required monitoring of air movements, runway takeoffs and landings by Local Control, together with the provision of necessary time spacing of runway operations, indicates that a successful system is one which requires only a moderate amount of communication activity.

A typical communication transaction sequence for a departure aircraft would be as follows:

1. Local Control contacts pilot and instructs him (typically) to follow the aircraft ahead of him in the departure queue.

   Pilot acknowledges.

   The above transaction may be repeated one or more times until the aircraft reaches the runway.

2. Controller instructs aircraft to position and hold on the runway and may provide a turn heading and perhaps weather advisory information.

   Pilot acknowledges the position and hold and heading instructions.

3. Controller clears aircraft for takeoff and may provide a turn heading if not previously given.

   Pilot acknowledges the clearance and heading and may report that the aircraft is rolling.

4. Controller (after noting satisfactory takeoff and turn) instructs the pilot to contact Departure Control on the appropriate frequency.

   Pilot acknowledges.

For arrival aircraft the following typical communication transaction sequences ensue:

1. Pilot contacts controller reporting at (or passing) the outer marker.

   Controller acknowledges and gives the landing runway designation.

2. Controller clears aircraft to land or advises pilot that he is Number 2 to land.

   Pilot acknowledges and may request weather information.

3. Controller may provide runway turnoff instruction when desired.

   Pilot acknowledges.

4. Controller (after noting aircraft has cleared the runway) instructs pilot to contact Inbound Ground on 121.9 and may provide limited taxi instructions.

   Pilot acknowledges.

The communication sequences can be seen to be quite straightforward but variations may occur due to the following causes:

1. Aircraft mechanical trouble causing an aborted takeoff.
2. Aircraft mechanical trouble or runway turnoff not completed by previous arrival requiring wave-off of incoming traffic.
3. Aircraft in departure queue may have to return to gate for various reasons.
4. Visibility conditions may be below airline minimums requiring resolution of pilot intentions.
5. General aviation aircraft are provided with very precise single message element instructions.
6. General aviation aircraft may "pop up" and request to land.

Inspection of the communications transactions indicated that controller activity should be a reasonably linear function of the number of aircraft handled. Limitations upon communication activity appear to be controlled simply by the capability of the airport runway systems.

Four TSC tape recordings--#29, 33, 35 and 39--were reduced and analyzed for the two Local Control positions. In addition, tape recordings--CSC #8A and #8B--were analyzed to depict conditions where heavy fog disrupts airport operations. Also included in part to add to the understanding of fog operations is 48 minutes of run TSC 24. A summary of transaction contents for one hour segments from the tapes (except TSC 24) is presented in Table 5-41. The rows for TSC 24 have been multiplied by 1.25 to show an equivalent hour.

Hourly time occupancy (HO) is the parameter which best describes the controller communication activity and this parameter has been plotted in Figure 5-31 against the number of aircraft handled (N_H). Each point in the figure is identified as to Local Control position and mode of runway arrival (east or west); data from runs CSC #8B and TSC 24 (heavy fog) are identified as circled points. Time occupancy increased in a reasonably linear fashion for the range of data secured, indicating that a rough measure of occupancy (for HO not approach 1.0) can be obtained from the relation

$$\text{normal conditions HO} \approx 0.52\ N_H \text{ percent}$$

The average communication transaction duration ($\overline{T}$) as measured appeared to be independent of the traffic volume for the occupancies observed. It can be determined from Table 5-41 that an average value of 5.8 seconds is best descriptive of the data for normal weather conditions. As with Ground Control, the average duration is probably most heavily a function of the controller.

Table 5-41. Summary of Local Control Communications Transactions

Run	TSC #29		TSC #33		TSC #35		TSC #39		CSC #8A		CSC#8B		TSC #24
Local Control	1	2	1	2	1	2	1	2	1	2	1	2	2[1]
Σ CTs	255	183	229	189	176	197	190	219	202	226	80	184	225
No. of A/C Handled	90	52	82	58	64	67	69	67	47	55	17	34	60
Message Elements													
110	164	147	210	120	78	143	113	166	70	80	28	57	-
120	48	24	34	34	1	41	22	27	10	35	6	1	-
151	40	22	40	25	27	42	35	22	18	27	4	22	-
152	37	30	33	41	34	25	34	45	24	24	1	9	-
160	0	0	3	6	31	4	14	9	29	32	5	34	-
230	79	52	76	52	53	56	57	53	44	54	17	34	-
310	59	10	23	32	27	12	40	32	76	48	24	46	-
450	28	6	23	21	9	2	9	15	19	29	6	30	-
500	12	8	7	25	7	14	3	32	9	10	5	18	-
Misc	4	-	-	-	-	-	6	-	-	-	-	-	-
Σ Message Elements	471	299	449	356	267	339	333	401	299	339	96	251	-
Avg CT Duration (secs)	6.5	5.7	7.0	6.7	5.3	4.9	5.9	6.1	5.2	5.3	7.2	7.4	8.1
Channel Time Occupancy (%)	44	30	45	35	27	27	33	37	28	34	16	38	51
Avg No. of CTs/Aircraft (complete sequences only)	3.2	3.4	2.8	3.3	3.0	3.0	2.8	3.2	-	-	-	-	-
Avg No. of CTs per A/C Handled	2.9	3.5	2.8	3.3	2.8	2.9	2.8	3.3	4.3	4.1	4.7	4.2	3.8
Ratio of Arrival/Departure A/C Handled	0.88	1.36	0.91	1.15	0.88	0.59	0.82	2.05	1.04	0.9	.42	.42	1.17

[1] Single runway in use. One controller only.

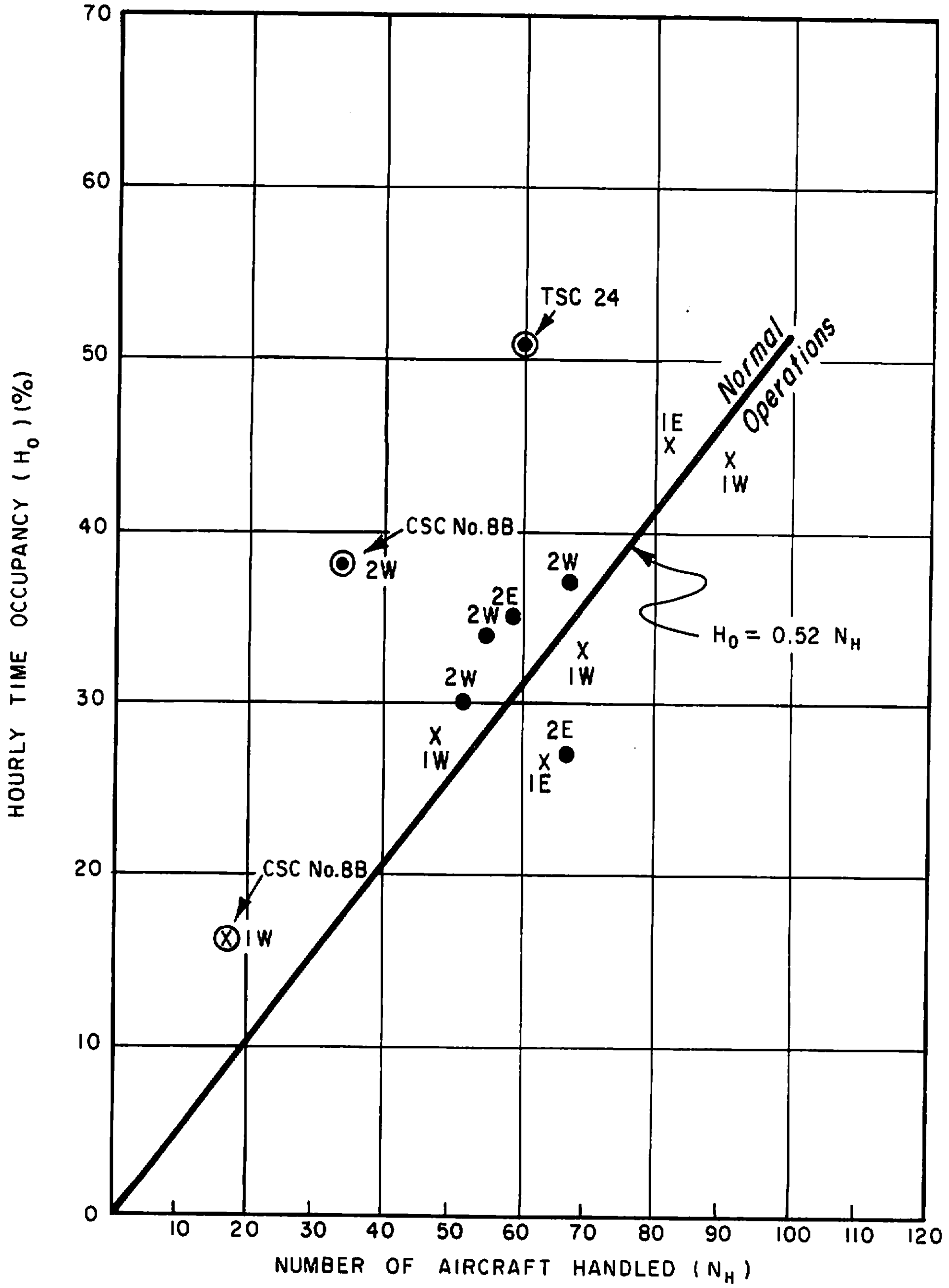

Figure 5-31. Local Control Hourly Occupancy Time vs Aircraft Handled

These two findings indicate that in good weather the average number of communication transactions per aircraft handled should also be reasonably constant. The data tabulation provided indicates the confirmation of this expectation with the average result of:

$$\text{Local Control \#1} \sum \frac{CT}{N_H} = 3.10 \text{ (variation approx. 10 percent for 80 percent of data)}$$

$$\text{Local Control \#2} \sum \frac{CT}{N_H} = 3.40 \text{ (variation approx. 10 percent for 80 percent of data)}$$

In bad weather the number of CTs is above the good weather average. This is due to such transactions as reporting the lights in sight and weather minimum discussions with aircraft in queue. RVR/visibility is given with landing clearance and will tend to lengthen the average CT time rather than the number of CTs. However, rate of delivery can overcome even this tendency as evidenced by CSC #8A. RVR/visibility was required on this run but rapid fire delivery by the controllers kept the mean CT duration down.

5.4.1.5 Short Term Aspects of Controller Voice Communications

In the preceding paragraphs, relationships were developed to permit interpolation and limited extrapolation of the measured data on an hourly basis. A reasonable question therefore exists as to what the limits of extrapolation are, and what are the associated implications on a short term basis.

For the Clearance Delivery Controller, no aircraft are in motion outside the terminal ramp areas and delays in clearance delivery accrued through communication channel congestion occur but are of minor consequence to the safety and efficiency of traffic flow. Also, the procedure for clearance delivery is relatively fixed, hence it is considered that the data derived for clearance delivery can be extrapolated to extremely high levels of hourly occupancy. The net effect of such high occupancy will be: (a) controller fatigue; (b) probably some confusion among aircraft crews in having to monitor a large numberof other aircraft transactions in securing their own clearance; and (c) inadvertent jamming and difficulty by aircraft crews in obtaining taxi clearance.

For all other controller positions, however, aircraft are in transit into and out of the airport and across the airport. As the hourly channel occupancy increases, the probability of communication channel saturation on a short term basis (say 5 minutes) increases, rendering control of various aircraft extremely difficult.

A good rule of thumb for most distributions is that the 95 percent point of the distribution can be approximated by the mean plus twice the standard deviation. Since the occupancy must be equal to or less than 1.0, and the mean hourly occupancy is the mean of the associated 5-minute occupancies, we can postulate an arbitrary boundary limitation for the mean 5-minute occupancy and its standard deviation as

$$q + 2\sigma \leq 1.0$$

where

q = mean occupancy, σ = standard deviation

In order to permit an assessment for the maximum degree of potential extrapolation of the previously derived hourly data relationships, it is necessary to know the levels of occupancy causing 5-minute saturation effects. Therefore measurements of q and σ for 5-minute periods of occupancy have been plotted as shown in Figure 5-32. The data thus obtained has been extrapolated as shown to determine the mean value for q for which apparently $q + 2\sigma = 1$. This value of occupancy has also been utilized to define the "aircraft handled" volumes which, when approached, indicate that the controller voice channel is saturating in some 5-minute periods producing problems in traffic control.

Actual data plots are provided in the figure which indicate that the maximum mean hourly occupancy when short term saturation problems occur is approximately 60 percent for all controllers. This value of hourly occupancy of 60 percent is also indicated as the limit of extrapolation in the previous sections. Sixty percent

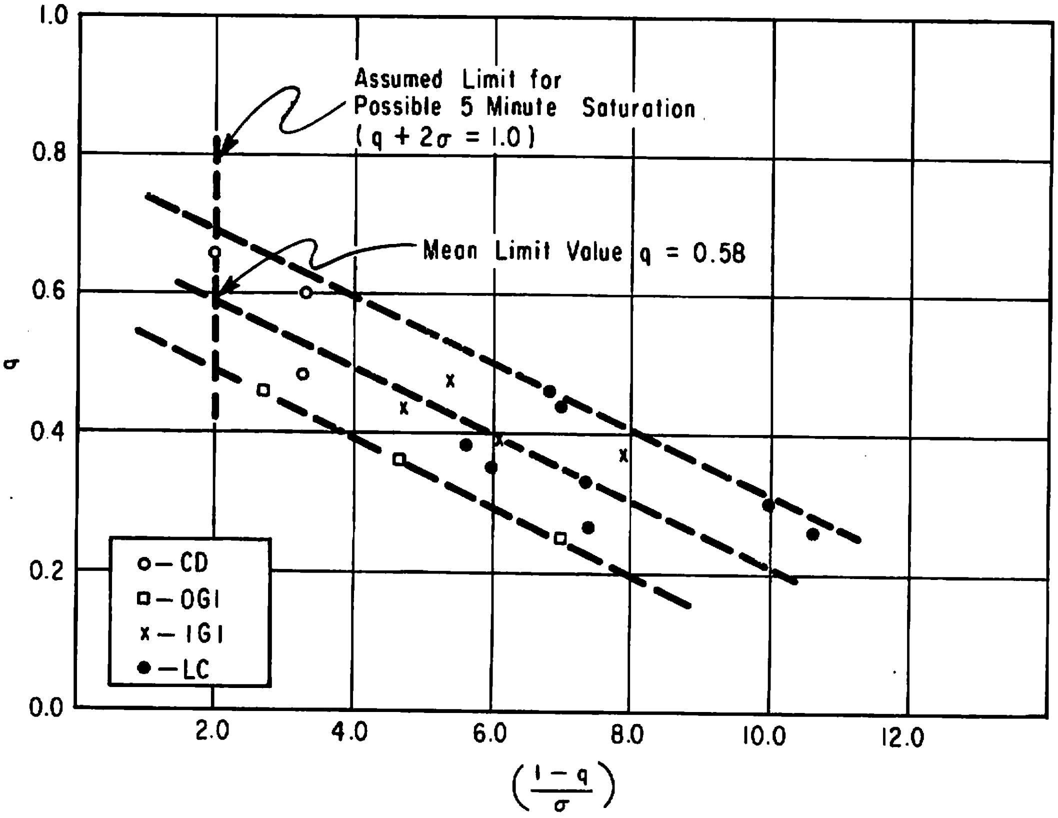

Figure 5-32. Analysis of Short Term Communication Saturation Effects

was used in capacity estimation in the Clearance Delivery discussion and will now be used to discuss Ground and Local Control.

To estimate the operations/hour capability of the Ground Controllers, the data from paragraphs 5.4.1.2 and 5.4.1.3 is plotted with respect to arrivals or departures/hour in Figure 5-33. In addition, since only run CSC #8B had bad visibility for the ground controllers, the bad visibility data for O'Hare from Reference 8 has been added. In all bad visibility cases ASDE was in use. The plot shows a range of data for both good and bad visibility conditions. The range is due to a combination of traffic problems (e.g., gate delays due to previous weather problems, aircraft equipment problems, and related hold ups in the taxiways) and controller delivery rate. Applying the 60 percent limit to the curves and multiplying by 2 to represent the two controller capacity, the estimates shown in Table 5-42 are arrived at. The estimates indicate that most of the time, in good visibility conditions, the controllers are operating with a comfortable loading. However, with the current quota (135 operations/hour), the controllers can be expected to saturate when traffic problems occur (a fairly frequent occurrence). In bad visibility, even when things go smoothly, Ground Control can just handle the two 14s running as independent single mixed operations (i.e., 108 operations/hour). Either increased operations or traffic problems (which are bound to occur when O'Hare is running near its quota for very long) will cause Ground Control serious problems.

Table 5-42. Communication Channel Saturation Estimates

		Two Controller Operations Rates	
		Smooth	Problems
Ground Control	Good Visibility	220	130
	Bad Visibility With ASDE	105	65
Local Control	Good Visibility	220	180
	Bad Visibility	195	115

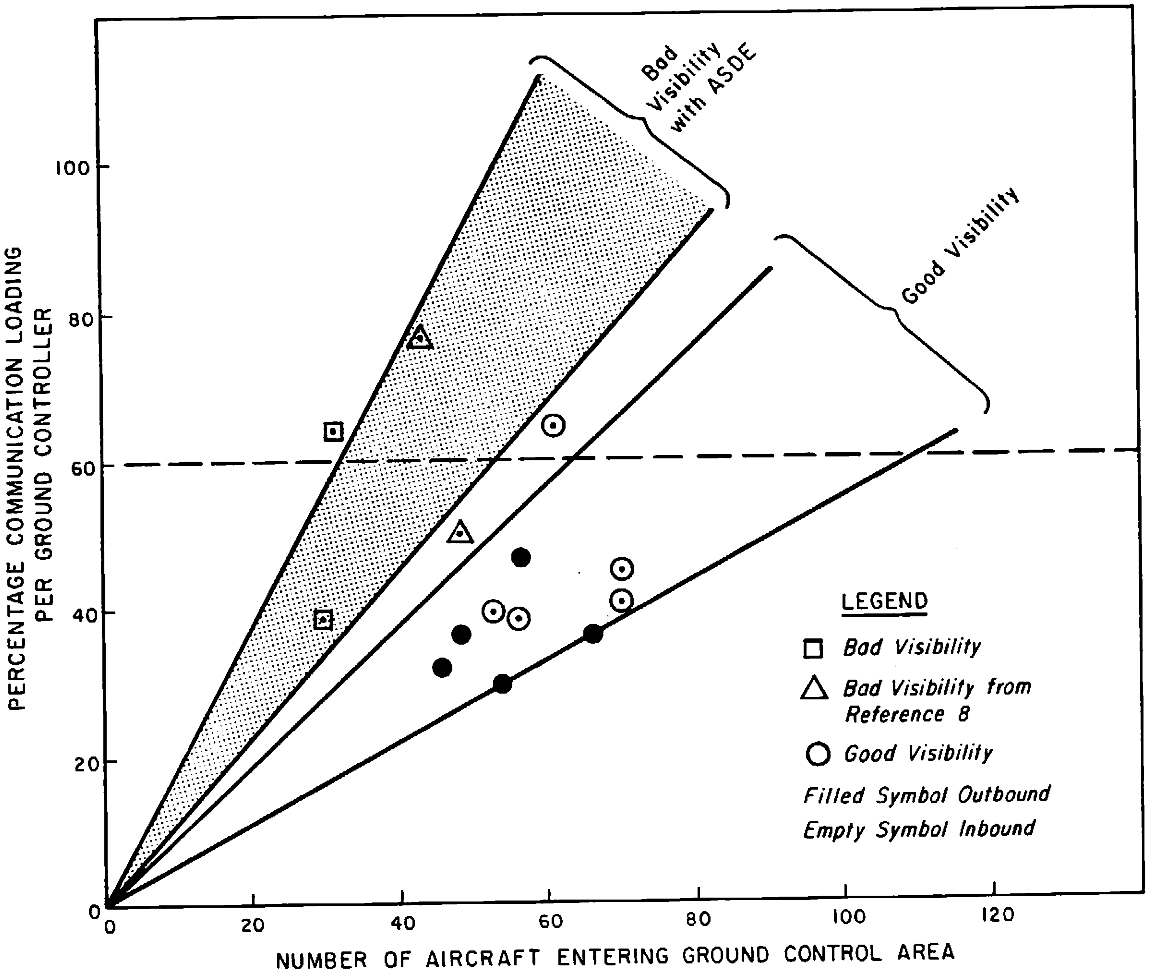

Figure 5-33. Ground Control Communication Saturation

To estimate the operations/hour capability of the Local Controller, the data from paragraph 5.4.1.4 is plotted with respect to arrivals or departures per hour in Figure 5-34. For Local Control, runs CSC #8A, CSC #8B and TSC #24 are considered bad visibility. CSC #8A is represented by the lower two points. A brief rapid fire delivery is responsible for the low values. The other points are a mix of ASDE and no ASDE operations. Apparently ASDE has little impact on Local Control communications.

As for Ground Control, the plot shows a range of data for both good and bad visibility conditions. The range is a combination of runway configuration (e.g., runway crossings require added communications) and controller delivery rate. Applying the 60 percent limit to the curves and multiplying by 2 to represent the two controller capacity, the estimates shown in Table 5-42 are arrived at. The estimates indicate that in good visibility the communication channel is not the pacing factor. Even with a bad configuration and slow message communication, the runways and their control will saturate (at above 142) even in the best configuration before the communication channel. However, in bad visibility conditions this is not the case. With slow message delivery Local Control would be just able to handle the two 14s running as independent mixed operation runways. If intersecting runways were in use, short terse commands would be a requirement.

5.4.1.6 Controller Communications Summary

1. Due to traffic fluctuations during an hour, if a 60 percent mean hourly communications loading limit is used to estimate channel capacity, it can be expected with about a 95 percent confidence factor that the channel will reach saturation (i.e., 100 percent loading) for at least five minutes in the hour. This 60 percent is used as the criteria for capacity estimation in this section.

2. The estimated channel capacity for Clearance Delivery is 66 departures/hour. On an even mix of arrivals to departures this is consistent with the runway capacity and the current quota. Clearance Delivery is just at saturation with little room for growth.

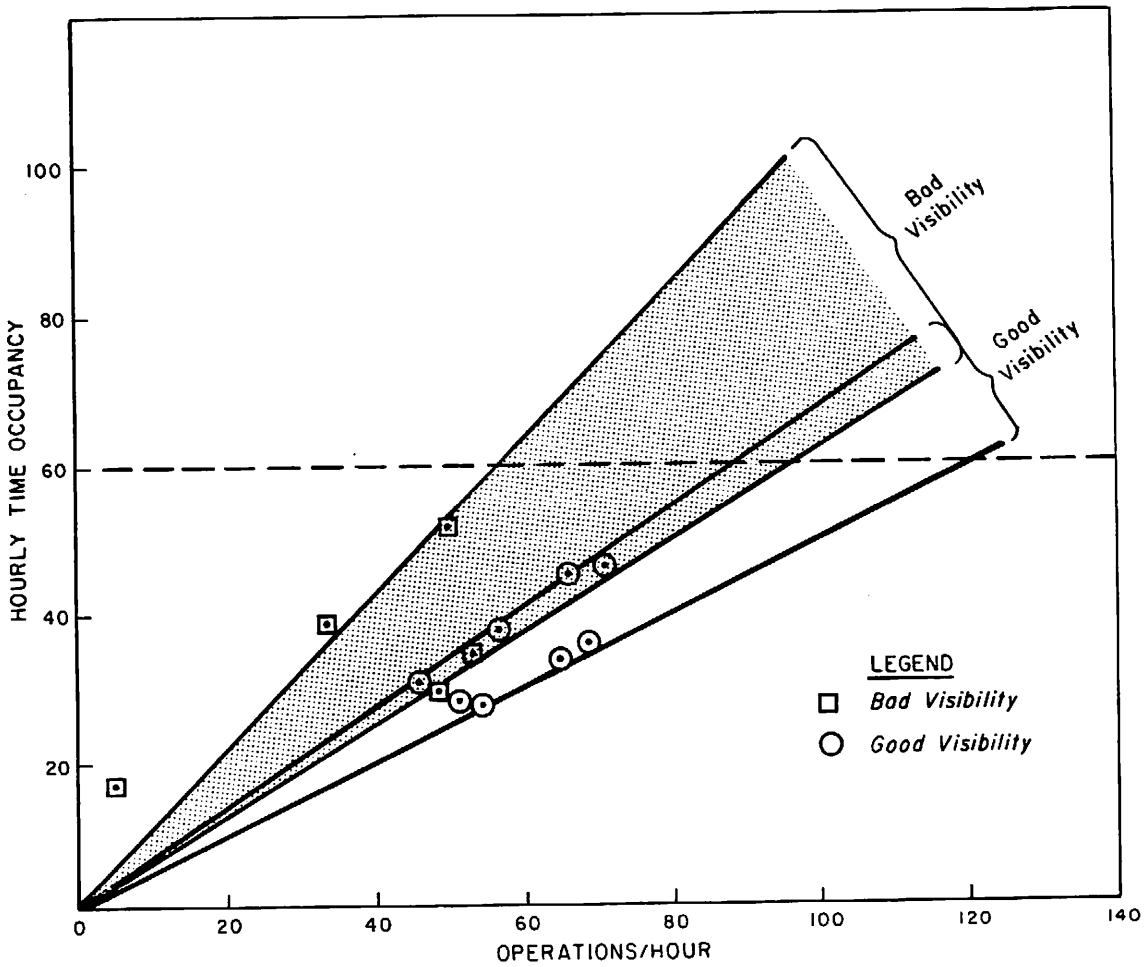

Figure 5-34. Local Control Communication Saturation

3. The estimated channel capacity for Ground Control is dependent upon visibility conditions and ASDE usage. For the bad visibility cases examined in this section, ASDE was in use. In good visibility conditions two channels (two Ground Controllers) can easily support a smooth operation. However with the current quota (135 operations/hour), when traffic problems occur (which is not infrequently) due to weather, gate tie ups, or aircraft equipment problems in the taxiways, the Ground Control channel(s) can be expected to saturate. On this basis Ground Control is approaching saturation in good visibility conditions with little room for growth.

   In "bad visibility" conditions for Ground Control (i.e., the controller cannot see the airport surface) the weather conditions are severe and the airport is usually operating the two 14s for arrivals. In this mode with a smooth operation, two Ground channels (with the controllers using ASDE) can just support the single independent mixed operations capacity of the two runways (i.e., about 108 operations/hour). However, this is below the current quota and, if operated for prolonged periods, can cause traffic tie ups. In this situation Ground Control channels are in serious difficulties. On this basis Ground Control is currently operating in a saturated fashion in "bad visibility conditions".

4. The major reason for increased Ground Control channel loading in "bad visibility" is the controllers use of pilot position reports, even with ASDE in use. This category of communication goes from one percent to two percent of all communications in good visibility to 30 percent when the Ground Controller cannot see (i.e., approaching or in Category II).

5. The estimated channel capacity for Local Control is dependent upon visibility conditions. In good visibility conditions the Local channels are well below saturation. The estimated capacity is 195 operations/hour. In "bad visibility" conditions (i.e., the controller cannot see the runways) a controller who delivers his messages in short terse commands will not saturate the channel. However, in two cases of the analysis, messages rates were observed which would have led to channel saturation had the operations rate been as high as 115 operations/hour. This would have just handled the two 14s as single independent mixed operations. For any operations rates in excess of that, short terse commands would be a requirement.

6. The major causes for increased Local Control channel loading in "bad visibility" are weather reports (RVR and visibility) and position reports (e.g., lights in sight by the pilot). In the case of single runway mixed operations, arrival turn-off negotiations are important position reports and have a substantial impact on channel loading.

5.4.2 Controller Non-Communications Activity Analysis

5.4.2.1 Descriptions of Non-Communications Activities

As noted in the beginning of this section the primary areas of concentration for quantitative investigation of controller non-communication activities were manual recordkeeping and flight strip handling. The activities studied for each position are listed below:*

1. Flight Data
    a. Retrieve flight strips from printer
    b. Separate strips
    c. Mount strips on flight strip holder
    d. Annotate strips for local restrictions and flight characteristics
    e. Post strips on Clearance Delivery Flight Strip Board
2. Clearance Delivery
    a. Retrieve strip from Flight Strip Board when (air carrier) pilot calls for clearance
    b. Record gate number
    c. Replace strip in Flight Strip Board until (air carrier) pilot calls for taxi
    e. Record time pilot called for taxi
    f. Pass strip to Ground Control (normally Outbound Ground)

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*These activities were described in detail in Section 4.2.

3. Outbound Ground

    a. Record departure runway on strip

    b. Position strip in Flight Strip Board (in sequence to the runway)

    c. Pass strip to Local Control #1 or #2

4. Inbound Ground

    a. Record flight call sign on scratch pad

    b. Record location where aircraft is holding for a gate on scratch pad.

    c. Eliminate flight call sign from scratch pad

5. Local Control

    a. Mark indication that pilot has been instructed to follow preceding aircraft in queue or to position and hold.

    b. Record departure heading on strip.

    c. Position strip in Flight Strip Board in order of takeoff sequence.

    d. Pass strip (down the Flight Strip Tubes) to Departure Control.

    e. Record arrival flight call sign on Arrival Log.

With the exception of activities 1(a), 4(b), 5(a), and 5(c) the activities are performed for all arrival and departure aircraft handled by the ASTC system. Thus, the total time spent in these manual activities will be approximately linearly related to the traffic volume.

In the case of activity 1(a) for Flight Data, flight strips are usually printed in batches, usually every 15 minutes. Therefore, the time spent in this activity per aircraft must be pro-rated among the aircraft for which strips were printed at each output. Although flight strips may be printed for individual aircraft, when it becomes necessary to request a clearance for a flight for which a strip has not been previously received or when a revised clearance is requested by the pilot, these instances occur infrequently and are treated in the computations in this analysis.

In the case of activity 4(b) for Inbound Ground the performance of this activity is strongly influenced by the traffic situation. Obviously, when heavy traffic levels or abnormal operating conditions result in increased gate availability problems, the requirement for this activity will increase directly with the number of aircraft required to hold for a gate. When there are only a few aircraft holding, it may be unnecessary for the controller to record the locations at which they are holding, since these locations would be limited to one or two areas, usually based upon the particular airline as discussed in Section 4.2. However, as the number of aircraft waiting for a gate becomes significant and a number of holding areas may have to be used, the requirement for recording of the holding location for individual aircraft increases.

In the case of activity 5(a) for Local Control, the performance of this activity appeared to differ between controllers. For some it was performed for all aircraft regardless of the traffic level. For others it was influenced by the traffic demand for the departure runway; that is, when there were only a few aircraft queued for the runway, the controller would not mark the strip but when there was a significant number of aircraft in the queue, the strip was marked for each flight. For some controllers it was never performed. However, in general this activity was performed at least for some departures by most controllers.

In the case of activity 5(c) for Local Control, the requirement to adjust the position of the flight strip in his Flight Board will be influenced by the runways in use, the operating conditions, and the arrival aircraft sequence. As noted in Section 4.2 Outbound Ground normally attempts to establish the aircraft in a reasonable sequence for the runway. Some modest adjustment of this sequence may be accomplished by Local Control when necessary or feasible. For example, for all runways but 4L there is a run-up pad where such an adjustment can be made. In the case of 4L Local Control basically has no option but to work the aircraft in the sequence set up by Outbound Ground and adjustment of the strip positions would not be performed. In situations where departures are established in two separate queues by virtue of the use of alternative routing by Outbound Ground, adjustment of strip positions is the rule while both queues exist. In some cases the nature of aircraft in the arrival sequence may lead Local Control to adjust the sequence of aircraft for departure, where this can be accomplished, to avoid delays in operation; for example, if heavy aircraft were in arrival sequence, he might sequence a heavy for departure ahead of another aircraft to avoid delays between these operations or minimize the impact of the turbulence caused by the arrival on departure operations.

The time required to perform each of the task activities for the various controller positions was measured. The measured values for each of the positions are shown in Tables 5-43 through 5-47 and include the computed average duration and standard deviation for each activity. It may be seen from these tables that the widest variation in performance times occurred for the Outbound Ground and Local Control activities related to the passing of flight strips to Local Control or Departure Control, respectively. This variation is anticipated based upon the manner in which the flight strips are passed to the succeeding position as described in Section 4.2; that is, the controller checked the flight's movements in reference to the strip, frequently holding the strip in his hand, while accomplishing this activity. The effect of this procedure is most effectively demonstrated in Table 5-45 with regard to the passing of the strip from Outbound Ground to Local Control #1. During the observation of two controllers, several measurements were specifically identified as having been made in the case where the controller was watching the movements of aircraft in the vicinity of the intersections of the Outer, New Scenic, and Bypass taxiways. For these specific instances the average duration of the activity was 8.8 seconds. The values shown in these tables are used in the following estimation of controller non-communications activity workload.

Table 5-43. Flight Data Activities Measurement

Controller Number	Retrieve Strip	Separate Strip	Mount Strip	Annotate Strip	Post Strip
1	2.0	2.5	3.0	0.5	2.5
	2.0	2.5	3.5	3.5	2.5
	2.5	2.0	3.0	3.0	2.0
	2.0	3.0	3.0	4.0	1.5
	2.0	2.5	2.5	3.5	2.0
	2.0	2.5	3.0	3.0	3.0
		2.0	3.0	4.0	2.5
		2.5	4.0	2.5	3.0
		3.0	3.0	0.5	3.0
		2.5	3.0	3.5	2.5
2	2.5	3.0	3.0	3.5	2.0
	2.0	3.0	3.0	4.0	1.5
	2.0	2.5	3.5	4.5	2.5
	2.0	2.5	4.5	2.5	3.5
	2.0	2.5	3.0	0.5	2.5
	2.5	2.5	3.0	3.5	2.5
	2.5	2.0	3.0	3.5	2.5
		2.0	2.5	3.5	2.0
		3.0	3.0	3.0	2.5
		3.0	3.0	3.5	2.5
3	2.0	2.5	3.0	3.0	2.5
	2.5	2.5	3.0	3.5	2.5
	2.5	2.5	3.0	3.5	2.0
	2.5	2.5	4.0	4.0	2.0
	3.0	2.5	3.5	4.0	1.5
		3.0	3.0	0.5	2.5
		3.0	2.5	0.5	1.0
		3.0	3.0	3.0	3.0
		2.0	3.0	3.5	2.5
		2.5	3.0	3.5	2.0
ΣT (seconds)	40.5	77.0	93.5	89.0	70.0
Avg Duration (seconds)	2.4	2.6	3.1	3.0	2.3
Std Deviation (seconds)	0.19	0.34	0.39	0.89	0.50

Table 5-44. Clearance Delivery Activities Measurement

Controller Number	Call for Clearance (Air Carrier)			Call for Taxi		
	Retrieve Strip	Record Gate	Replace Strip	Retrieve Strip	Mark Time	Pass Strip GC
1	1.5	0.5	1.5	1.5	2.0	1.0
	2.5	0.5	2.0	2.0	2.5	1.0
	2.5	1.0	2.0	2.5	2.5	1.5
	2.5	0.5	2.0	2.0	2.5	1.0
	3.0		2.5	2.5	3.0	1.0
	3.5	0.5	2.0	2.0	3.0	1.5
	2.0	0.5	1.5	1.5	3.5	1.5
	2.5	1.0	2.0	2.0	2.5	1.0
	3.0	0.5	2.0	2.0	2.5	1.5
	2.0		2.0	2.0	2.0	1.0
2	1.5	0.5	2.0	2.0	1.5	1.5
	2.5	0.5	2.0	2.0	2.0	1.0
	3.0	0.5	3.0	3.5	2.0	1.0
	3.5	0.5	2.5	2.0	2.5	1.0
	3.0	1.0	1.5	2.0	2.5	1.0
	2.5		2.5	2.0	3.0	1.5
	2.5	0.5	1.5	1.5	3.0	1.5
	3.0	0.5	2.0	2.0	3.5	1.0
	1.5	0.5	2.0	2.0	2.0	1.0
	2.5	0.5	2.0	2.0	2.5	1.0
3	2.5	0.5	2.0	2.0	2.0	1.5
	2.5	0.5	2.5	2.0	2.5	1.0
	3.0	0.5	1.5	2.0	3.0	1.0
	3.0	1.0	2.0	2.0	2.5	1.0
	1.5	0.5	2.0	2.0	2.5	1.5
	2.0	1.0	2.0	2.5	3.0	1.5
	2.5	1.0	2.0	3.0	2.5	1.0
	2.5	0.5	3.0	2.0	3.0	1.0
	2.5	0.5	3.0	1.5	3.5	1.0
	2.5	1.5	2.0	2.0	2.0	1.0
ΣT (seconds)	75.0	17.5	62.5	62.0	71.0	35.0
Avg Duration (seconds)	2.5	0.7	2.1	2.1	2.4	1.2
Std Deviation (seconds)	0.53	0.26	0.41	0.41	0.52	0.25

Table 5-45. Departure Ground Activities Measurement

Controller Number	Record Runway	Position Strip	Pass Strip to LC #1	Pass Strip to LC #2
1	1.0	1.5	3.5	4.5
	1.0	2.0	3.0	5.0
	1.0	1.0	3.5	6.0
	1.0	1.5	3.5	9.5
	1.0	2.0	2.5	4.5
	1.0	2.5	2.5	4.5
	1.5	1.5	3.5	7.5
	1.0	1.5	3.5	5.5
	1.0	2.0	2.5	3.0
	1.0	1.0	3.0	4.0
2	1.0	1.0	3.0	3.0
	1.5	1.0	2.5	3.5
	1.0	1.5	3.5	4.5
	1.0	2.5	5.0	16.0
	1.0	1.5	3.0	3.0
	1.5	1.5	12.0	4.5
	1.0	1.5	7.0	3.0
	1.5	2.0	15.0	4.0
	1.0	1.5	3.5	4.5
	1.0	2.0	3.5	3.5
3	1.0	1.5	3.0	2.0
	1.5	1.5	7.0	3.0
	1.0	2.0	3.0	3.0
	1.0	1.5	6.0	3.5
	1.0	1.5	3.5	3.5
	1.0	1.5	11.5	4.0
	1.5	1.0	7.5	3.5
	2.0	1.0	13.0	2.5
	1.0	2.0	6.0	3.0
	1.0	1.5	6.0	3.5
ΣT (seconds)	33.5	47.5	155.5	135.0
Avg Duration (seconds)	1.1	1.6	5.2	4.5
Std Deviation (seconds)	0.26	0.39	3.12	1.55

Table 5-46. Inbound Ground Activities Measurement

Controller Number	Record ID on Scratch Pad	Mark Noted Point	Eliminate ID
1	2.5		0.5
	3.0		0.5
	3.0	1.5	0.5
	3.5		0.5
	2.0		0.5
	2.5		0.5
	3.0		0.5
	3.0	1.5	0.5
	3.0		0.5
	3.5		0.5
2	3.0		0.5
	3.0		0.5
	3.0		0.5
	3.5		0.5
	2.0		0.5
	3.0	1.5	0.5
	2.5		0.5
	3.0		0.5
	3.0		0.5
	3.0		0.5
3	2.5		0.5
	3.0		0.5
	3.0		0.5
	3.0		0.5
	3.5	1.5	0.5
	2.5		0.5
	3.0		0.5
	3.0		0.5
	3.0		0.5
	3.0		0.5
ΣT (seconds)	87.5	6.0	15.0
Avg Duration (seconds)	2.9	1.5	0.5
Std Deviation (seconds)	0.37	-0-	-0-

Table 5-47. Local Control Activities Measurement

Controller Number	Mark P&H	Record Heading	Position Strip	Pass Strip to DC	Record ID on Arrival Log
1	0.5	1.5	3.0	3.5	2.5
	0.5	0.5	2.0	3.5	2.5
		1.5	2.5	12.5	3.0
	1.0	1.0	3.0	7.0	3.0
		1.5	3.0	3.0	3.0
	0.5	1.5	2.5	3.0	4.5
	0.5	1.5		2.0	2.5
		2.0		3.5	2.0
	1.0	3.0	2.0	5.0	3.0
		1.5		4.0	2.5
2	0.5	1.5		2.0	1.5
		2.0		2.5	3.5
	1.0	1.0		1.5	2.0
	0.5	1.5	2.0	7.5	1.5
		2.0	2.5	3.5	2.0
		2.0	3.0	1.5	2.5
	0.5	1.5		2.0	2.0
		2.0	2.5	3.0	5.0
	0.5	1.5		3.5	3.0
		1.0		2.5	2.0
3		1.0		3.0	3.5
	0.5	2.0		2.5	2.5
		1.5		4.0	3.0
		1.5		3.0	2.0
		2.0		5.0	3.0
	0.5	3.5		3.5	3.5
		2.0		3.5	2.5
		1.0		2.5	2.0
		2.0		3.0	3.0
		1.5		3.0	3.0
ΣT (seconds)	8.0	57.0	28.0	105.5	78.5
Avg Duration (seconds)	0.6	1.9	2.5	3.6	2.7
Std Deviation (seconds)	0.24	0.53	0.34	2.01	0.78

5.4.2.2 Computation of Non-Communications Activity Workload

The relationships employed in computing the activity workloads for the various controller positions for busy hours are described below:

1. $\overline{T}_{FD} = \left[k_p \overline{T}_{RS} + \overline{T}_{SS} + \overline{T}_{MS} + \overline{T}_{AS} + \overline{T}_{PS}\right]$ x Avg. No. Dep/Hour

where

$\overline{T}_{FD}$ = avg. time spent by Flight Data/Hour

k_p = pro-rating factor for individual flight

$\overline{T}_{RS}$ = avg. time to retrieve strips from printer

$\overline{T}_{SS}$ = avg. time to separate strip

$\overline{T}_{MS}$ = avg. time to mount strip

$\overline{T}_{AS}$ = avg. time to annotate strip

$\overline{T}_{PS}$ = avg. time to post strip in Flight Strip Board

2. $\overline{T}_{CD} = \left[k_{AC}(\overline{T}_{RSC} + k_{RG}\overline{T}_{RG} + \overline{T}_{RS}) + \overline{T}_{RSC} + \overline{T}_{RT} + \overline{T}_{PSG}\right]$ x
x Avg No. Dep/Hour

where

$\overline{T}_{CD}$ = avg. hourly workload for Clearance Delivery

k_{AC} = percentage of departures involving air carriers

$\overline{T}_{RSC}$ = avg. time to retrieve strip for delivery of clearance to air carriers

k_{RG} = percentage of departures requiring recording of gate

$\overline{T}_{RG}$ = avg. time to record gate number

$\overline{T}_{RS}$ = avg. time required to replace strip in Flight Strip Board

$\overline{T}_{RST}$ = avg. time required to retrieve strip for aircraft ready to taxi

$\overline{T}_{RT}$ = avg. time to record time

$\overline{T}_{PSG}$ = avg. time to pass strip to Ground Control

3. $\overline{T}_{OG} = \left[\overline{T}_{RR} + \overline{T}_{POS} + k_S\overline{T}_{PLS} + k_N\overline{T}_{PLN}\right]$ x Avg. No. Dep/Hour

where

$\overline{T}_{OG}$ = avg. hourly workload for Outbound Ground

$\overline{T}_{RR}$ = avg. time to record runway

$\overline{T}_{POS}$ = avg. time to position strip in Flight Strip Board

k_S = Percentage of flights using south departure runway

$\overline{T}_{PLS}$ = avg. time to pass strip to Local Control #1 (south runways)

k_N = percentage of flights using north departure runway

$\overline{T}_{PLN}$ = avg. time to pass strip to Local Control #2 (north runways)

4. $\overline{T}_{IG} = \left[\overline{T}_{RI} + k_H\overline{T}_{RHP} + \overline{T}_{EI}\right]$ x Avg. No. Arrivals/Hour

where

$\overline{T}_{IG}$ = avg. hourly workload for Inbound Ground

$\overline{T}_{RI}$ = avg. time to record ID on scratch pad

k_H = percentage of flights requiring recording of holding point

$\overline{T}_{RHP}$ = avg. time to record holding point

$\overline{T}_{EI}$ = avg. time to eliminate ID from scratch pad

5. $\overline{T}_{LC} = \left[k_{PH}\overline{T}_{MPH} + \overline{T}_{RDH} + k_{POS}\overline{T}_{POS} + \overline{T}_{PDC}\right]$

$\times$ Avg. No. Dep/Hour + $\overline{T}_{RAI}$ x Avg. No. Arrivals/Hour

where

$\overline{T}_{LC}$ = avg. hourly workload for Local Control

k_{PH} = percentage of strips for which controller will mark that position and hold instruction was given

$\overline{T}_{MPH}$ = avg. time to mark strip that position and hold instruction was given

$\overline{T}_{RDH}$ = avg. time to record departure turn heading

k_{POS} = percentage of strips which will have to be positioned in order other than received from Outbound Ground

$\overline{T}_{POS}$ = avg. time to adjust position of strips

$\overline{T}_{PDC}$ = avg. time to pass strip to Departure Control

$\overline{T}_{RAI}$ = avg. time to record arrival ID on Arrival Log

6. a) $\overline{T}_{DO} = \overline{T}_{FD} + \overline{T}_{CD} + \overline{T}_{OG} + \overline{T}_{LC}$ (departures)

b) $\overline{T}_{AO} = \overline{T}_{IG} + \overline{T}_{LC}$ (arrivals)

where

$\overline{T}_{DO}$ = avg. total hourly workload for all departure operations

$\overline{T}_{AO}$ = avg. total hourly workload for all arrival operations

Several general assumptions were made in developing the estimates for the non-communications activity workload to simplify the computational process. These are:

1. An average busy hour traffic volume of 120 operations/hour based on scheduled air carrier traffic and traffic levels observed in the traffic flow analysis.

2. General aviation (and commuter airline) operations account for approximately 15 percent of total busy hour operations (with VFR and IFR departures evenly divided).

3. Equal distribution of departure and arrival traffic within a typical busy hour.

4. Equal distribution of traffic operations between the north and south runways.

5. Normal visual operating conditions (so that the measured times for the various activities hold).

5.4.2.2.1 Flight Data

For the Flight Data the parameter k_P in equation (1) is determined from the following estimates. Flight strips are normally printed every 15 minutes. The average number of strips printed per hour is equal to the percentage of air carrier and general aviation IFR departures or

$$(0.85 + 0.07)\ (.50)\ 120 \approx 55 \text{ strips}$$

Thus

$$k_P = \frac{1}{\frac{15}{60} \times 55} \approx 0.073$$

Using this value $\overline{T}_{FD}$ is computed as

$$\left[(0.073)\ (2.4) + 2.6 + 3.1 + 3.0 + 2.3\right]\ 60 = 670.5 \text{ seconds}$$

5.4.2.2.2 Clearance Delivery

The parameter value k_{RG} in equation (2) is estimated to be 0.90 based upon Clearance Delivery procedures pertaining to gate recording. This is based on the fact that operations from 91.5 percent of the gate require such recording but that operations from other than American, Trans World and United gates are at a lower volume than for these airlines. Using this value and other parameters previously defined $\overline{T}_{CD}$ is computed as

$$\left\{(0.85)\ \left[2.5 + (0.90)\ (0.7) + 2.1\right]\ + 2.1 + 2.4 + 1.2\right\}\ 60 = 608.7 \text{ sec.}$$

5.4.2.2.3 Outbound Ground

Based on the general assumptions and parameter values shown in Table 5-29 $\overline{T}_{OG}$ is computed as

$$\left[1.1 + 1.6 + (0.5)\ (5.2) + (0.5)\ (4.5)\right]\ 60 = 453 \text{ seconds}$$

5.4.2.2.4 Inbound Ground

The determination of a practical value for the parameter k_H involved some additional assumptions since no direct relationship between the aircraft experiencing gate holds could be readily discerned from the results of the traffic flow analysis described in paragraph 5.3.2. An assumption was made that under normal conditions (i.e., no weather disruptions of airline schedules) the requirement for aircraft to hold for a gate could be determined using queueing theory. Therefore, using the estimated value of approximately 100 available aircraft docking spaces (refer to paragraph 5.3.1) the family of curves shown in Figure 5-35 was developed for the various gate occupancy times shown at extreme right of each curve. The number of gate holds observed in the traffic flow analysis for various traffic levels were then plotted. As shown in the figure the data appeared to approximate a curve with a gate occupancy time of 0.635 hour or 38 minutes. Since the average gate occupancy time measured in the ramp area flow analysis was 45 minutes or 0.75 hour, an interpolation was made between the curve for this value and the apparent curve for the observed data yielding an approximate number of 3 aircraft/hour requiring a gate hold for (0.85) 120 operations per hour. For the purposes of this analysis it was assumed that the holding location was recorded for all aircraft so that

$$k_H = \frac{3}{(0.85)\ (60)} \approx 0.06$$

Using this value and measured activity times for Inbound Ground, $\overline{T}_{IG}$ is computed as

$$\left[2.9 + (0.06)\ (1.5) + 0.5\right]\ 60 = 209.4 \text{ seconds}$$

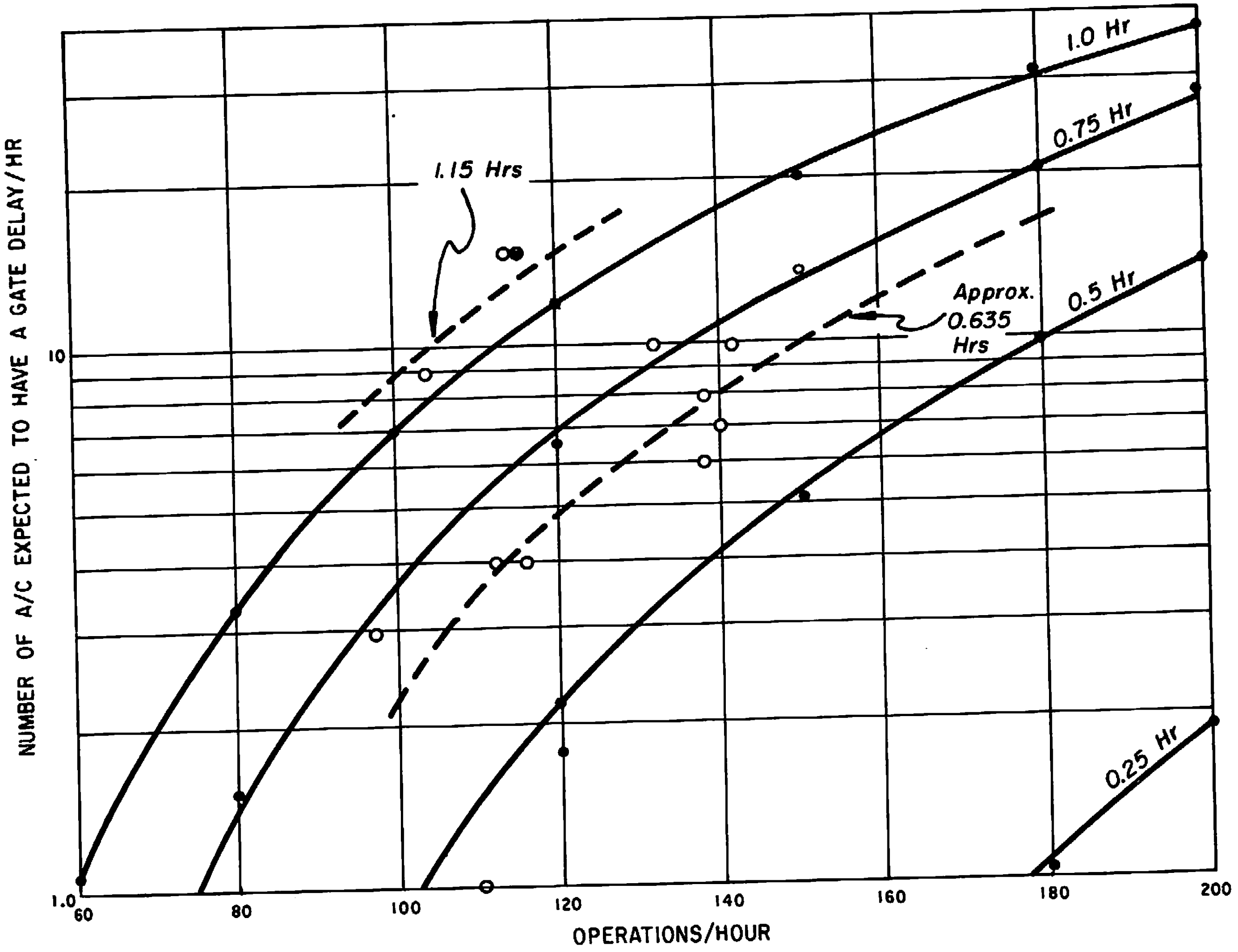

Figure 5-35. Gate Delay Curves

5.4.2.2.5 Local Control

The values for the parameters k_{PH} and k_{POS} in equation (5) were derived from the measurement data as the percentage of the observations for which the position and hold marking and strip positioning occurred. Thus,

$$k_{PH} = \frac{13}{30} \approx 0.43 \text{ and } k_{POS} = \frac{11}{30} \approx 0.37$$

Using these parameter values and measured activity times from Table 5-31, $\overline{T}_{LC}$ is computed as

$$\left[(0.43)\ (0.6) + 1.9 + (0.37)\ (2.5) + 3.6\right]\ 60 + (2.7)\ 60$$

$$401 \text{ (departures)} + 162 \text{ (arrivals)} = 563 \text{ seconds}$$

However, it should be noted that this workload is for both Local Control positions. Therefore, the workload for each Local Controller would be equal to 283.15 seconds.

5.4.2.2.6 Total Manual Workload

Using equations (6.a) and (6.b) and the values computed above, $\overline{T}_{DO}$ and $\overline{T}_{AO}$ are computed as

$$\overline{T}_{DO} = 670.5 + 608.7 + 453 + 401 = 2133.2 \text{ seconds}$$

$$\overline{T}_{AO} = 209.4 + 162 = 371.4 \text{ seconds}$$

5.4.2.3 Summary of Non-Communications Activity Workload

The results of the preceding computations are summarized in Table 5-48. From the table it may be seen that Flight Data is the busiest position in terms of non-communications activity relative to traffic operations. Since this position has no responsibility for communications with aircraft and only infrequent interphone communications with the ARTCC, this level of activity may appear low. However, the other task activities of the Flight Data position discussed in Section 4.2 were not measured because they are not directly related to traffic flow.

Table 5-48. Summary of Non-Communications Activity Workload

	CONTROLLER NON-COMMUNICATIONS (MANUAL) ACTIVITY										All Departures and Arrivals (sec)
	Flight Data		Clearance Delivery		Outbound Ground		Inbound Ground		Local Control(2)		
	Activity (sec)	% of Hour	Activity (sec)	% of Hour	Activity (sec)	% of Hour	Activity (sec)	% of Hour	Activity (sec)	% of Hour	
Departures	670.5	18.6	608.7	16.9	453	12.9			200.5 (401)*	5.6	2133.2
Arrivals							209.4	5.8	81.0 (162)*	2.3	371.4
							Total Departures and Arrivals		281.5 (563)*	7.9	2504.6

*Activity level for both Local Control positions.

The next highest levels of non-communications activities may be observed for the Clearance Delivery and Outbound Ground positions. As the communications analysis for these positions showed a modest channel occupancy time, they would both appear to be fairly busy positions.

5.4.3 Traces of Individual Flights Through the ASTC System

The analyses of traffic flow statistics in Section 5.3 as well as the analyses of controller communications and non-communications activities presented above have examined the operation of the ASTC from an overview level. To examine the effect of the system operation on an individual aircraft as well as the interaction between control positions in handling aircraft, a number of arrival and departure flights were traced through the system by observation from the tower cab. Two departure and two arrival traces have been selected for presentation in the following paragraphs.

5.4.3.1 Flight Trace 1 - Air Carrier Departure From Southside Runway 14R

This flight trace was specifically selected because it incorporates a number of key points regarding the ASTC system operation. These include:

1. Blockage of the movements of aircraft within the ramp area by other aircraft.
2. Use of the joint responsibility philosophy of traffic control, i.e., use of yield type instructions, involving pilot adjustment of aircraft movement to comply with controller instruction.
3. The major problem associated with control of combined arrival and departure operations on the same runway; i.e., the need for very close monitoring of relative aircraft movements.

This flight trace took place during the approximate time period of 4:45 to 5:45 p.m. (2145 to 2245 GMT). Visibility conditions were normal. The flight was UA 247 and the equipment was a B727. Figure 5-36 illustrates the completed flight strip and shows the results of the various controller strip marking activities identified in the previous paragraphs and the flight trace description. The numbers associated with the various markings correspond to specific event numbers in the flight trace.

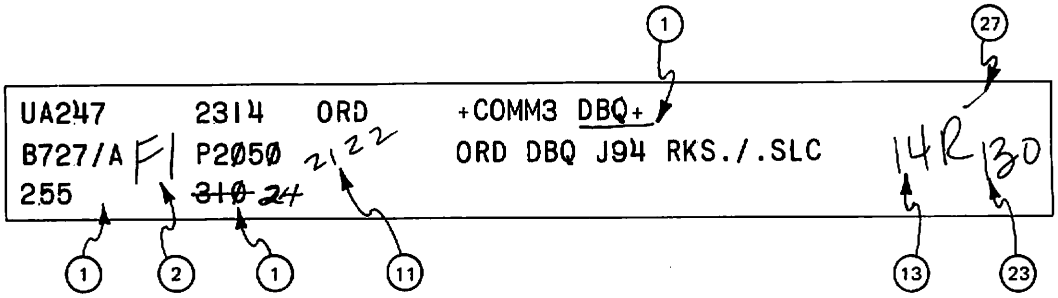

Figure 5-36. Flight Strip for UA 247

1. When the trace was initiated the flight strip had already been processed (including annotation) by Flight Data and was located in the left hand side of the Clearance Delivery Flight Strip Board.

2. 2043:30 Aircraft called for clearance. Clearance Delivery checked clearance, marked the gate (F1) on the strip and put the strip in right side of the Flight Strip Board. The complete transaction took about 20 seconds.

3. 2056:15 A member of the flight crew was observed physically checking the exterior of the aircraft.

4. 2115:05 The jet way began to pull away from United 247.

5. 2117:00 United 247 started pushback.

6. 2117:09 United 247 stopped pushback because a TWA 707 was being pushed back from G4.

7. 2117:54 TWA uncoupled and tug pulled away.

8. 2117:57 TWA called for taxi instructions while starting a pivot to face out of the ramp area.

9. 2119:50 United 247 resumed pushback.

10. 2121:27 United 247 pushback completed with the nose of the aircraft facing the F5-7 gates.

11. 2122:19 United 247 called for taxi. Clearance Delivery wrote the time on the strip and placed it in the Outbound Ground Flight Strip Board. The transaction took about 2 seconds.

12. 2122:38 TWA was given taxi instructions by Outbound Ground and moved out of the ramp area.

13. 2123:23 United 247 was given taxi instructions to runway 14R via the Outer and Bypass and told to "pass behind a TWA (not the same as aforementioned) coming from the right at the end of the building". Outbound Ground marked 14R on the strip. United 247 moved out slowly as the TWA passed.

14. 2123:53 United 247 stopped at the end of the ramp area.

15. 2124:07 United 247 resumed taxi as the TWA passed.

16. 2124:30 United 247 was across the inner taxiway.

17. 2124:37 United 247 started a right turn on the Outer.

18. 2127:17 Outbound Ground instructed United 247 to "turn left on the Bypass, monitor local". While talking, Outbound Ground picked up the United 247 strip, along with two others, walked over to the Local Control #1 position and put the strips in his Flight Strip Board. The transaction took about 10 seconds.

19. 2130:47 United 247 was on the 14R parallel following an Ozark DC-9.

20. 2131:37 United 247 was fourth in a line of taxiing aircraft.

21. 2134:45 United 247 had stopped along with other aircraft holding position for a 14R arrival.

22. 2136:15 The Ozark in front of United 247 was instructed to taxi into position.

23. 2136:30 United 247 was instructed to hold short of runway.

24. 2137:13 Ozark cleared for immediate takeoff.

25. 2137:49 The Local Controller examined United 247's strip.

26. 2138:02 Arrival touched down on runway.

27. 2138:23 United 247 instructed to position and hold and be ready for immediate takeoff and checkmark made next to runway number.

28. 2138:44 Local Control instructed "United 247, after departure it will be left to heading 130; expedite through 3500. Be ready for immediate takeoff when cleared". Heading was marked on strip while issuing instruction. This transaction took about 7 seconds.

29. The arrival aircraft on the runway decelerated, appearing to be able to make the T3 turnoff but did not. Instead, the aircraft moved slowly, appearing to be only at taxi speed, to the T2 turnoff. This delayed the clearance to roll for United 247 who was presently in position on the runway. Another arrival was on final.

30. 2139:15 Local Control contacted United 247:
Tower-"Do you have room to clear the runway off your left side?"
Pilot-"Affirmative".
Tower-"Okay, taxi clear of the runway. Report clear".
This transaction took about 9 seconds.

31. 2139:30 United 247 reported clear of runway and was instructed "United 247 make a 180. Hold short 14R".

32. 2141:47 United 247 instructed to position and hold again.

33. 2141:52 Local Control inquired of current arrival confirming his ability to make the T3 turnoff.

34. 2142:02 Local Control instructed current arrival to expedite clearing the runway at T3.

35. 2142:17 Local Control instructed "United 247, 14R, cleared for takeoff. Turn left to 130; expedite through 3500 feet". This transaction took about 5 seconds.

36. 2142:58 United 247 was rotated and airborne.

37. 2143:11 Local Control picked up the strip and dropped it down the chute, giving the handoff simultaneously. "United 247 contact departure. Good day". The entire transaction took about 5 seconds with about 2 seconds of that time allocated to verbalization.

Observation: During this trace the observer was located to the left and slightly behind Local Control #1 so that aircraft movements could be visually monitored and the ASDE Brite could be referenced. It was noted that while UA 247's movements at the extreme end of the 14R/32L parallel and in turning on to 14R could be visually observed, these movements could not be similarly observed on the ASDE screen.

5.4.3.2 Flight Trace 2 - General Aviation TCA VFR Departure from Northside Runway 27R

This flight trace was selected because it demonstrates the requirement for preparation of a flight strip for general aviation VFR flights and the relative ease with which general aviation aircraft are handled by the ASTC system.

This flight trace took place during the approximate period of 5:45 p.m. to 6:00 p.m. (2245 to 2252 GMT). Visibility conditions were good. The flight was N309VS and the equipment was an Aero Commander 68. Figure 5-37 illustrates the completed flight strip and indicates the strip marking in the same manner as for the previous trace.

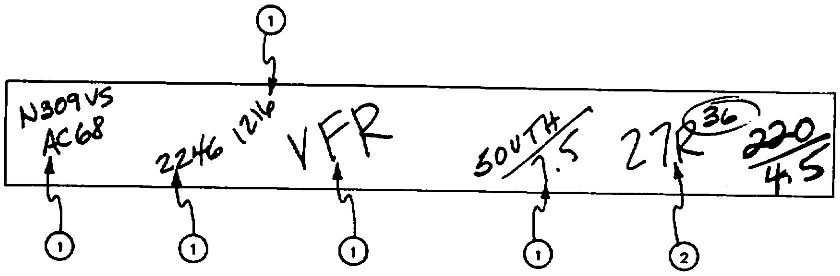

Figure 5-37. Flight Strip for General Aviation N309VS

1. 2246:54 The aircraft called for taxi and TCA VFR clearance. Clearance Delivery prepared a flight strip with the following information: Aircraft ID and type, the time of the call, VFR, the intended heading and altitude, and a beacon code selected from a list of available codes. Clearance Delivery then gave the pilot his clearance and instructed him to "monitor ground control .75" while placing his strip in the Outbound Ground Flight Strip Board.

2. 2248:09 The Outbound Ground controller marked runway 27R (36) on the strip while giving the pilot his taxi instructions. Runway 36 was circled to indicate that the aircraft would start his roll on runway 27R at the intersection of runway 36. This transaction took about 2 seconds.

3. 2249:05 Outbound Ground picked up the strip and dropped it down the Flight Strip slide for Local Control #2. This transaction took 2 seconds.

4. 2249:08 Local Control #2 picked up the strip almost immediately and took about 1 to 2 seconds to bring it back to his position.

5. 2249:51 The aircraft was at the intersection of runway 36 and the 9L/27R parallel.

6. 2250:49 Local Control #2 moved the strip further down in his Flight Strip Board, indicating an earlier takeoff than previously anticipated.

7. 2251:00 The aircraft was holding short of 27R.

8. 2251:06 The aircraft was moving.

9. 2251:13 The aircraft was in position at 27R/36 for a 27R takeoff. Local Control issued takeoff clearance instructing pilot that his heading was 220 and his altitude out of TCA was 4500 feet while marking "220/4.5" on the strip.

10. 2251:20 The aircraft started to roll.

11. 2251:42 The aircraft was airborne.

12. 2252:08 Local Control picked up the strip and instructed pilot to contact Departure Control.

13. 2252:13 Local Control dropped the strip down the Flight Strip tube to Departure Control.

5.4.3.3 Flight Trace 3 - Air Carrier Arrival on Southside Runway 32L

This flight trace was selected as representative of normal operations but illustrates a problem associated with Local Control having to record the flight call sign in lieu of an arrival flight strip.

The flight trace took place during the approximate time period of 6:45 p.m. to 7:00 p.m. (2345 to 2400 GMT). Visibility conditions were good. The flight was UA 490 and the equipment was a B727.

1. 2349:07 UA 490 was just outside the Outer Marker. Local Control #1 looked at the ARTS Brite and in error wrote UA 470 on the Arrival Log.

2. 2349:10 The pilot contacted Local Control to report at the Outer Marker. Local Control corrected the flight call sign on the Arrival Log.

3. 2350:39 UA 490's alphanumeric tag dropped off the Brite display.

4. 2351:30 The aircraft touched down.

5. 2351:35 Local Control #1 advised the aircraft "contact ground when clear".

6. 2352:00 The aircraft turned off runway.

7. 2352:09 The pilot contacted Inbound Ground and gave his gate. Inbound wrote down "United 490" on his list of aircraft arriving on the south runways, while issuing taxi instructions to the gate "via T-3 and right on the outer".

8. 2353:38 United 490 was entering the outer taxiway.

9. 2354:15 The aircraft was starting to turn toward the ramp area.

10. 2355:15 The aircraft was starting to pull into its gate.

11. 2355:35 United 490 was stopped at the gate.

Observation: Local Control #1 had to jump up several times to see 27L departure aircraft over the heads of the two ground positions.

5.4.3.4 Flight Trace 4 - Air Carrier Arrival on Northside Runway 14L

This flight trace was selected as demonstrating operations under reduced visibility and poor weather conditions as well as the effects of aircraft movements in the ramp area.

The flight trace took place during the approximate time period of 4:45 p.m. to 5:05 p.m. (2155 to 2205 GMT). The operating conditions were Category I and the surface had a covering of snow from precipitation earlier in the day. The flight was Northwest 736 and the equipment was a B727.

1. 2156:00 NW 736 passed the outer marker at Lima.

2. 2156:33 The pilot reported crossing the Outer Marker. Local Control #2 advised "Northwest 736 clear to land 14 Left. Braking action fair to poor. Report the lights in sight".

3. 2159:30 NW 736 alphanumeric tag dropped off the Brite display.

4. 2159:45 The pilot reported the lights in sight and was given clearance to land by Local Control.

5. 2200:05 The aircraft touched down on runway 14L.

6. 2200:21 Local Control advised NW 736 to "turn right at 18 and contact ground at .9".

7. 2201:00 The aircraft was clear of runway 14L. The pilot contacted Inbound Ground and was cleared directly into his gate via the 9L/27R parallel and Inner.

8. 2201:19 The aircraft crossed the 14L/32R parallel.

9. 2201:43 The aircraft was approaching the outer taxiway.

10. 2202:00 The aircraft entered the Northwest ramp area.

11. 2202:28 NW 736 was observed taxiing behind a Braniff 727 which had entered the ramp.

12. 2202:46 NW 736 was observed heading to his gate which was between two "blocked" DC-10s.

13. 2202:53 The aircraft stopped its forward motion and began swinging its nose into the gate. The aircraft was in this mode for about two seconds.

14. 2203:38 NW 736 was stopped at his gate.

Observations: After NW 736 was docked both DC-10s began to pushback. This is the basis for terming these aircraft as "blocked" in 12 above. These pushbacks would appear to have been blocked by both the Braniff and NW 736 movements.

Runway 4L was being used for departures during this trace. In this configuration there is no requirement for the arrival to cross an active runway when 9L is used for departures. Thus, the aircraft was able to taxi at a fairly high speed as indicated by the event times noted above.

5.4.4 Other Observations of Tower Cab Activities

During various periods in the tower cab several interesting observations regarding controller non-aircraft communications activities were made which are discussed below.

5.4.4.1 Controller Visual Surveillance Activities

As noted in previous discussions, visual surveillance of traffic movements is nearly continuous during good visibility conditions. However, when the visibility decreases and the ASDE is employed to aid in visual surveillance, a number of interesting observations were made.

In one situation the procedure of a controller operating at the Local Control #2 position was studied. The locations of equipment used by this position relative to the normal working location are as follows:

1. The ARTS Brite Display is to the left of the position.
2. The Flight Strip Board containing the departure flight strips is directly in front of the normal working location.
3. The pedestal-mounted Arrival Log is slightly to the right of the controller's working location.
4. The ASDE Brite is at the extreme right of the position equipments. The display was set up so as to focus the picture not on the runway touchdown area on 14L (for which coverage was poor, though available on the screen) but on the area covering the normal exit points for 14L (22R and 18) and the intersection of those runways with 9L, the departure runway.

The controller was observed to utilize these equipments in a continuing scanning operation. Starting from the left he would observe the ARTS Brite for 5 to 10 seconds, then begin moving his area of vision to the right to visually observe movements out of the cab window, dropping his vision to the Flight Strip Board momentarily. When his scan reached the ASDE Brite he would observe it for about 5 to 10 seconds and then begin scanning back to the left. If, during this scanning process, he noted on the ARTS Brite that a flight was approaching the Outer Marker, he would record the flight call sign on the Arrival Log as it was passed in his scan.

This operation is strongly contrasted to that of the Local Control #1 position during the same period. The locations of equipments which may be employed by this position are as follows:

1. The ASDE Brite is too far left of the normal working location of the controller. It is actually located adjacent to the Inbound Ground position and is too far from his normal working position to be used easily without the controller having to walk to the left to observe it.

2. The Flight Strip Board is located slightly to the left of the normal working position.

3. The ARTS Brite is at the normal working location.

4. The pedestal mounted Arrival Log is to the right of the ARTS Brite.

This controller was observed to rely most heavily on the ARTS Brite and visual observation of aircraft movements. The movements of departure aircraft at the end of the 14R/32L parallel and 14R could be visually observed. In fact, during the period of observation he did not use the ASDE Brite at all. This is probably due to the problem of the display's reliability at the end of the parallel and runway noted in the flight trace for UA 247 (paragraph 5.4.3.1) and the requirement for the controller to move left from his position to use the display.

During this observation period and others this ASDE Brite display appeared to be more heavily used by the Inbound Ground position. This display appeared to be set up to focus the presentation on the area between the normal aircraft runway turnoffs for 14R arrivals and the intersection of T-1 and T-3 taxiways with the Outer where these arrivals enter the main ground traffic flow. It appeared that the Inbound Ground controller was utilizing the display to verify the aircraft's position (or reported position) when the pilot contacts him for taxi to the terminal and to observe the aircraft's position as it approached the Outer on T-1/T-3 in order to determine what control instructions were necessary to take the aircraft across the departure traffic on the Outer and into the traffic flow in the Inner coming from the Northside arrival runway.

5.4.4.2 Coordination Between Control Positions

Coordination between controllers was observed to take two forms: direct conversations between two or more controllers, or by one controller simply calling out to another, with the latter being the most frequent. This type of exchange generally occurred between:

1. Local controllers when one controller's departure was going to cross the airspace controlled by the other; in these cases the first controller merely called out to the other that "I've got one going west" or other appropriate direction.

2. Outbound Ground and Local Controllers when an aircraft wanted a particular runway for departure.

3. Between Local Controllers and Inbound Ground or Outbound Ground when they wanted particular instructions given to aircraft to facilitate the clearance of aircraft from the runway or to allow a flight to cross a runway (normally between Local Control #1 and Outbound Ground).

4. Between Local Controllers and Outbound Ground when they cannot reach a flight on their frequencies and want Outbound Ground to contact the flight and instruct him to change frequency now.

The direct conversation approach generally occurred between the two Ground Controllers and on a few occasions between Outbound Ground and the Local Controllers. Primary examples of the situation in which this type of coordination occurred are briefly described below.

It was generally observed that, when a controller returned from a relief break or came on-shift and was assigned to one of the ground positions, a conversation took place between the new ground controller and the controller staying in position and occasionally the Ground Controller going off duty. The purpose of this conversation was to discuss the current flow pattern and particular routings that might be used in instances where departures operations were backing up on to the Outer.

One incident was observed which required direct coordination between controllers to change the flow of traffic on the Inner and Outer. In this situation the airport was operating in the Arrivals from the West mode with departures taxiing clockwise on the Outer and arrivals counterclockwise on the Inner. A DC-10 arrival from 14L was taxiing west on the 9L/27R parallel. Instead of turning slightly to the left and taking the Inner, the aircraft continued straight ahead and on to the Outer. An immediate conversation took place between Outbound and Inbound to "swap" the movements of aircraft on the Outer and Inner from the T-1 intersection to the New Scenic until the DC-10 turned off the Outer at T-3 (its gate was in the ramp area between C and D concourses).

During one observation period the airport was operating in the Arrival from the West mode with 14L and 9L being used for arrivals and departures, respectively, and 14R being used for both arrivals and departures. A long queue of traffic had built up from the 9L pad, down the New Scenic, and on to the Outer because in this configuration all departures follow the Outer on to the New Scenic until departures for 14R can turn left at the Bypass to the 14R/32L parallel. To attempt to relieve this congestion Local Controller and Outbound Ground held a conversation and decided to re-route some of the 9L departure traffic further along the Outer to the Old Scenic, left on Old Scenic to the 9L/27R parallel, and left on the parallel (in essence creating two queues for 9L departures). This approach appeared to be relieving the congestion somewhat until a DC-10 arrival on 14L exited the runway at 22R and taxied down 22R to the intersection with 9L. At this point the aircraft's further movement across the runway and to the terminal was blocked by the aircraft that had been re-routed. The aircraft stayed in this location for at least 2 minutes with no apparent prospect for an end of its blockage in the near term. At this point another conversation took place between Outbound Ground and Local Control #2. This conversation led to re-routing of a 747 that was in the queue on the 9L/27R parallel in a position just to the east of the intersection with the New Scenic. The 747 was turned right on the New Scenic up to the Scenic and the 14L/32R parallel for departure on 14L. This allowed aircraft on 9L/27R parallel and Old Scenic to move up. Outbound Ground instructed the re-routed aircraft which had not yet turned on to the Old Scenic to hold their position. Local Control #2 then gave priority to sequencing aircraft on the parallel into the 9L pad for departure. After two more departures Local Control #2 was able to clear the DC-10 across the runway and turned it over to Inbound Ground for taxi to the 9L/27R parallel. However, no further aircraft were sent to 9L by the routing that had led to the problem.

5.4.4.3 Missed Approaches

On two occasions multiple missed approaches were observed. In the event of a missed approach Local Control normally provides altitude and heading (i. e., runway heading) instructions to the aircraft, turns it over to Departure Control, and prepares an abbreviated flight strip which is dropped down the Flight Strip Tubes to Departure Control.

The first observation of multiple missed approaches occurred during CSC Run #8 as visibility deteriorated to Category II conditions. The approaches for at least three arrivals for 14L, which was being observed, had to be terminated because visibility had decreased below the permissible minimums for 14L. In this situation only one of the arrivals had just been turned over to Local Control. Therefore, Approach Control in the TRACON still had its own strip for this flight as well as strips for the following flights. Thus, Local Control only had to turn the one arrival back to the TRACON which handled the vectoring of the aircraft to holding points.

The second observation occurred as a result of the failure of the ILS glide slope for 14L under low Category I conditions. Departures were taking place on 4L in the North. There were three arrivals being handled by Local Control (one having just reported in at the 14L Outer Marker) and a departure had just previously been cleared for takeoff when the failure occurred. The departure had been given a heading of "090", which was toward the runway heading which had to be followed by the arrivals executing the missed approach. The controller had to call for blank strips to prepare the abbreviated strips for the arrivals. As each strip was being prepared he requested the altitude of both the departure and the particular arrival before instructing the arrival to contact Departure Control and dropped the strip down to Departure Control.

With the exception of his urgent call for flight strips, the controller was observed to work smoothly and rapidly to perform the actions described, although it was evident that he was under substantial pressure.

5.5 COCKPIT CREW ACTIVITY (WORKLOAD) ANALYSIS

The functional responsibilities of the cockpit crew as it pertains to ASTC operations were discussed in Section 4.3. This section provides a more detailed insight into the workload of the crew during passage through the system. Although sufficient cockpit time was not available to perform a comprehensive time and motion study, members of the CSC staff did have the opportunity to ride the jump seat on a number of flights and record their impressions of the crew's activity. These observations and the pilot interviews cited in Section 2.4 form the basis for the following discussions.

5.5.1 Crew Activities During Departure and Arrival

5.5.1.1 Departure Activities

The cockpit crew is expected to be on board the aircrat at least 20 minutes prior to the scheduled departure time. Prior to this, the Captain and the First Officer have coordinated the flight plan with the company dispatcher and have initiated the paperwork necessary for clearance delivery. The Second Officer has evaluated the maintenance status of the aircraft and has performed a visual inspection of external aircraft mechanisms.* Once on board and seated, the crew executes the initial aircraft status check list. Approximately 10 minutes prior to scheduled departure, radio contact is established by the First Officer with the tower on the Clearance Delivery frequency to obtain their flight clearance. If the clearance has not yet been received in the tower or if a modification of the clearance received is desired, the First Officer will be advised that his "clearance is on request" and he "will be advised". If the clearance has not been received from the tower when the flight is nearly ready to push back, he will initiate communications with Clearance Delivery.

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*If there is only a two-man crew this check will be made by the First Officer.

Having received clearance, all crew activities are directed toward preparing the aircraft for pushback. Pre-pushback checks are made by pairs of the crew members. The first is made by the First and Second Officers, with the First Officer calling out the checks and recording the results and the Second Officer making the checks and calling out the results. These checks generally include the fuel, power, and electrical systems. The second check is made by the Captain and First Officer with the latter again calling out the checks and recording the results.

When all checks have been completed, the Second Officer monitors the status of all doors--cabin and belly--to determine when they are securely closed. At this point the flight is normally ready for pushback and departure. If the doors are not closed by the scheduled departure time, the First Officer (or Captain) will contact the company to determine the cause of the delay and to obtain a new departure time.

When the flight is ready for departure, the First Officer will communicate with the company ramp controller for pushback clearance. The Captain will be maintaining contact with the tug operator via the internal public address system. The engines are usually started after pushback; however, ignition may be initiated prior to or during pushback. During this time, the Captain will be issuing commands within the cockpit and will check with the tug operator about the condition of the nose gear after the tug is unhooked.

After pushback is completed, the First Officer will contact Clearance Delivery on the ATC frequency of radio set 1 indicating that the flight is ready to taxi. The Second Officer will monitor various cockpit instruments and the company frequency in case of any last minute ramp control directions from the company controller. Upon direction from Clearance Delivery, the pilot (not flying) will switch to the Outbound Ground control frequency. While the pilots are awaiting instructions from Clearance Delivery to switch frequency or contact from Outbound Ground, they will generally maintain the aircraft in the pushback position.

However, if the handoff takes too long and/or if they have to maneuver within the ramp area to allow passage of an arriving aircraft, they will start to move and may drift as far as the end of the ramp before contact with ground control is established; they will not go beyond this point without contact.

When the ground controller contacts the aircraft, gives the runway assignment (taxi route), and any other specific directions for taxi, the pilot (not flying) will acknowledge the taxi instructions and the pilot (flying) will release the brakes and proceed into the taxiway network. Generally, the pilot (flying) does not use the throttle to move the aircraft since the engines' idle thrust is sufficient to cause movement. Taxi stops and yields to other traffic are accomplished by controlled braking action and turns are accomplished through the use of the nose gear steering wheel. Only in the event of an unusually fast acceleration requirement (e.g., active runway crossing) will the throttle be used during taxi.

While in transit from the ramp to the departure runway, the cockpit crew activity can vary substantially depending on the specific route, traffic conditions, and the weather. For the most part, the pilot (flying) uses common sense in controlling the speed and direction of the aircraft; strict speed limits are not in effect. The pilot (flying) uses his judgment to determine the safe speed and separation based on the condition of the taxiway surface and the type of leading aircraft. Primary aircraft separation considerations are protection against the ingestion of foreign matter into the engines (e.g., melting chunks of ice) and jet exhaust ingestion into the cabin.

Unless specifically contacted by the controller most intersection conflicts are resolved by pilots ussing common courtesy and the rules of the road basis. When it appears to a pilot that his aircraft and another aircraft have equal contention for the intersection right of way, he will stop and yield or contact the ground controller to resolve the conflict if the situation is more complex, i.e., involving several aircraft or a serious blockage. Most pilots feel that the controller should resolve these conflicts prior to the occurrence rather than during the occurrence and that this is usually the case at O'Hare. Such contacts are made by the pilot (not flying) who handles all communications with the tower. Pilots always hold short of runways and await direction from the ground control unless previously given clearance to cross. Unfortunately in poor visibility it is not always that easy for the pilot to detect when the aircraft is approaching an active runway. During the ride to the departure runway, additional check lists are being accomplished within the cockpit. In addition, the Captain usually will talk to the passengers, particularly if there are delays anticipated under poor conditions.

Upon entering an area where no further ground control appears to be required, the ground controller will advise the aircraft to switch to the Local Control frequency. As the aircraft enters the departure queue (if there is one) the Captain may again address the passengers indicating the flight's position in the queue and the estimated time until takeoff. At this time the pre-takeoff check list is accomplished. In the event that taxiing was accomplished with any engines shut down, the complete start-up procedure and check list will be accomplished at this time. When the aircraft is next to take off the Local Controller will contact the aircraft indicating that the aircraft has clearance to position and hold on the runway or hold short of the runway until further advised. Once the instruction to position and hold is given to the cockpit, the aircraft is maneuvered by the pilot (flying) on to the center of the runway and he gives the commands to put the aircraft into the takeoff configuration and the instruments are monitored. When clearance for takeoff is received the throttles are applied, the brakes are released, and the aircraft begins to roll. Prior to liftoff the pilot will maintain visual reference with the runway surface to ensure proper centering. If at this time he detects aircraft crossing the runway in front of him, there is relatively nothing he can do to avoid a collision. The Second Officer monitors the engines to ensure safe operation and will positively verify engine status. The pilot (not flying) calls out the velocity V_1 which is the maximum speed at which the pilot can safely abort the takeoff and stop short of the end of the runway. The next velocity called out is V_R which is the velocity at which the pilot raises the nose of the aircraft (rotates). Shortly thereafter the main gear will lift off and the aircraft will be airborne at which time the pilots will ensure that a positive rate of climb and the initial climb velocity V_2 is maintained. Some time after liftoff, the Local Controller will contact the aircraft giving the departure heading (if not previously given) and direction to switch to departure control for final vectoring for noise abatement and handoff to the center. The activities which take place after this are not directly applicable to the cockpit workload analysis as it relates to ASTC system operation.

5.5.1.2 Arrival Activities

Although a preliminary gate assignment may have been received by the Second Officer prior to the final approach, (e.g., United Airlines obtains gate assignments approximately 50 miles out for all aircraft except the B737), surface traffic is not a cockpit consideration until the pilot sets the aircraft into the landing configuration and sees the runway. This preliminary gate assignment is obtained by the Second Officer.

After entering the O'Hare TCA the aircraft is vectored into final approach by Approach Control and instructed to switch to the Local Control frequency. The pilot (flying) will acquire the ILS localizer to establish the aircraft on the runway heading. Where an approach is being made to a runway with an ILS glide slope the pilot (flying) normally performs an instrument landing with primary emphasis placed on throttle control in maintaining the proper glide slope. This same emphasis is placed on throttle control to maintain a proper approach path when a visual approach is made to a runway without an ILS glide slope.

When instructed by Approach Control the pilot (not flying) will contact Local Control and report at Outer Marker. He will acknowledge the clearance to land and any other information conveyed by Local Control. The Second Officer will be monitoring the engine status and controlling cabin environment. Prior to reaching decision height, both pilots are obtaining runway visual reference and are making certain that the preceding aircraft is sufficiently clear of the runway and that other crossing aircraft will not interfere with the landing and rollout course.

The clearance to land or subsequent communication from Local Control may include an exit ramp advisory in which case the pilot can, to some degree, plan his touchdown point to facilitate the accomplishment of that turnoff. Pilots interviewed indicated that they would prefer to know the desired exit ramp prior to touchdown so they can plan the landing and make a comfortable turnoff. Late notification of the desired exit ramp may cause the pilot to slow down too quickly for a smooth and continuous rollout or may result in a missed turnoff, both of which will reduce runway and taxiway efficiency.

The pilot (not flying) does not usually report that the aircraft is clear of the runway, except when requested to do so. However, he will call Local Control if a requested turnoff could not be made for any reason (e.g., due to poor braking action caused by snow or ice on the runway). The final contact with Local Control will be acknowledgment of the controller's instruction to switch to the (Inbound) ground control when clear of the arrival runway or the last active runway under the controller's jurisdiction.

At this point the pilot (not flying) will switch frequency and contact Inbound Ground. Normally, this will include an indication of the arrival runway and turnoff (e.g., "off 32L at T-6") or the runway crossing (e.g., "across 9L at 22R"). Duringthe rollout or normally when clear, the Second Officer will verify the aircraft's gate assignment and availability. If this is accomplished before contact with Inbound Ground, this information will also be included in the communication. If the pilot's initial contact did not include gate availability information, the ground controller's first message may include a request for gate status which determines whether he will direct the aircraft directly to the ramp area or to the penalty box.

Crew activity during arrival taxi is similar to the departure with regard to local traffic collision avoidance, runway crossings, and intersection conflicts. The crew will also be "cleaning up" the aircraft at this time, i.e., adjusting flaps to the ground configuration. During taxi, one or two engines may be shut down. They will also be performing post flight checklists. The Second Officer may also be communicating with the company to verify gate status (if there has been a substantial taxi delay or penalty box hold) and to determine gates for connecting flights. The Captain may also address the passengers for a final time or instruct the flight attendants to advise them on the status of connecting flights and gates. If there are no gate delays the pilot will maneuver the aircraft directly into the ramp area and guide the aircraft into the jetway using guidance lights on the building. No further communications with the tower will be made unless there is a conflict at the entrance to the ramp area. The ground control activity of the cockpit crew is complete after the aircraft is docked at the jetway and the blocks are placed on the wheels. The crew then goes through a final shutdown checklist.

5.5.2 Cockpit Workload Analysis

5.5.2.1 Cockpit Communications Activity

The results of the detailed analysis of communications activity for the various controller positions described in Section 5.4 were used to derive the inferences on cockpit communications activity discussed in the following paragraphs.

5.5.2.1.1 Departure Aircraft

The analysis of Clearance Delivery communications indicated that the mean number of communications required per aircraft in securing a flight plan clearance and handover to the Departure Ground Controller is approximately 2.6 or between 2 and 3 transactions. The mean time between first and last contact with the Clearance Delivery Controller averaged 560 seconds. It is presumed that the pilot monitors the Clearance Delivery Controller for a few minutes prior to first contact and, after securing his flight clearance, does not monitor the

Clearance Delivery Controller again until he is ready to taxi. If it is assumed that 5 minutes is spent under this communication activity, then each aircraft pilot has to monitor approximately 0.22 N_D communication transactions (where N_D is the number of aircraft departing/hour) in order to enter the Departure Ground Control system.

The mean number of communication transactions per aircraft determined for Outbound Ground was 2.8 and the mean time under control approximately 4 minutes. Hence each crew has to monitor approximately a mean of 0.19 N_D communication transactions in order to determine when Outbound is attempting to communicate with them.

The mean number of communication transactions per aircraft by Local Control was 3.2 and the average time under control was approximately 3 minutes. Hence each crew has to monitor 0.16 N_D communications in order to determine when Local Control is attempting to communicate with them.

This data indicates that an aircraft requires an average of 8.6 communication transactions to three controllers in departing O'Hare. A mean of about 0.57 N_D (or approximately 34 at a departure volume of 60/hour) communication transactions have to be monitored in securing these transactions. Observations of the standard deviation for these quantities indicate that maximum variations can be estimated by doubling these values; that is, the maximum number of CTs per aircraft required is about 17 and/or the maximum number of total CTs to be monitored could be 1.14 N_D.

5.5.2.1.2 Arrival Aircraft

The mean number of communication transactions required per aircraft by Inbound Ground was approximately 2.3 and the mean time under control estimated at approximately 4 minutes. Hence each aircraft has to monitor a mean of approximately 0.15 N_A (where N_A is the number of arrival aircraft per hour) communication transactions in responding to the Arrival Ground Controller.

However, the variation of time under control was noted to be quite extensive due to gate availability problems (up to 30 minute waits noted for the penalty box).

Requirements for arrival aircraft under Local Control are essentially the same as for departure aircraft.

This data indicates that an aircraft requires a mean of 5.5 communication transactions to two controllers in arriving at O'Hare. A mean of 0.34 N_A (or approximately 21 at an arrival volume of 60 aircraft/hour) communication transactions have to be monitored in securing these transactions. Again, observations of the standard deviation for these quantities indicate that typical maximum variations can be estimated by doubling; that is, the expected maximum number of CTs per aircraft is about 11 and/or the maximum number of total CTs to be monitored could be 0.7 N_A.

5.5.2.1.3 Interpretation of Cockpit Communications Analysis

The above data indicates that at normal busy hour traffic volumes of about 120 operations a departure flight crew has to monitor on the average of 34 (and possibly 68) communication transactions and an arrival flight crew has to monitor on the average of 21 (and possibly approximately 70) communication transactions in order to determine when a communication is addressed to them and some response (both communication and aircraft control) is required. Thus, it would appear that this represents a significantly greater workload than that actually associated with the control of the particular aircraft. This data also implies a significant potential for missing a contact from the tower or non-intentional interference between communications.

5.5.2.2 Other Workload Considerations Derived from Pilot Interviews

It is obvious from the preceding descriptions of cockpit crew activities that the cockpit workload is well distributed among the three flight officers. Some airlines, however, operate certain aircraft (e.g., B737 and DC9) without a second officer and therefore the individual pilot workloads are increased in this situation.

In addition to the manual adjustment of maneuver controls, the crew must collectively monitor instruments, maintain visual reference outside the cockpit, perform checklists within the cockpit, advise flight attendants and passengers of pertinent situations as well as monitoring and acknowledging ASTC system controller instructions and company gate control. The large number of communications which must be monitored (referred to as "chatter on the frequency" by pilots) to obtain these instructions represents a fundamental distraction in the accomplishment of the aircraft management functions. Pilots indicated that it would be desirable for future ASTC systems to include features to minimize this cockpit disturbance while still providing the essential information required to safely and efficiently process the traffic.

However, while it is vital that the future voice communications workload per aircraft be reduced, the optimum techniques for providing the necessary cockpit information must be carefully analyzed in terms of other human factors affecting the crew. For example, while the possible use of a data link and a printer or cockpit display device may reduce "chatter" on the ATC channel, it may also present a serious visual distraction to the pilot while he is concentrating on visual cues outside the aircraft. Pilots interviewed were very interested in the various techniques which could be employed to improve the surface guidance available to them. While there did not appear to be distinct preference for any specific conceptual approach, all seemed to agree on the following:

- Some type of automated ground traffic control is definitely desirable.
- Many pilots would have to have hands-on involvement in the human factors evaluation of any new concepts.
- The processing of ground traffic is the ground controller's function; however, any automated system should provide for a redundant backup on the taxiway network such that the pilots can react in case of a system failure.

- More and better signs, lights, and markings are desirable especially in IFR conditions.
- Less voice communications (chatter) is a must.

5.5.3 Cockpit Observations

Detailed timing studies on the activities of various cockpit crew members were not performed as in the case of tower controllers. The limited number of opportunities available for in-flight observation did not permit a reasonably comprehensive study of the activities of all crew members, considering the division of functional responsibilities among the crew members. However, the information presented in the following paragraphs provides some further insight into cockpit operations.

5.5.3.1 In-Cockpit Flight Trace 1 - Detailed Timing Study

This flight trace provides a detailed timing study of the movements and control of a flight from the viewpoint of the cockpit. It is particularly significant in that it represents a flight under good visibility conditions which demonstrates some of the problems noted in previous discussions in this section (as well as others) including:

1. Delay of flight departures
2. Pilot unawareness of the delay until it occurs
3. Missed communications because of "chatter" on the ATC frequency

The flight was UA 366, with a scheduled departure time of 10:45 a.m. from O'Hare to Newark. The equipment was a DC-8-62 (heavy). As noted above, the weather and visibility conditions were clear. All times given below are GMT.

1. 1535 Observers in position in the cockpit. Headsets had been provided to permit monitoring of all communications. It was noted that the Captain had his flight manual on top of his flight bag open to the O'Hare plate.

2. 1537:30 The First Officer contacted the tower for the flight clearance.

3. 1540 The First and Second Officers went through a checklist. This took about 1 minute.

4. 1542 The Captain and First Officer went through another checklist. This also took about 1 minute.

5. 1545 Scheduled departure time. The cockpit crew was ready. Lights at the Second Officer's position indicated that the belly and cabin doors were still open. Both the Captain and First Officer commented that they had no idea what was causing the delay.

6. 1549 The cabin door light went out but the belly door light was still on.

7. 1552 The Captain contacted United ramp control to determine the new departure time and the cause of the delay.

8. 1552:45 Captain advised by ramp controller that new departure time was 10:55 (1655) and that baggage was still being loaded.

9. 1555 The belly door light went out.

10. 1555 Pre-taxi checklist was initiated immediately by Second Officer reading checklists to both the Captain and First Officer.

11. 1558 Checklist completed.

12. 1559 First Officer called United ramp controller for "clearance to push". Clearance given.

13. 1559:30 Captain advises tug crew to pushback. Pushback began almost immediately.

14. 1601 Captain advised by tug mechanic that he was ready to go.

15. 1601:30 First Officer called tower for taxi and was instructed to "monitor ground .75".

16. 1602 Flight given taxi instructions by Outbound Ground. "Your runway is 14L via the Outer, Bridge, and parallel". First Officer acknowledged while Captain released brakes and began taxiing.

17. 1603 Aircraft out of ramp area.

18. 1605 Aircraft taxiing on to Bridge at 22 knots.

19. 1605:45 Aircraft taxiing into 32R pad.

20. 1606:30 Aircraft crossing 9L/27R. Captain suggests that they go through checks enroute.

21. 1608 Aircraft crossing 18/36. It was observed that there was only one aircraft ahead of flight, a North Central DC-9.

22. 1609 Aircraft crossing 4L/22R.

23. 1609:30 Aircraft entered 14L pad.

24. 1610:15 Aircraft at end of 14L pad turning in behind NC holding short of 14L.

25. 1610:35 NC into position on runway. UA 366 instructed to "hold short."

26. 1611:15 NC received takeoff clearance and rolling.

27. 1611:35 UA 366 cleared into position. First Officer acknowledged.

28. 1612:00 Aircraft turning on to 14L.

29. 1612:30 Aircraft in position.

30. 1613:15 UA 366 cleared for takeoff and First Officer acknowledged; rolling almost immediately.

31. First Officer called V_1 and V_2 to Captain but times were missed in recording event 30.

32. 1613:50 Aircraft airborne.

33. 1614:40 UA 366 given heading instruction and told to contact Departure Control. First Officer acknowledged.

34. 1615:20 First Officer contacted Departure Control.

35. 1616:20 UA 366 given turn heading; acknowledged by First Officer.

36. 1618:50 UA 366 given climb instructions; First Officer acknowledged.

37. 1619:40 UA 366 instructed to contact Chicago Center; First Officer acknowledged and changed frequency.

38. 1619:55 First Officer contacted Chicago Center and was instructed to "report passing 12000."

39. 1621:20 First Officer reported "out of 12000."

40. 1623:45 UA 366 requested to "report leaving 22000."

41. 1624:15 First Officer reported "out of 22000" and was instructed to change frequency (new sector).

42. 1624:30 First Officer contacted new sector.

43. 1626:00 UA 366 told to "maintain 370."

The observers returned to cabin at this time. They returned to cockpit when flight was in arrival descent phase to record the following observations:

44. 1815:10 Flight at 23,000 feet and descending.

45. 1817:40 First Officer contacted N.Y. center (flight at 18,000 feet) and was given descent instructions.

46. 1820:40 UA 366 given instruction to cross a specific fix at 9000 feet.

47. 1820:40 First Officer began scanning out window for other aircraft.

48. 1822:30 UA 366 instructed to reduce speed. First Officer acknowledged and reached down to adjust throttles.

49. 1824:10 UA 366 requested to report altitude. First Officer replied "leaving 10,000."

50. 1824:25 UA 366 instructed to contact Newark Approach Control. First Officer acknowledged.

51. 1824:40 First Officer switched frequency and contacted Newark. UA 366 given vector to runway 22L; he acknowledged.

52. 1825:40 UA 366 instructed to change frequency; First Officer acknowledged, and switched frequency, and made contact.

53. 1825:45 UA 366 given traffic advisory. First Officer and Captain scanning for traffic.

54. 1826:00 UA 366 given instruction to "descend to 4000." First Officer acknowledged. Captain initiated descent.

55. 1826:45 First Officer reported to Approach Control that they "have the traffic (in sight)."

56. 1827:30 UA 366 given another traffic advisory. Traffic spotted by Captain.

57. 1828:11 UA366 given another traffic advisory. Both Captain and First Officer looking for the traffic.

58. 1829:20 Flight reached 4000 feet and Captain leveled out aircraft.

59. 1830:20 UA 366 given vector.

60. 1830:40 UA 366 given another traffic advisory. First and Second Officers looking for traffic.

61. 1831:40 UA 366 given vector instruction and told by controller that he will "have a descent for you soon."

62. Sometime in period between events 61 and 63 the observers noted a controller transmission smeared by the transmission from another aircraft.

63. 1832:50 The flight was approximately 6-1/2 miles from Outer Marker. UA 366 was "cleared for a 22 left approach."

64. 1832:55 Second Officer called the company for a gate and gave a landing estimate.

65. 1834:50 UA 366 contacted by Approach Control and altitude was requested. First Officer indicated altitude as 4000 feet. Approach Control asked "didn't you get my earlier instruction to descend to 2500." First Officer replied "negative." Controller instructed UA 366 to "expedite your descent now." First Officer acknowledged and Captain put aircraft into a rapid descent.

66. 1835:10 UA 366 instructed to contact Newark Tower. First Officer acknowledged and changed frequency.

67. 1835:20 First Officer contacted Newark Tower.

68. 1835:55 First Officer reported at Outer Marker. Control responded "UA 366 cleared to land 22 left. Hold short 22 right." First Officer acknowledged.

69. 1837:20 Flight touched down.

70. 1837:40 Flight clear of runway at high speed and holding on taxiway Echo at 22R.

71. 1838:10 Controller instructed "UA 366 cross 22 right. Contact ground when across." First Officer acknowledged. Captain accelerated aircraft to cross runway.

72. 1838:40 Flight across 22R. First Officer changed frequency and reported "UA 366 across 22 right at Echo. Going to 18." Controller responded "UA 366 left turn on the Inner to your gate."

73. 1839:40 Flight turning off Inner into ramp area.

74. 1841:00 Captain swinging aircraft into gate position.

75. 1841:15 Second Officer reports "UA 366 docked at gate 18."

76. 1842:15 Crew completing shutdown check list.

After check list was completed observers talked with crew members for a few minutes about events observed. The Captain indicated that the missed descent instruction is not a common occurrence, but occasionally instructions are garbled by channel chatter. He was asked if he had ever experienced this at O'Hare. He indicated that he had, but could not give an estimate of how many times it happened. The Second Officer was asked about the difference in procedures for company communications noted for O'Hare and Newark. He indicated that the reason for the earlier contact at O'Hare was due to higher volume of traffic at O'Hare and transmission of gate information for connecting flights. Verification of the gate on arrival at O'Hare was necessary because of the higher potential for delay problems. He indicated that the traffic volume at Newark was substantially lower, there was basically no interconnection of flights, and gate availability problems were rare. Thus, contact with the company was only made once under normal conditions when a reliable estimate of landing time could be given. If a gate change became necessary for any reason the company would call the flight after landing.

5.5.3.2 In-Cockpit Flight Trace 2 - Effects of Poor Weather/Visibility

This flight observation provides an excellent example of the effects of poor weather visibility conditions on flight ground operations from the point of view of the cockpit. The events which occurred included:

1. Controller loss of or confusion in aircraft position.
2. Pilot loss of visual reference for taxi.
3. Interference between aircraft and surface vehicle operations.
4. Resolution of a nose-to-nose aircraft conflict.

These events occurred at Newark Airport and thus are not directly related to the study of O'Hare operations. However, they do represent situations that occur at O'Hare or any other airport under similar conditions.

The flight was UA 142 and the equipment was a DC-10. The scheduled departure time was 2:30 p. m. (1930 GMT). The weather at O'Hare was clear and the airport was operating in the Arrivals from the East mode. The weather in Newark on landing was heavy blowing snow with Category II conditions.

Detailed timing of cockpit activities was not performed for this flight. Flight movements at Newark and salient aspects of the observations are illustrated in Figure 5-38. Thus, the observations are presented in narrative form.

At 1940 (a ten minute delay from scheduled departure) the flight pushed back and engines were started. The flight was called by Outbound Ground almost immediately after the frequency change instruction from Clearance Delivery. It was cleared to runway 32R via the Outer and Bridge. Traffic appeared light. The flight taxied to 32R without any delays and was cleared into position on 32R almost immediately after entering the runup pad. The flight held for an arrival on 27R and was cleared for takeoff after it had passed. Takeoff roll was started at approximately 1947.

Half way to Newark the flight was advised that John F. Kennedy and LaGuardia Airports were closed but that Newark was open. The weather at Newark was 700 ft. ceiling and an RVR of 4000 with blowing snow.

After entering the New York TCA the flight was cleared to hold at Budd Lake. The Captain indicated that he anticipated a delay. However, before reaching the Budd Lake fix the flight was cleared for an approach.

The clearance read "Cleared for an Approach Runway 4R, wind 020 degrees at 10 knots, braking action on runway 4R is poor reported by DC9, touchdown RVR 2400, rollout 2200."

The Captain intersected and acquired the ILS course on runway 4R. He then locked on to the ILS course and set the instruments for a fully automated (hands off) landing, including flare out. The flight broke out at 500 ft. and the runway lights were visible. The flight appeared to be lined up dead-center to the

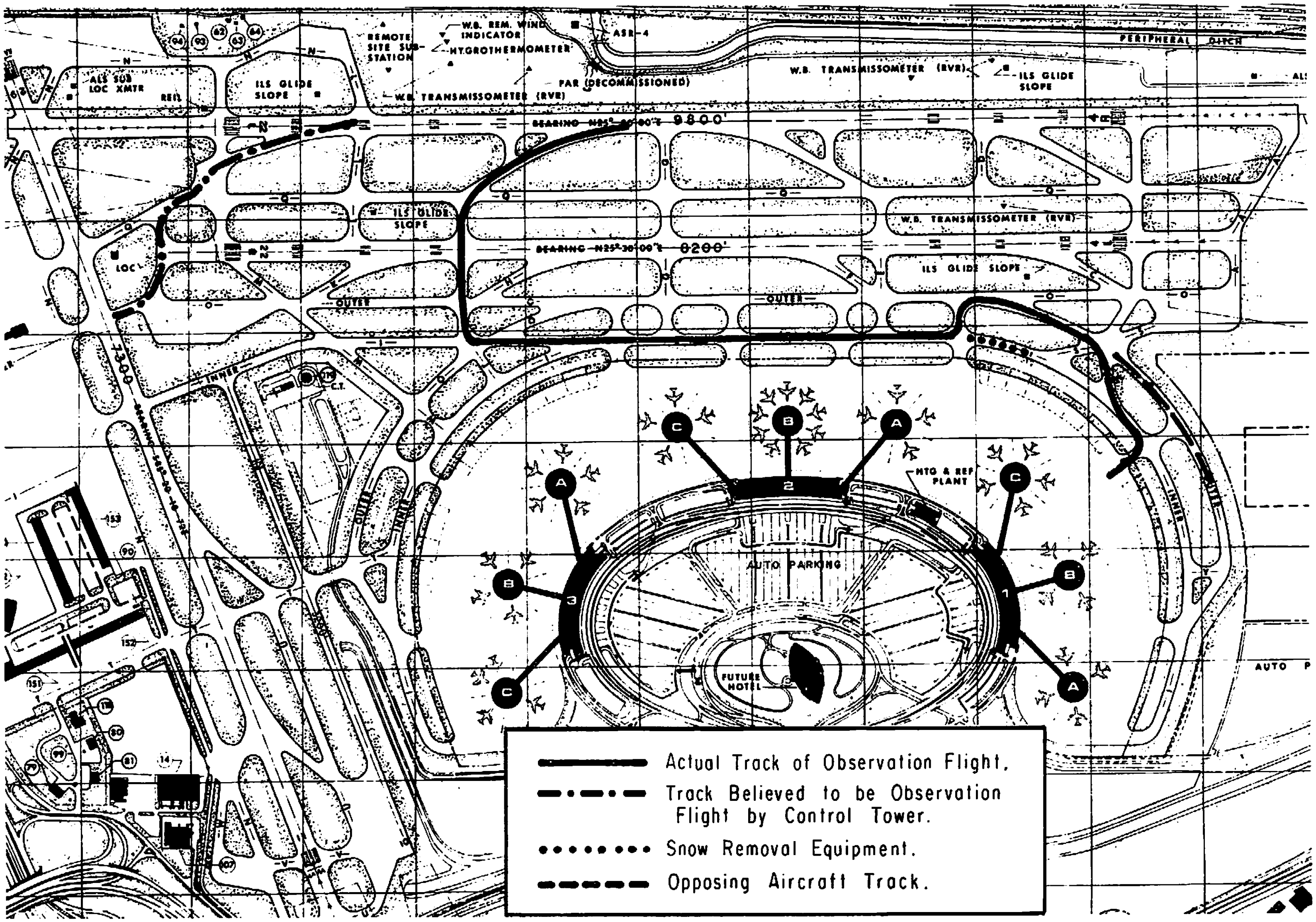

Figure 5-38. Illustration of In-Cockpit Flight Trace 2

runway. The aircraft touched down at approximately taxiway E (refer to Figure 5-38), but since braking action was poor, it passed taxiways F and G and turnoff was made at taxiway J (high speed turnoff). The Captain taxied the aircraft slowly, using the brakes, up to and held short of runway 4L, which was being used for departure operations. The Captain was asked by the observer to indicate when he believed the aircraft's tail was clear of the runway. He did so and explained how he determined it. He explained that he taxis with his landing lights set at approximately 45° to the horizontal. When the lights cross the edge line of a taxiway, the taxiway edge lights, or the edge lines of a runway, the aircraft is usually clear. In this case he also used the lights to determine when to hold short of 4L. At this point, the First Officer advised Local Control that he was clear of runway 4R and holding short of runway 4L. The flight was then cleared to the gate via taxiway J and the Outer and instructed to contact Ground Control on 121.8. The flight proceeded to cross 4L but not before the Captain confirmed with the First Officer that it was in fact cleared to cross 4L.

The First Officer contacted Ground Control and was advised by the Ground Controller to "continue on taxiway Pappa and hold short of runway 11/29." It was evident that the Ground Controller did not know where the flight was. Reference to Figure 5-38 indicates that taxiway P (Pappa) is past the end of runway 4L/22R and crosses 11/29. The First Officer advised the Ground Controller of the aircraft's position. After a long pause the flight was cleared to the inner taxiway to the gate.

The flight turned off taxiway J and proceeded on the Inner. The Captain began following the taxiway centerline lights and painted centerline very slowly and cautiously.* After taxiing a short distance the flight came to an area where the blowing snow had covered the centerline lights and painted center. Thus, visible

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*Newark airport has installed centerline lights along the yellow painted centerline. However, there are no taxiway edge lights installed.

reference to the taxiway was lost. As the flight came to an area clear of blown snow, the Captain, First Officer, and observer could see a double line indicating the boundary of the taxiway surface and the shoulder slightly to the right of the aircraft nose.* The Captain then brought the aircraft back to the left and taxied even more cautiously until the centerline lights could be seen again.

As the flight was abreast of the A satellite of terminal 2 the cockpit was illuminated by headlights of several surface vehicles apparently caused by about six snow removal vehicles clearing the snow on the Inner and approaching the flight head-on. The First Officer contacted the Ground Controller to report the situation. The Ground Controller indicated that he was not aware of snow removal equipment in the area. After a brief discussion on what to do the flight was instructed to make a left at the intersection and a right on the Outer.

As the flight proceeded along the Outer, lights were again observed approaching the aircraft. At this point it could be heard that a TWA flight taxiing on the Outer reported to Ground Control that an aircraft was approaching it on the Outer and asked what the other flight was supposed to do. The Ground Controller informed TWA about the status of UA 142. The pilot of the TWA aircraft then asked the controller if United is supposed to give way to him or he to United. The controller indicated that it would depend on their positions . The TWA pilot then contacted the UA flight to ask if there was room for them to hold and allow him to turn right (on taxiway S). The UA Captain replied that he did not think so but thought he could make the right toward the Inner. The situation was resolved in that manner and the flight was cleared to the gate. The aircraft docked at the gate at approximately 2142.

After the final checkout the observer spent some time talking with the crew about the arrival events and the objectives of the study. The crew

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*Considering the size of a DC-10, the right main gear were probably over the grass area.

indicated that under such poor conditions in-cockpit instrumenation for aircraft taxi guidance would be very desirable and that some of the problems could be avoided if there was better information available to the control tower.

SECTION 6 - ASTC SYSTEM OPERATIONS EFFECTIVENESS ANALYSIS

6.1 GENERAL

The purpose of this section is to present the results of the operations effectiveness analysis for the current O'Hare ASTC system and for the projected future operating environment at O'Hare. The results for the current system include both quantitative and qualitative analysis of the operations observed using the data derived from the functional activity analysis of system operation. The quantitative analysis is very gross and is included only as an indication of the magnitudes of delay and associated operating costs, etc., involved in the operation of the ASTC system. That small fraction of delay which new systems and procedures can reduce will be estimated as part of the second phase of this study. The results for the projected O'Hare environment are described only qualitatively due to the uncertainty of that environment.

6.2 SYSTEM EFFECTIVENESS CRITERIA MEASURES

The criteria selected and the computation of criteria measures for the ASTC system effectiveness analysis were previously discussed in Section 2.3. The effectiveness criteria included both directly measured system performance variables and performance variables derived from extrapolation of the directly measured variables. The effectiveness criteria employed in this analysis included:

Directly Measured Variables	Indirect Performance Variables
Delay Time	Operating Cost
Controller Communications Workload	Fuel Consumption
Pilot Communications Workload	Passenger Inconvenience

The computational methodology of the effectiveness scores for these performance variables is illustrated in Section 6.3. In the case of the indirect performance variables it was necessary to apply weighting factors for the characteristics of the various aircraft operating at O'Hare. Therefore, the actual flight schedules for airlines operating at O'Hare were examined to determine the type of equipments employed for the various flights. Each aircraft type as well as general aviation aircraft were assigned a class type and frequency of occurrence of the operation of aircraft by class type was derived. The results of this activity is presented in Table 6-1. It may be seen that the predominant number of operations at O'Hare are B727 and DC9 equipments.

Table 6-1. Distribution of Aircraft Types at O'Hare

Aircraft Equipment Type	Class Type	Frequency of Operation
B747	1	0.0247
DC10	1	0.0465
L1011	1	0.0046
B707	2	0.0620
DC8[1]	2	0.0912
B727[2]	3	0.3359
B737	3	0.0540
DC9	3	0.2021
B720	2	0.0023
CV880	2	0.0092
Other[3]	4	0.1675

Notes

1. Includes all DC8-50 and DC8-60 (stretch) series operations.
2. Includes all B727-100 and B727-200 (stretch) series operations.
3. Composite of all other air carrier and general aviation turbojet, light jet, and propeller equipments.

The frequency of occurrence values shown in Table 6-1 and the various performance characteristics [e.g., fuel flow (consumption) rate, operating cost per minute, average passenger loading] for the aircraft class type were employed to derive composite average performance parameters according to the formula:

$$\text{Avg Performance Parameter} = \sum_{i} \frac{n_i}{n} (PC_i)$$

where

i = aircraft class type

$\frac{n_i}{n}$ = frequency of occurrence of operation of aircraft in the ith class type

PC_i = particular performance characteristic for aircraft in the ith class type

6.3 CURRENT O'HARE ASTC SYSTEM EFFECTIVENESS

The following paragraphs present the results of the effectiveness analysis of the current O'Hare ASTC system. Several assumptions were made to allow practical computations of the effectiveness criteria values. These include:

1. Average traffic operations rate of 120 operations/hour during weekday busy traffic hours 0700 to 2300.
2. Average traffic operations rate of 40 operations/hour during weekday night operations hours 2300-0700.
3. The arrival/departure ratio = 1 for any hour.
4. The ratio of northside/southside operations = 1 for any hour.
5. The ratio of hours of operation in Arrivals from the East mode/ Arrivals in the West mode = 1 for the year.
6. The data derived from the traffic flow and communications analysis for the sample periods holds on the average throughout the year.
7. There are negligible or no delays during night operations hours.
8. Since minimum data was derived for Category II conditions and the hours of such conditions throughout the year is small compared to total operations, all computations were based upon visual operating conditions.
9. Saturdays and Sundays are equivalent to a single weekday, yielding approximately 300 equivalent operations days per year.
10. All aircraft taxi with all engines operating at idle and engine start-up and shutdown takes place at the gate.

6.3.1 Traffic Delay Effectiveness

Using the above assumptions the traffic delay effectiveness values can be derived using the relationships:

$$\overline{TD}_{BE} = \frac{\overline{ST}_E}{\overline{ST}_E + \overline{HT}_W}$$

$$\overline{TD}_{BW} = \frac{\overline{ST}_W}{\overline{ST}_W + \overline{HT}_W}$$

$$\overline{TD}_{BY} = 0.50\left(\overline{TD}_{BE}\right) + 0.50\left(\overline{TD}_{BW}\right)$$

$$\overline{AMDR}_B = \frac{\overline{TD}_{BW}}{\overline{TD}}$$

$$TD = 16 \times \overline{TO}_D \left(\overline{HT}_W + \overline{HT}_E\right) \times 300$$

where

$\overline{ST}_E$ and $\overline{HT}_E$ $\left(\overline{ST}_W \text{ and } \overline{HT}_W\right)$ = the average service time and holding time per operation in the Arrival from the East mode (Arrival from the West mode)

$\overline{TO}_D$ = Average busy hour operations rate (120 opns/hr)

$\overline{TD}_{BE}$ $\left(\overline{TD}_{BW}\right)$ = Average delay effectiveness for busy hour operations in the Arrival from the East (West) mode.

$\overline{TD}_{BY}$ = Average busy hour delay effectiveness throughout the year.

$\overline{AMDR}_B$ = Average busy hour airport operations mode effectiveness ratio

TD = Total average yearly delay

Using the values for taxi service times and holding times derived in Section 5.3, the values for $\overline{ST}$ and $\overline{HT}$ are computed as

$$\overline{ST}_W = \overline{ST}_{Ramp} + \overline{ST}_{Ground(E)} + \overline{ST}_{Local(E)}$$

$$= \frac{128.9 + 258 + 30}{60} = 6.95 \text{ minutes/operation}$$

$$\overline{HT}_W = \overline{HT}_{Ramp} + \overline{HT}_{Ground(W)} + \overline{HT}_{Local(W)}$$

$$= \frac{8.1 + 59.1 + 255}{60} = 5.37 \text{ minutes/operation}$$

$$\overline{ST}_E = \overline{ST}_{Ramp} + \overline{ST}_{Ground(E)} + \overline{ST}_{Local(E)}$$

$$= \frac{128.9 + 204 + 30}{60} = 6.04 \text{ minutes/operation}$$

$$\overline{HT}_E = \overline{HT}_{Ramp} + \overline{HT}_{Ground(E)} + \overline{HT}_{Local(E)}$$

$$= \frac{8.1 + 25.1 + 186}{60} = 3.65 \text{ minutes/operations}$$

Using these values, the effectiveness measures are computed as

$$\overline{TD}_{BE} = \frac{6.04}{6.04 + 3.65} = 0.623 \text{ or } 62.3\% \text{ effective}$$

$$\overline{TD}_{BW} = \frac{6.95}{6.95 + 5.37} = 0.572 \text{ or } 57.2\% \text{ effective}$$

$$\overline{TD}_{BY} = 0.5(.623) + 0.5(572) = 0.598 \text{ or } 59.8\% \text{ effective}$$

$$\overline{AMDR}_B = \frac{0.572}{0.623} = 0.918$$

$$TD = 16 \times 120\ (3.65 + 5.37) = 5,195,520 \text{ minutes or } 86,592 \text{ hours per year}$$

From these computations it may be seen that about 40 percent of the time an aircraft is on the ground at O'Hare he is in a delay waiting for a gate, a runway, other taxiing traffic, or service from the ASTC system. It may also be seen that the East mode is more effective than the West mode on the average. This is generally due to less runway crossing required. If operations under Category II conditions had been considered, the effectiveness of the West mode and the ratio of West/East operations would be slightly less than the values computed above.

6.3.2 Controller Communications Workload

Controller communications workload effectiveness values for busy hour operations can be derived using the relationships:*

$$\overline{CCW}_{OG} = \left[0.50\ \overline{CO}_{(E)OG} + 0.5\ \overline{CO}_{(W)OG}\right] 60$$

$$\overline{CCW}_{IG} = \left[0.5\ \overline{CO}_{(E)OG} + 0.5\ \overline{CO}_{(E)OG}\right] 60 \times 1.15$$

$$\overline{CCW}_{LC} = \left[0.5\ \overline{CO}_{(E)LC} + 0.5\ \overline{CO}_{(W)LC}\right] 60$$

$$\overline{AMCR} = \left[\frac{\overline{CO}_{(W)OG} + 1.15\ \overline{CO}_{(W)IG} + 2\ \overline{CO}_{(W)LC}}{\overline{CO}_{(E)OG} + 1.15\ \overline{CO}_{(E)IG} + 2\ \overline{CO}_{(E)LC}}\right]$$

where

$\overline{CCW}$ = Average percentage Channel Occupancy for each position throughout the year.

$\overline{CO}_{(W)} \left[\overline{CO}_{(E)}\right]$ = Average Channel Occupancy per operation in Arrival from West(East) mode.

Subscripts OG, IG, and LC stand for Outbound Ground, Inbound Ground, and Local Control, respectively.

$\overline{AMCR}$ = Average airport operations mode effectiveness ratio

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*Clearance Delivery communications are not considered in this analysis because this operation is independent of East or West Mode of operation.

Using the data derived in Section 5.4 these effectiveness values can be computed as:

$$\overline{\text{CCW}}_{OG} = [.5(.56) + .5(59)]\ 60 = 34.5\%\ \text{Occupancy}$$

$$\overline{\text{CCW}}_{IG} = [.5(.55) + .5(59)] \times 60 \times 1.15 = 39.3\%\ \text{Occupancy}$$

$$\overline{\text{CCW}}_{LC} = [.5(.49) + .5(55)]\ 60 = 31.2\%\ \text{Occupancy}$$

$$\overline{\text{AMCR}} = \left[\frac{0.59 + 1.15(0.59) + 2(0.55)}{0.56 + 1.15(0.59) + 2(0.49)}\right] = 1.07$$

From the above data it can be seen that communications workload for the Inbound Ground is somewhat higher on the average through the year. In addition, it may also be seen that the Arrival from the West mode is again less effective on the average than the Arrival from the East mode.

6.3.3 Fuel Consumption Effectiveness

The annual fuel consumption for operations at O'Hare is derived from the relationship:

$$\text{FC} = \left[k_W\ \text{FC}_W + k_E\ \text{FC}_E\right] 300$$

Expansion of this equation gives:

$$\text{FC}_W = \left[16 \times \overline{\text{TO}}_D \times \left(\overline{\text{ST}}_W + \overline{\text{HT}}_W\right) + 8\ \overline{\text{TO}}_N \times \left(\overline{\text{ST}}_W\right)\right] \times \left[\sum \frac{n_i}{n}\ \text{FF}_i\right]$$

$$\begin{bmatrix}\text{Total Aircraft - mins in} \\ \text{ASTC system per day}\end{bmatrix} \times \begin{bmatrix}\text{Avg Aircraft Fuel Flow} \\ \text{Gallons per aircraft min.}\end{bmatrix}$$

where

$\overline{TO}_D$ = Avg hourly daytime operations rate.

$\overline{ST}_W$ = Avg service time for West arrival mode.

$\overline{HT}_W$ = Avg holding time for West arrival mode.

$\overline{TO}_N$ = Avg hourly nightime operations rate.

$\sum \frac{n_i}{n} FF_i$ = Weighted average gallons of fuel used per idle aircraft minute

and

$$FC_E = \left[16 \text{ x } \overline{TO}_D \text{ x } \left(\overline{ST}_E + \overline{HT}_E\right) + 8\ \overline{TO}_N \text{ x} \left(\overline{ST}_E\right)\right] \text{ x } \sum \frac{n_i}{n} FF_i$$

where

$\overline{ST}_E$ = Avg service time for East arrival mode.

$\overline{HT}_E$ = Avg holding time for West arrival mode.

The values of $\overline{TO}_D$ and $\overline{TO}_N$ were given earlier as 120 operations/hour and 40 operations/hour, respectively. The value of $\sum n_i/n\ FF_i$ is derived from Table 6-2 as 8.615 gallons/minute/aircraft.

Thus,

FC_W = [(16 x 120 x 12.32) + (8 x 40 x 6.95)] x 8.615

FC_W = 222,940 gallons/day

FC_E = [(16 x 120 x 9.69) + (8 x 40 x 6.04)] x 8.615

FC_E = 176,930 gallons/day

Table 6-2. Weighted Average Gallons of Fuel per Idle Aircraft Minute at O'Hare

Aircraft Type	Class	Freq. of Occurrence x	Estimated Idle Fuel Engine (gallons/minute/engine) x	No. of Engines =	Weighted Fuel Consumption (gallons/idle engine minute)
B747	1	0.0247	5.24	4	0.518
DC10	1	0.0465	3.07	3	0.428
L1011	1	0.0046	3.07	3	0.042
B707	2	0.0620	3.58	4	0.888
DC8	2	0.0912	3.58	4	1.306
B727	3	0.3359	3.18	3	3.205
B737	3	0.0540	3.24	2	0.350
DC9	3	0.2021	3.24	2	1.310
B720	2	0.0023	3.58	4	0.033
CV880	2	0.0092	1.70	4	0.063
Other	4	0.1675	1.41	2*	0.472
					8.615

*Composite mix.

and

$$FC = [0.5\ (222,940) + 0.5\ (176,930)]\ 300$$

$$\boxed{FC = 59,980,700 \text{ gallons/year}}$$

letting $\overline{HT}_W$ and $\overline{HT}_E = 0$ for optimum effectiveness gives:

$$FC_{W\ min} = [(16 \times 120 \times 6.95) + (8 \times 40 \times 6.95)] \times 8.615$$

$$= 134,120 \text{ gals/day}$$

$$FC_{E\ min} = [(16 \times 120 \times 6.04) \times (8 \times 40 \times 6.04)] \times 8.615$$

$$= 116,560 \text{ gals/day}$$

$$FC_{min} = [0.5\ (134,120) + 0.5\ (116,560)]\ 300$$

$$= 37,602,000 \text{ gals/year}$$

Thus,

$$\text{Fuel Consumption Effectiveness} = \frac{37,602,000}{59,980,700} = \boxed{0.627}$$

From these computations it is estimated that the gasoline consumed by aircraft taxiing at O'Hare is roughly that of the gasoline consumed by all the cars, buses and trucks in the nearby city of Peoria (population 126,000). The gasoline consumed in delays alone could satisfy nearly 10 percent of the needs of the District of Columbia or the State of Vermont.

6.3.4 Operating Cost Effectiveness

This analysis provides an estimate of the operating cost for aircraft in the ASTC System at O'Hare. The associated effectiveness score and potential cost savings for an optimized system are also computed. The same airport operating assumptions which were made for the fuel and pollution analyses are used in this evaluation; therefore, the overall effectiveness score which is based primarily on delay ratios is 0.627. The annual estimated cost for ground operation at O'Hare is calculated from the formula.

$$OC = \left[k_W \, OC_W + k_E \, OC_E\right] 300$$

where

$$OC_W = \left[16 \, \overline{TO}_D \left(\overline{ST}_W + \overline{HT}_W\right) + 8 \, \overline{TO}_N \left(\overline{ST}_W\right)\right] \times \sum_i \frac{n_i}{n} CF_i$$

and

$$OC_E = \left[16 \, \overline{TO}_D \left(\overline{ST}_E + \overline{HT}_E\right) + 8 \, \overline{TO}_N \left(\overline{ST}_E\right)\right] \times \sum_i \frac{n_i}{n} CF_i$$

Table 6-3 summarizes the cost factors (CF_i) for the various aircraft types at O'Hare. The average weighted cost per aircraft minute is \$11.23. Substituting this value and the previous delay data gives

$$OC_W = [(16 \times 120 \times 12.32) + (8 \times 40 \times 6.95)] \times \$11.23$$

$$OC_W = \$290{,}614 \text{ per day}$$

$$OC_E = [(16 \times 120 \times 9.69) + (8 \times 40 \times 6.04)] \times \$11.23$$

$$OC_E = \$230{,}638 \text{ per day}$$

The annual cost is therefore estimated to be

$$OC = [0.5 \,(\$290{,}614) + 0.5 \,(\$230{,}638)]\ 300$$

$$\boxed{OC = \$78{,}187{,}800 \text{ per year}}$$

The estimated annual costs due to delays on the O'Hare Airport surface are therefore:

$$\text{Annual Operating Cost Due to Delays} = (1 - 0.627)\ \$78{,}187{,}800 = \boxed{\$29{,}164{,}049}$$

Table 6-3. Weighted Average Operating Cost per Idle Aircraft Minute at O'Hare

Aircraft Type	Class	Freq. of Occurrence x	Estimated Cost of Operation (dollars/minute) =	Weighted Cost (dollars/minute/ idle aircraft)
B747	1	0.0247	29.88	0.74
DC10	1	0.0465	18.37	0.85
L1011	1	0.0046	27.17	0.12
B707	2	0.0620	13.88	0.86
DC8	2	0.0912	15.00	1.37
B727	3	0.3359	11.25	3.78
B737	3	0.0540	10.30	0.56
DC9	3	0.2021	8.15	1.65
B720	2	0.0023	15.67	0.04
CV880	2	0.0092	15.67	0.14
Other	4*	0.1675	6.67*	1.12
				11.23

*Assumed avg mix.

6.3.5 Passenger Inconvenience

Passenger inconvenience is evaluated by estimating the total passenger delay minutes per year and the number of passenger stops. Measured data on the total aircraft delay minutes and the number of holds per aircraft are analyzed in conjunction with passenger loading statistics at O'Hare.

Passenger Delay minutes are calculated for the year using the formula

$$PD = \left[k_W \, PD_W + k_E \, PD_E \right] 300$$

where

$$PD_W = \left[16 \, \overline{TO}_D \, \overline{HT}_W \right] \times \sum \frac{n_i}{n} PL_i$$

and

$$PD_E = \left[16 \, \overline{TO}_D \, \overline{HT}_E \right] \times \sum \frac{n_i}{n} PL_i$$

Table 6-4 estimates the average aircraft passenger loading at O'Hare to be 58.939 passengers per aircraft. Using the holding time estimates for the east/west modes of operation passenger delay is computed as

$$PD_W = [16\ (120)\ 5.37]\ x\ 58.939$$

$$PD_W = 607{,}685 \text{ passenger delay minutes/day}$$

$$PD_E = [16\ (120)\ (3.65)]\ x\ 58.939$$

$$PD_E = 413{,}045 \text{ passenger delay minutes/day}$$

$$PD = [0.5\ (607{,}685) + 0.5\ (413{,}045)]\ 300$$

$$PD = 153{,}109{,}500 \text{ passenger delay minutes/year}$$

$$PD = 219.3 \text{ passenger delay years/year}$$

The passenger delay effectiveness score is based on the ratio of delay time to actual transit time measured. Therefore, the effectiveness score will be identical to that for fuel consumption, pollution emission, and cost, i.e., 0.627.

In addition to delay, passenger discomfort is an inconvenience which is somewhat related to the number of accelerations and decelerations that the aircraft makes. This can be partially evaluated in terms of the number of holds encountered while traveling on the ground.

The measurements taken at O'Hare indicate that there are an average of 0.1 holds per aircraft operation in the ramp area and 0.5 taxiway holds per aircraft for the west mode of operation and 0.23 holds per aircraft in the east mode. The annual number of passenger stops plus starts can be calculated from the formula

$$PC = \left[k_W\ PC_W + k_E\ PC_E\right] 300$$

where

$$PC_W = \left[16\ \overline{TO}_D \times 2\ \overline{NH}_W\right] \times \sum_i \frac{n_i}{n} PL_i$$

and

$$PC_E = \left[16\ \overline{TO}_D \times 2\ \overline{NH}_E\right] \times \sum_i \frac{n_i}{n} PL_i$$

Substituting the appropriate values gives

$$PC_W = [16\ (120) \times 2\ (0.5 + 0.1)] \times 58.939$$

$$= 135{,}795 \text{ passenger starts and stops/day}$$

$$PC_E = [16\ (120) \times 2\ (0.23 + 0.1)] \times 58.939$$

$$= 74{,}688 \text{ passenger starts and stops/day}$$

$$PC = [0.5\ (135{,}795) + 0.5\ (74{,}688)]\ 300$$

$$= 31{,}572{,}450 \text{ passenger starts and stops/year}$$

The passenger comfort effectiveness score is best evaluated in terms of the average number of starts and stops that a single passenger can expect at O'Hare. Since this varies for the east and west mode of operation the scores are:

Comfort Effectiveness Score	Mode
0.60	West
0.33	East
0.465	Weighted Average 50/50
0.0000	Optimum

This analysis does not account for starts and stops encountered after the aircraft enters the departure queue nor does it include those stops which are essential to proper aircraft movement (e.g., after pushback, during docking).

Table 6-4. Weighted Passenger Loading for Aircraft at O'Hare

Aircraft Type	Class	Freq. of Occurrence	x Estimated Passenger Loading Capacity	= Weighted Passenger Capacity
B747	1	0.0247	338	8.35
DC10	1	0.0465	234	10.88
L1011	1	0.0046	254	1.17
B707	2	0.0620	141	8.74
DC8	2*	0.0912	157	14.32
B727	3*	0.3359	110	36.95
B737	3	0.0540	95	5.13
DC9	3	0.2021	89	17.99
B720	2	0.0023	140**	0.32
CV880	2	0.0092	140**	1.29
Other	4*	0.1675	40**	6.70
		Total Avg Capacity/Aircraft		111.84
		Avg Passenger Loading Factor for Domestic Flts (173)		52.7%
		Avg Passengers/Flt at O'Hare		58.939

*Assumed avg mix of various models.
**Data not available - Estimated value.

6.4 FUTURE O'HARE ASTC SYSTEM EFFECTIVENESS ASSESSMENT

6.4.1 Projected Future Operating Environment

During this study several attempts were made to determine a reliable estimate of the future operating environment of O'Hare. The areas of interest included:

1. New runway construction and modification of existing runways.
2. New taxiway construction (which is, for the most part, related to new runway construction).
3. New terminal facilities construction or modification of existing facilities.
4. Traffic projections, including both the volume and mix of traffic.
5. Revised runway and taxiway operations patterns (which is related to areas 1-3 above).

In discussions with airport management, ATCT, and airline management personnel it was clear that no firm plan existed which could be considered reliable. However, based on these discussions certain assumptions were made pertaining to airport developments which could be considered reasonable for the purposes of this analysis. These assumptions, illustrated in Figure 6-1, include:

1. Construction of a new runway 9L/27R
2. Construction of a new runway 4L/22R
3. Construction of a new segment of taxiway connecting the 14R/32L parallel to the current 4L/22R runway
4. Construction of a new International Terminal complex at the location of the current USAF/Air National Guard area
5. Development of the area southeast of the intersection of runways 14R/32L and 9R/27L for a new general aviation terminal. *

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*A strong possible alternative to this is development of an area adjacent to the assumed new International Terminal complex for this purpose.

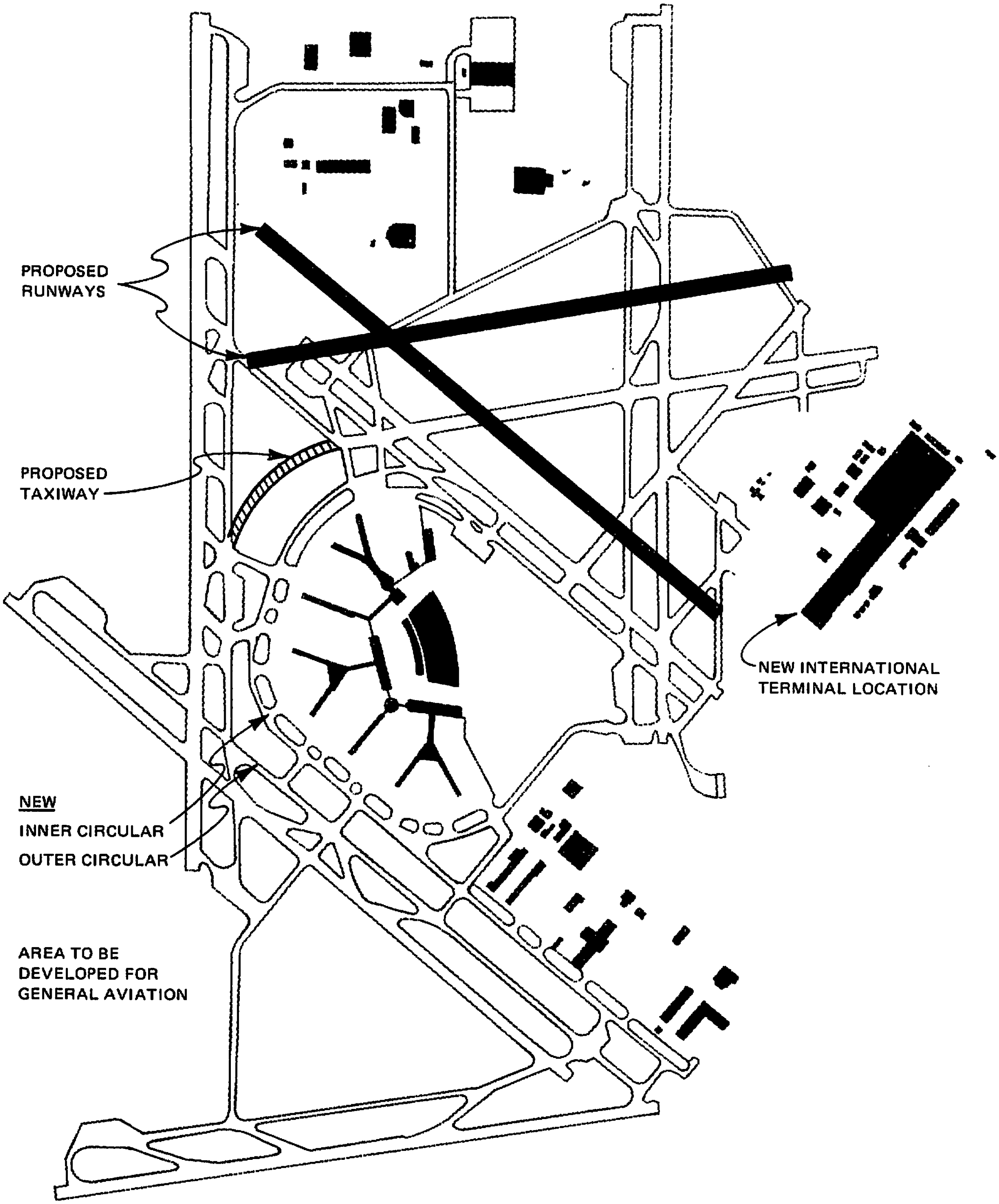

Figure 6-1. Projected Future Operating Environment at O'Hare

Based on these assumptions, further assumptions were made relative to aircraft taxi flow. These include:

1. The current runways 4L/22R and 9L/27R would be used as parallel taxiways for the new runways
2. Use of the current Inner Circular taxiway would be discontinued in favor of the use of the current Outer Circular for this purpose
3. The combination of the 9R/27L parallel, 14R/32L parallel, and new taxiway segment identified above would be used as the new Outer Circular

However, since no information was available pertaining to the construction of taxiways in relation to the new 4L/22R and 9L/27R runways, no assumptions could be made relative to any potential changes in traffic taxi patterns for departures to or arrivals from these new runways.

6.4.2 Assessment of the ASTC System Effectiveness in the Projected Future Operating Environment

In the following paragraphs a qualitative assessment of the impact of the various changes in the physical operating environment is made based upon the understanding of current airport operations. These assessments are based upon use of the runways in basically the same primary configurations discussed in Section 3.3. In summary, they indicate that the planned facility changes can streamline the current ground operations and increase gate capacity, easing the current gate limitations, but that the overall capacity will not be affected. If anything, overall capacity will be reduced as the percent of heavy aircraft increases. New ATC equipments and/or procedures are required if capacity is to be increased.

6.4.2.1 New Runways (9L/27R and 4L/22R)

The basic benefits derived from adding the new runways would be to lengthen the rollout capacity of the heavily used 27R and 22R runways (30 percent of all arrivals) and to relieve the departure queue congestion associated with departures from 4L and 9L in the West arrival mode. For the latter it is assumed that departures will be from near the new 4L/9L intersection. The benefits are achieved while permitting the addition of the proposed taxiway from the current 4L.

The benefits would be at the expense of taxi time since the new runways are away from the terminal. It does not appear that the runways would increase the airport's runway capacity since they will simply be used in lieu of the current runways. Thus, without new ATC equipments (e.g., Metering and Spacing) or procedures, the current quota would be expected to continue or be reduced due to increases in heavy aircraft operations.

No reliable quantitative projections could be made for the aircraft mix that would operate in the future at O'Hare. However, based on the changes in the aircraft mix following the flight schedule reductions in January 1974, it is reasonable to assume that future traffic demands will be met in part by the use of higher passenger capacity aircraft. This would probably involve use of 727s in place of DC9s and increased use of stretched 727 aircraft since these equipments comprise about 53 per cent of the current fleet. It could also conceivably involve increased use of DC10 and L1011 equipments as well as re-introduction of 747s which have been deactivated in the schedule reductions by the major carriers.

6.4.2.2 New International Terminal Location

The basic benefit of the new terminal is the addition of gates at an airport which is currently gate limited. International gates currently number 13. If only these 13 were moved to the new terminal, the gate capacity estimate would increase to 170 operations/hour from the current 150 operations/hour (see paragraph 5.3.1.2). Until new ATC procedures and equipments permitted the runways to deliver the increased operations, these gates would tend to reduce the current gate delays.

This benefit will be accomplished at the expense of increased taxi times. Examination of Figure 6-2 indicates that for all primary runway configurations in both airport operating modes there will be a marked increase in the average taxi service time ($\overline{ST}$) for both arrivals and departures. The only instances of decreased taxi time would occur for arrivals from the north and east on 32R (parallel 32s - East Arrivals mode) and 4L (parallel 4s - West Arrivals mode). In addition, marked increases in the taxi delays ($\overline{HT}$) for these operations could be anticipated, as explained below.

In the East Arrivals mode, operations on the northside arrival runways 27R or 22R would have to cross the active departure runway. Where 22R and 27R are being used for arrivals and departures, respectively, the exit point from 22R would determine whether 27R has to be crossed. Operations on the southside arrival runways would have to cross both northside runways as well as the traffic around the main terminal. Departures to the southside runways would similarly have to cross the northside runways and terminal traffic.

In the West Arrivals all operations on the southside runways would similarly have to cross the airport. Since 14L is the primary arrival runway in the north for this mode, or when the 9L arrival/4L departure configuration is used, arrivals in the north will not generally have to cross an active runway. However, in any of the primary northside configurations, departures in the north will have to cross an active arrival runway.

As a result it would be anticipated that international traffic would encounter a significant increase in taxi delays at taxiway-taxiway and taxiway-runway intersections, particularly as the total traffic volume increases.

6.4.2.3 Development of New General Aviation Facility

The development of a new general aviation facility in the area shown in Figure 6-2 (or in the alternate area adjacent to the New International Terminal Complex) would tend to result in the same type of benefits and problems discussed in the preceding paragraph. However, in this case the resultant problems are likely to be more pronounced. This is due to the fact that general aviation operations (and commuter traffic which currently operates from the general aviation area) constitute a signficantly higher percentage of the traffic volume than does international operations and is likely to continue to do so in the future. The change is likely to be more significant in the East Arrivals mode where the general aviation traffic rather easily taxies directly from the Butler Terminal to the 9L/27 parallel for departure on runway 36 or on runway 27R from the 27R/36 intersection.

6.4.2.4 New Inner and Outer Circular Taxiway

The purpose of the new proposed taxiway link is to reduce the requirement for using the current inner as a taxiway. The inner cannot take heavy aircraft in some areas due to space limitations. In addition, ramp congestion due to gate limitations and one-way flows between the fingers would be reduced, ramp holds to deal with gate limitations andone-way flows could be more easily employed, and pushbacks from the finger ends would be facilitated.

Its success is examined for the three most used configurations. Configuration 1 (Figure 3-5, Arrivals from the East) is used 36 percent of the time. Its only requirement on the Inner is along concourse A-C. In the ASDE films it was seen that occasionally, rather than use the Inner, aircraft were routed up the 14R parallel and down the By-pass. The new taxiway link would eliminate this requirement entirely.

In Configuration 11 (Figure 3-15, Mixed Arrivals) which is used 16 percent of the time, the traffic can simply be moved out with the New Inner (current Outer) counter clockwise and the new Outer clockwise. The heavy traffic currently on the Inner (27L departures and almost all arrivals) would be eliminated and put on the current Outer which is more suitable.

In Configuration 6 (Figure 3-10, West Arrival Mode), which is used 10 percent of the time and in bad weather the traffic can simply be moved out with the New Inner (current Outer) counter-clockwise and the New Outer clockwise. The benefits are similar to those in Configuration 11.

Therefore, it appears that the benefits of the new section of taxiway can be realized. However, conflicts between arrivals (especially coming off high speed exits) and traffic on the parallel taxiway (now the Outer), and conflicts caused by aircraft taxiing on a parallel accidentally missing the turn at the intersection with an active runway and blundering out onto the runway (e.g., departures on their way to 9R missing the turn at the 14R/27R parallels intersection and blundering out onto 14R) will become emphasized by this proposed change. Consideration will have to be given to its use in bad weather and/or at night. In addition, in response to the arrival conflicts with parallel taxiway traffic, pilots may slow down their exit speed and even stop prior to clearing the runway. This would directly impact on runway capacity. Such a reduction would negate any benefits in taxi flow.

SECTION 7 - FINDINGS AND CONCLUSIONS

7.1 GENERAL

This section provides a summary of the salient findings of this study effort and the conclusions and recommendations derived from these findings.

7.2 SUMMARY OF FINDINGS

7.2.1 Functional Responsibilities of Operational Personnel

7.2.1.1 Air Traffic Control Tower

The functional responsibilities for management and control of flight operations for O'Hare are divided between the TRACON and Tower Cab. The TRACON is responsible for organizing the flow of traffic to arrival runways and establishing the aircraft on final before turning them over to the tower; this is accomplished by the Approach Control positions. The TRACON is also responsible for accepting aircraft from the tower after takeoff (or missed approaches) and vectoring them enroute out the TCA; this is accomplished by the Departure Control positions.

Tower Cab is responsible for the traffic operations which are the subject of this study. During normally busy periods the following positions are manned in the Tower:

1. Flight Data
2. Clearance Delivery
3. Outbound (Departure) Ground
4. Inbound (Arrival) Ground
5. Local Control #1 (south runways)
6. Local Control #2 (north runways)
7. Watch Supervisor

Flight data has three major functional responsibilities. The first is to receive departure Flight Strips from the printer and prepare them for posting on the Clearance Delivery Flight Strip Board. The second is to assist Clearance Delivery in obtaining flight clearances from the Chicago ARTCC when required and in obtaining beacon codes for VFR departures. The third is to update the Automated Terminal Information Service (ATIS) when changes in the runway configuration or weather conditions require.

Clearance Delivery has two major functional responsibilities. The first is to deliver ARTCC clearances to departures and verify that the flights have properly received their clearances. In addition, he obtains information on the departures gates, where necessary, to assist Outbound Ground in handling the traffic. This second responsibility is to receive notification from aircraft that they are ready for taxi and turn them over to Outbound Ground for taxi instructions. In the case of VFR departures this also includes issuing a clearance (i.e., direction and altitude) out of the TCA.

Outbound Ground has three major functional responsibilities. The first is to issue instructions for aircraft taxi to the appropriate departure runways. Although it is not a specified duty of this position, Outbound Ground does, through his instructions, attempt to establish a practical sequence of aircraft to each of the departure runways. The second responsibility is to maintain the safe and expeditious flow of departure traffic by issuing control instructions to resolve potential conflicts at taxiway intersections or adjust the sequence of aircraft to minimize delays or gaps in the flow. His third responsibility is to turn departures over to the appropriate Local Control position when the aircraft are safely established on the final portion of their route to the runway. In certain operating configurations this includes responsibility for seeing aircraft across an active runway.

Inbound Ground has four major functional responsibilities. The first is to issue instructions for aircraft taxi, after they are clear of the runways, to their gates. This also includes determination of whether the aircraft's gates are available and, if not, to provide taxi instructions to an appropriate holding area. When the gates are available taxi instructions to the gates are then provided. Inbound Ground's second responsibility is control of the movements of aircraft between facilities on the airport surface; that is, between terminal gates and the cargo or hangar areas between terminal gates. The third responsibility, similar to Outbound Ground, is to maintain the safe and expeditious flow of aircraft under his control by issuing the necessary control instructions. Inbound Ground is also responsible for control of the movements of vehicular traffic to, on, or between airport taxiways or runways; however, he is not responsible for control of these vehicles within areas on taxiways or runways that have been closed to aircraft traffic for maintenance operations.

The two Local Control positions have four major functional responsibilities. With respect to arrivals they are responsible for issuing clearances to land and other advisory information required by the pilots for operation of their aircraft and for monitoring the approach to assure that it can be safely made. When the operations of other aircraft on the runway or other conditions will result in unsafe landing conditions he will issue missed approach instructions to the arrivals. He is also responsible for turning the arrivals over to Inbound Ground for taxi instructions when the aircraft are clear of the runway or across the last active runway under his jurisdiction. With respect to departure, Local Control is responsible for establishing the aircraft in the final sequence for optimum use of the runways. When it is safe to do so, he will establish the aircraft on the runway and issue the necessary takeoff clearance instructions, including departure heading and advisory information. He is also responsible for monitoring the takeoff to assure that safe separations are maintained and turning the flight over to Departure Control when the aircraft is established on its assigned departure heading.

7.2.1.2 Airlines

The functional responsibilities related to ASTC operations are divided between airline terminal operations personnel and the aircraft cockpit crew. Airline gate planning and control personnel are responsible for establishing and monitoring adherence to the scheduled usage of gate facilities. They are also responsible for managing aircraft operations from or to these facilities, including control of aircraft pushback and advising arriving flights of their assigned gates and the availability of these gates. While Ramp or Gate Operations Supervisors are responsible for adherence to departure schedules, it was noted that they typically do not know whether or not the flight departures will be made on time until the scheduled time is reached and the flight has or has not departed. This is primarily due to the fact that preparation of the aircraft for departure is the function of separate working units who do not usually coordinate with one another. These units include: gate attendants, fuelers, baggage/cargo loaders, food service loaders, and mechanics. When delays occur, the Gate Operations Supervisors and/or Gate Control Operators must contact the various units to determine the status of the operations and when completion is expected. Typically, the flight crews are not aware of the delays until they occur.

The flight cockpit personnel are responsible for managing the physical operations of the aircraft, establishing and maintaining contact with the ATCT and responding to instructions given, and for establishing and maintaining contact with airlines gate planning/control personnel. Typically these responsibilities are divided among the members of the crew; that is, Captain (pilot), First Officer (pilot) and Second Officer (flight engineer) for three man crews for 727 and larger aircraft. Either of the pilots (i. e., the pilot flying) will be responsible for the physical control of aircraft movements. The other pilot (i. e., the pilot not flying) will be responsible for ATC communications. However, the pilot flying monitors these communications so that he can discharge his responsibility for control of the aircraft movements. With the exception of obtaining the clearance to pushback from Gate Control, which is accomplished by the Pilot-Not-Flying, communications with the company is the responsibility of the Second Officer.

7.2.1.3 Airport Management

The major functional responsibilities of the airport management with respect to ASTC operations are maintenance of airport surface and visual guidance aid facilities in operating condition, direction of the response to emergency situations, and coordination of maintenance and emergency operations with the ATCT. These responsibilities are divided between the Airport Operations Office, City of Chicago Fire Department, and Construction, Electrical Maintenance, and Automotive Sections. Operations office personnel make a daily check of the airport conditions to determine where surface or visual guidance facilities require maintenance. The maintenance operations are scheduled, usually with an attempt to avoid interference with normal airport operations, and scheduled closings of the work areas coordinated with the ATCT. When snow removal on taxiway or runway surface is required, the Operations Office coordinates these with the ATCT as well. The Operations Office maintains a Coordination Center in the old control tower to accomplish these activities. The Center will advise the ATCT when scheduled maintenance or snow removal operations are about to begin. Center personnel visually observe and maintain contact with work crews to monitor the status of these operations and provide the ATCT with reports of estimated completion and completion of these operations. The Center also monitors the status of emergency response operations and keeps the ATCT advised of the progress of these operations.

7.2.2 Current O'Hare Operating Configuration

O'Hare Airport generally operates in two basic operating modes, Arrivals from the East (departures to the west) and Arrivals from the West (departures to the east). There is also a mixed mode of operations where arrivals in the north approach from the west and arrivals in the north approach from the east.

The eleven primary runway configurations identified for these operating modes are shown in Table 7-1. An airport map is shown in Figure 7-1.

It may be seen from the table that these configurations involve two basic approach patterns. These are Dual Approaches, where the arrival runways (and usually departure runways) have non-parallel headings, and Parallel Approaches, where arrivals (and usually departures) use parallel runways. In general, Parallel Approaches are mandatory when operating conditions are below 800-foot ceiling and 2 miles visibility. They may also be made when wind velocity and direction dictate.

Based upon examination of runway utilization patterns it is clear that Configuration 1 is the predominant runway configuration in the East Arrivals mode and the most popular configuration in general. For the West Arrivals mode there is no similarly predominant configuration. However, Configuration 6 would appear to be the most popular. Under reduced visibility conditions the tendency is for operation in Configuration 6 and in Configuration 7 under Category II conditions.

In general, departures to or arrivals from the north and east of O'Hare are operated on the northside runways; those from the west, south, or southwest are operated on the southside runways. Occasionally, when operations in either the northside or southside are heavy due to short term concentrations of traffic to particular directions, some of the traffic for the more heavily loaded runways may be shifted to the other runways to even out the load.

Traffic taxi flow patterns are essentially fixed by the runway configurations in use. In each configuration the traffic flows on the Inner and Outer circular taxiways are in opposing directions. The directions in each configuration are essentially constrained by the unidirectional traffic flow over the Bridge from or onto the Outer. In general, the Outer is used for departures and the Inner for arrivals. However, the constraints of the direction of flow for the Inner and Outer may require mixing of traffic on either taxiway. While the taxi routes between the

Table 7-1. Primary Runway Configurations Identified by ATCT

Configuration Number	Airport Operating Mode (Arrivals From _____)	Primary Runways (Arrival/Departure)		Supplemental Runways		Runway Operations (Approach) Mode	Applicable Conditions [Ceiling (ft)/Visibility (mi)] and/or Winds (kts)
		South	North	GA Dept.	VFR Arr.		
1	East	32L/27L	27R/32R	36	22R Hold Short 27R	Dual	>800/2 and <15 knots
2	East	32L/27L	32R/32R	36		Parallel	<800/2 and/or >15 knots from NW
3	East	27L/32L	27R/32R		22R Hold Short 27R	Parallel	<800/2 and/or >15 knots from W
4	East	27L/22L	22R/27R		14L Hold Short 22R	Dual	>800/2 and <15 knots
5	West	9R/9R or 14R	14L/9L		22R Hold Short 14L	Dual	>800/2 and <15 knots
6	West	14R/9R	14L/9L			Parallel	<800/2 (but above Cat. II) and/or >15 knots from SW
7	West	14R/14R	14L/14L			Parallel	Category II
8	West	9R/4R	9L/4L			Parallel	>800/2 (clear) and >>15 knots from E
9	West	14R/9R	14L/4L			Parallel	<800/2 and >15 knots from SW (if 9L not available)
10	West	4R/9R	4L/9L				<800/2 and >>15 knots from NE
11	Mixed	14R/27L	22R/9L or 14L		14L Hold Short 22R	Dual	>800/2 and <15 knots

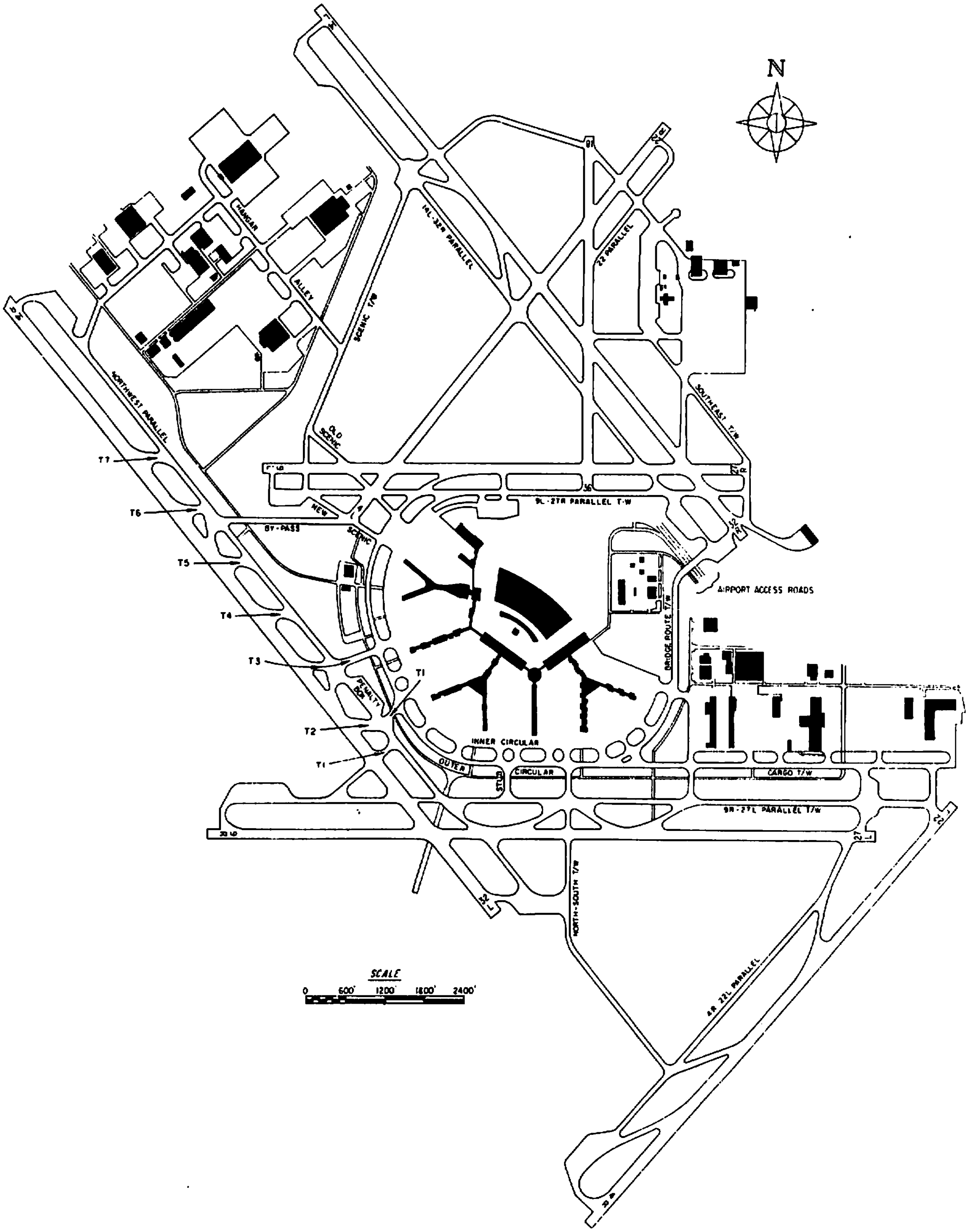

Figure 7-1. Current O'Hare Layout

terminals and runways are basically standard for the various runway configurations, alternate routings are applied by the Ground Controllers under certain conditions. These include congestion on the basic taxi route, establishment of separate departure queues when flights in a particular direction have in-trail separation restrictions, and routing of arrival aircraft to areas where they can hold for gates when they are not available for occupancy.

The terminal configuration in which these gates are located is a series of alternating Y and single corridor | concourses. The current terminal capacity appears to be limited to approximately 100 aircraft "docking" spaces, including both nose-in and off-gate parking. However, the number of gates available for occupancy at any time is influenced by the types of aircraft equipment in use. Each of the major carriers and carriers with significant operations volumes at O'Hare have plans for utilization of their gates which are based in part on the space required by the types of aircraft scheduled. Typically, when the number of operations of large-bodied aircraft increases in a given period the number of gates available for all operations is effectively reduced.

7.2.3 Future O'Hare ASTC System

Several assumptions were made in defining the most probable future operating environment for O'Hare. The resulting projected environment includes the construction of the runway, taxiways, and terminal facilities illustrated in Figure 7-2. Also indicated in the figure is the projected use of the current Outer as the new Inner Circular and the combination of the 9R/27L parallel, 14R/32L parallel and new taxiway segment as the new Outer Circular.

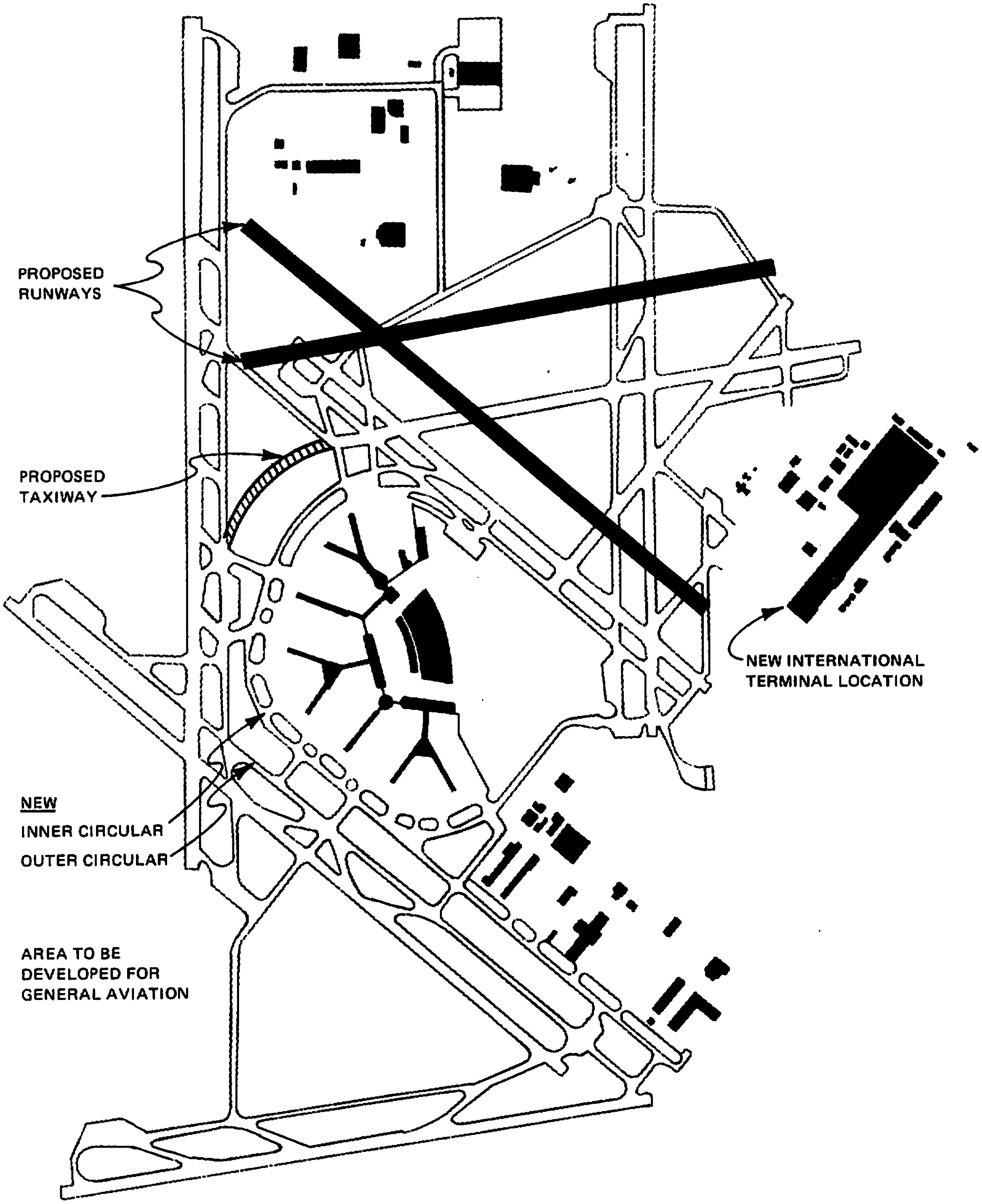

Figure 7-2. Projected Future Operating Environment at O'Hare

7.3 CONCLUSIONS

7.3.1 Capacity and Delay

7.3.1.1 Ramp Area Capacity and Delay

1. It appears that the gate structure at O'Hare will and does support a traffic flow of 1.6 operations/hour/gate. This is consistent with a 60 percent gate utilization (i.e., 60 percent of the gates occupied at any one instant) and a mean turn-around time of 45 minutes. This translates to 150 operations/hour overall when considering O'Hare's 94 gates and is just in excess of their current quota.

2. Approximately 90 percent of all arrivals encounter no delay inside the ramps. The remaining 10 percent experience holds with an average duration of about 1.5 minutes primarily due to the gate not being ready, other pushbacks or service vehicle movement in the ramp area.

3. Approximately 10 percent of the departures experience holds with an average duration of a minute. In most instances the holds can be attributed to near simultaneous departures or waits for arrivals to dock.

7.3.1.2 Ground Control Area Delay

1. Penalty box delay time does tend to increase with operations/hour. At 150 operations/hour the mean delay is estimated at about 18 seconds per operation. This appears to be very low compared with runway queue delays (see paragraph 7.3.1.3); however, at this operations rate the delay is concentrated in about 10 arrivals. This amounts to an average hold time of over four minutes per arrival held.

2. Non-penalty box delay time tends to increase with operations/hour. Delays in the West Arrival mode are much higher (a mean delay of a minute at 140 operations/hour) due to runway crossing delays in that mode. Excluding runway crossing delays, the average delay per operation in either mode is about 20 seconds per aircraft. This is similar to the penalty box delay but remains distributed over a much larger number of aircraft. In addition, of the 20 seconds delay in the taxiways as much delay is associated with ramp congestion (again gate related problems) as competing taxiway traffic. On this basis, it does not appear that the basic taxiways are operating near saturation with the current quota (135 operations/hour).

3. Very few arrival aircraft experience entrance waits before taxiing after runway turnoff. Thus, although during peak hours Ground channels can reach saturation (see paragraph 7. 3. 1. 4), its impact in delay is not currently showing up as substantial. Pilot interviews indicate they tend to taxi while waiting for clearance from Ground. This may be why so few waits were detected.

4. Excessive runway crossing hold times (about a minute/aircraft) in the West mode in the 130 to 140 operations/hour region can be attributed to runway saturation with long departure queues on the outside of the arrival runway and the lack of controller incentive to hasten to cross the departures into a queue. In addition, creating two departure queues on the inside of the arrival runway can facilitate moving aircraft into the departure queue in an advantageous sequence.

7. 3. 1. 3 Local Control Area Capacity and Delay

1. In good visibility conditions runway capacity estimates support a quota of 135 operations/hour evenly split between arrivals and departures, evenly split between the North and South sides and with a 20 percent mix of heavy aircraft. However, unbalanced operations (between North and South sides) such as those run in the West Arrival Mode cases herein put a severe load on the South side controller even with the 135 operations/hour quota. Since this tendency is natural at O'Hare as it is located in the North Central part of the country, even a quota of 135 operations/hour is ambitious. In addition, an increase in heavy traffic should bring a corresponding reduction in the quota.

2. The estimate for capacity improvements which could be achieved in good visibility conditions by assisting the controller in getting departures out in tight inter-arrival spaces is just over 10 percent. This amounts to about five percent of the total operations and would lead to a quota of about 140 operations/hour. All of the improvement lies in the Near-Far, Far-Far and single runway configurations, an average improvement of over 25 percent. This would be very important at other airports with less favorable runway configurations than O'Hare.

3. Although the potential for increasing departure capacity in the current system is significant (i. e., 10 percent at O'Hare and up to 25 percent at other airports), this potential will increase greatly with the deployment of Metering and Spacing. Metering

and Spacing will be designed to create tight inter-arrival spacings to increase the arrival rate. These are precisely the spacings in which the unassisted Local Controller has trouble getting off departures.

4. Since current operations rates can often exceed the current runway capacity in good visibility conditions (i. e., mean capacity over all configurations is 132 operations/hour, the quota is 135 operations/hour), it would be expected that the delays would exceed the standard 4-minute delay criteria for acceptable (unsaturated) service. The average departure delay is 6.2 minutes in the East Arrival Mode and 7.0 minutes in the West Arrival Mode.

5. When operating a single runway mixed mode in bad cab visibility conditions, a substantial reduction in capacity is experienced (i. e., 25 percent in total operations). Thus, in Category II at O'Hare with the two 14s operating an independent mixed operation, the capacity would be 86 operations/hour. The use of ASDE provides substantial improvement. With ASDE the two 14s have a capacity of 108 operations/hour. This is still well below quota and can result in delays. If it currently tends to remain manageable at O'Hare it is because demand tends to become reduced under Category II conditions; several of the air carriers at O'Hare have not yet equipped their aircraft for these conditions.

6. Most bad cab visibility operations are taken in the West Arrival Mode. For the two cases examined herein the delay/departure averaged 11.6 minutes reflecting the lost capacity under poor cab visibility.

7.3.1.4 Controller Communications Channel Capacity

1. Due to traffic fluctuations during an hour, if a 60 percent mean hourly communications loading limit is used to estimate channel capacity, it can be expected with about a 95 percent confidence factor that the channel will reach saturation (i. e., 100 percent loading) for at least five minutes in the hour. This 60 percent is used as the criteria for capacity estimation in this section.

2. The estimated channel capacity for Clearance Delivery is 66 departures/hour. On an even mix of arrivals to departures this is consistent with the runway capacity and the current quota. Clearance Delivery is just at saturation with little room for growth.

3. The estimated channel capacity for Ground Control is dependent upon visibility conditions and ASDE usage. For the bad visibility cases examined in this section, ASDE was in use. In good visibility conditions two channels (two Ground Controllers) can easily support a smooth operation. However, with the current quota (135 operations/hour), when traffic problems occur (which is not infrequently) due to weather, gate tie ups, or aircraft equipment problems in the taxiways, the Ground Control channel(s) can be expected to saturate. On this basis Ground Control is approaching saturation in good visibility conditions with little room for growth.

   In "bad visibility" conditions for Ground Control (i. e., the controllers cannot see the airport surface) the weather conditions are severe, and the airport is usually operating the two 14s for arrivals. In this mode with a smooth operation, two Ground channels (with the controllers using ASDE) can just support the single independent mixed operations capacity of the two runways (i. e., about 105 operations/hour). However, this is below the current quota and if operated for prolonged periods will cause traffic tie ups. In this situation Ground Control channels are in serious difficulties. On this basis Ground Control is currently operating in a saturated fashion in bad visibility conditions.

4. The major reason for increased Ground Control channel loading in "bad visibility" is the controller's use of pilot position reports, even with ASDE in use. This category of communication goes from one percent to two percent of all communications in good visibility to 30 percent when the Ground Controller cannot see (i. e., approaching or in Category II condition).

5. The estimated channel capacity for Local Control is dependent upon visibility conditions. In good visibility conditions the Local channels are well below saturation. The estimated capacity is 195 operations/hour. In "bad visibility" conditions (i. e., the controller cannot see the runways) a controller who delivers his messages in short terse commands will not saturate the channel. However, in two cases of the analysis, message rates were observed which would have led to channel saturation had the operations rate been as high as 115 operations/hour. This would have handled just the two 14s as single independent mixed operations. For any operations rates in excess of that, short terse commands would be a requirement.

6. The major causes for increased Local Control channel loading in "bad visibility" are weather reports (RVR and visibility) and position reports (e.g., lights in sight by the pilot). In the case of single runway mixed operations, position reports of arrivals committed to turn off are important and have a substantial impact on channel loading.

7.3.1.5 Delay Summary and Airport Loading with Good Cab Visibility

1. The delay/turnaround (i.e., arrival and departure) is summarized in Table 7-2 as drawn from the preceding paragraph. It indicates that the vast majority of delay at O'Hare is due to runway limitations (75 per cent). Of the remaining surface delays only 15 percent (4 percent of all delay) is due to taxiway congestion. The remainder is either runway or ramp/gate related.

2. To illustrate the total airport load at any time, Table 7-3 has been prepared. Each entry represents the average hourly occupancy of the cited areas based upon the flow values (operations/hour) and service times previously determined. The value of 4.6 for the ramp areas, for example, is based upon 120 operations/hour and a mean service time of 137 seconds and is for the total ramp area, i.e., sum of the eight ramp areas. The values shown for the Local Control area represent the airspace near the runway and include an allowance of 15 seconds after takeoff and 120 seconds prior to touchdown since aircraft are under surveillance and control as part of the runway control process.

   The last entry in this table provides an estimate of the total surface load and represents an addition of the individual load values. Interpretation of a total value of 21, for example, would lead to the conclusion that, at any one instant of time, on the average 20 active aircraft, excluding those in departure queues, would be observed. Short term peak values of perhaps 26-29 would be expected for this case. The peaking effect is expected to be more important in the ramp and Ground Control areas where random entries take place; in the Local Control area, only a minimum amount of short term peaking is expected.

   It should be noted that two components of delay which have not been included in an analysis are those occurring at the gates prior to departure as well as the arrival delays instituted by Approach Control or the Center due to airport congestion.

Table 7-2. Average Delay Summary in Good Visibility Conditions

Area and Cause of Delay	Average Delay Turnaround* (seconds)	Average Delay Percent Total
Ramp Area Due to Ramp Congestion	15	3
Penalty Box Due to Gate Unavailability	36	7
Taxiways Due to Ramp Congestion	20	4
Taxiways Due to Competing Traffic	20	4
Runway Crossing	40	7
Runway Departure Queue	396	75
TOTAL	528	100

*Arrival and a Departure

Table 7-3. Summary of Aircraft Load (Density)

	Airport Operations Mode		
	Arrivals from East		Arrivals from West
Ramp Areas		4.6	
Ground Control Area	6.6-10.6 (7.1-11.7)[1]		7.6-15.4 (8.2-16.6)[1]
Local Control Area (130 Ops/Hr)			
Arrivals $Q_a = \frac{65 \times 120}{3600}$		2.2[2]	
Departures $Q_d = \frac{65 \times 120}{3600}$		2.2[3]	
Total (Estimated Range)[1]	16 - 21		17 - 26

NOTES

1. Includes aircraft taxiing between ramp and cargo/hangar areas which comprise approximately 15 percent of the traffic handled by the Inbound Ground Position.
2. Arrival Service Time of 120 seconds composed of 50 seconds R/W Occupancy plus 10 seconds turnoff plus approach time of 60 seconds.
3. Departure Service Time of 120 seconds composed of 25 seconds while aircraft is at top of departure queue, 30 seconds taxi time, 50 seconds R/W Occupancy time, and 15 seconds for handoff.

7. 3. 2 System Effectiveness Assessment

7. 3. 2. 1 Current System

1. The mean delay for the good visibility periods examined was 4. 5 minutes/operation. This is representative of an airport near or at capacity. The 4. 5 minutes represented about 40 percent of the total time the aircraft was on the airport surface being serviced by the ASTC system.

2. While on the surface of the airport, the aircraft tend to expend fuel at the average rate of 8. 6 gallons/minute. On a yearly basis that amounts to about 60 million gallons or enough gasoline to support all the cars, buses and trucks in nearby Peoria (population 126, 000). The gasoline consumed by the 40 percent delays alone could satisfy nearly 10 percent of the needs of the District of Columbia or the State of Vermont.

3. While on the surface of the airport, the aircraft (and associated crew) tend to cost the airlines (and indirectly the riding public) $11. 23/minute. On a yearly basis that amounts to about 78 million dollars. The operating costs due to the delays alone amount to nearly 30 million dollars.

4. On the average, one minute of aircraft delay amounts to almost one man hour of passenger delay. On a yearly basis, this amounts to 220 man years of passenger time spent holding on the surface of the airport.

7. 3. 2. 2 Future Airport Configuration

1. The new runways (9L/27R and 4L/22R) can streamline the taxiway operation and give longer potential rollout safety to aircraft but if operated in lieu of the current runways will not increase airport capacity.

2. The new international terminal will increase the gate capacity and probably reduce gate delays (assuming no increase in operations). The benefits would be at the expense of increased taxi times, runway crossing holds and controller workload to perform runway crossings. The extent of these increases was not estimated.

3. The new general aviation facility will have costs and benefits similar to those of the new international terminal.

4. The new proposed use of the current outer as a new inner and the current 27L/9R, 14R/32L parallel taxiways as part of a new outer should nearly eliminate the need to use the current inner taxiway. This would facilitate dealing with ramp congestion, gate limitations, one-way flow between fingers and pushbacks from the finger ends. However, conflicts between arrivals and traffic on the parallels and conflicts caused by aircraft taxiing on a parallel accidentally missing the turn at the parallel to an active runway and blundering out onto the runway will both be emphasized by the proposed change. Consideration should be given to this, expecially at night and/or in bad weather.

7.3.3 General Observations

1. The Inbound Ground position is the busiest position in the tower and yet he has the least information with which to work regarding the number or nature of the aircraft he will be required to handle over the next few minutes. In addition, this position is likely to experience communications workload (and channel) saturation well before the Outbound Ground and Local Control positions.

2. The movements of aircraft within the ramp areas, particularly the area between the Y and linear concourses, have a definite impact on the operations of the Outbound Ground and Inbound Ground. Delays to aircraft movements because of pushbacks and competition for taxi between outbound and incoming aircraft cause additional workload for these positions in having to monitor these movements and adjust the traffic flow. As traffic increases the significance of this problem will also increase.

3. Peaking of flight operations around specific hours of the day is characteristic of O'Hare's operation; that is, it is predominantly a through airport with the airlines planning based on maximum interconnection of flights. This is the primary cause in gate delays for arriving aircraft during good operating conditions and impacts most heavily on the operations of the Inbound Ground position. Increases in traffic volumes and operations under poor weather conditions in which flight schedules are generally disrupted will only aggravate the problem.

4. Under low visibility conditions there is a potential for traffic flowing on the combination of the 9R/27L and 14R/32L parallel to miss the transition between the parallels and wander out to the active runways even in the current operating environment. Discussions with airport management and ATCT personnel indicated that such events have occurred in the past. If the traffic flowing along these parallels increased in the future by their use as part of a new Outer, the potential for such occurrences would increase.

5. The analysis indicates a general tendency for a proportionately higher number of holds: (a) in the area of the intersections of the New Scenic and Old Scenic with the Outer and the Old Scenic and Inner in the West Arrivals mode; (b) at the intersection of the Outer and T-3 in both operating modes; (c) on the Inner and Outer opposite the ramp areas between the F and G concourses and the G and H concourses; (d) at the intersection of the stub and North-South taxiways with the Outer. Instances (a) and (b) above appear to be related to the merging of traffic flows in these areas while instances (c) and (d) appear to be related to ramp congestion/gate delays.

7.3.4 Summary

O'Hare is currently operating at or near capacity in the area of gates, runways, Local Control, Ground Control and Clearance Delivery. Delays in the taxiways which do not result from ramp or runway related problems are relatively minor. Planned airport layout changes can streamline the taxi flows reducing the impact of ramp delays and departure queues and can furnish added gate capacity. However, overall capacity due to runway/Local Control limitations will not increase. If anything, due to North side/South side traffic imbalance and the increase of heavy aircraft traffic, overall capacity will drop. Only new ATC equipments and/or procedures can increase the overall capacity of the airport.

While operating at or near capacity, very large costs are being expended--costs in fuel, money (airlines and riding public), and lost time to the passengers. Increased capacity will provide the option of increasing the traffic volume to satisfy projected demand with those same costs or serving the same traffic volume with potential cost savings. If new ATC equipments and/or procedures can increase the capacity, it appears that there is a substantial potential in cost saving to aim at.

7.4 RECOMMENDATIONS

The significant recommendations that can be made on the basis of the study findings are primarily related to the objectives and features that should be provided in an improved future ASTC system for O'Hare. These include:

1. Automated intersection control equipments could be very usefully applied to the taxiway intersections in the areas northwest of the terminal (opposite the ramp area between Butler and the International concourse) and at the Outer/T-3 intersection.

2. Any future ASTC system should emphasize relief of the Clearance Delivery and Inbound Ground positions through more automated transmission of flight plan and taxi clearances and by providing more information regarding imminent arrivals to Inbound Ground. More automated transmission of taxi clearance would also significantly relieve the workload of the Outbound Ground position.

3. Any future ASTC should provide for improved coordination of airline gate operations and the operations of the Ground Control positions to reduce ramp area delays as well as controller workload resulting from ramp congestion.

4. Future ASTC systems should attempt to provide improved information to Local Control positions for use in sequencing runway operations.

With respect to near term improvements in the current ASTC system a few recommendations may be made:

1. As traffic volume increases, relief of the Clearance Delivery workload and frequency saturation can be accomplished by a dual-postion operation in peak traffic periods; that is, one controller (pre-taxi) would be responsible exclusively for delivery of flight plan clearances to air carrier traffic and the second controller (taxi) would be responsible for aircraft that are ready to taxi, including IFR and VFR flight plan clearances to genral aviation traffic.

2. Consideration should be given to the feasibility of the ARTS computer generating minimal flight strips for (or at the minimum a sequenced list of) aircraft estimated to be landing on the active arrival runways in the next 5-minute period to increase the information available to Inbound Ground for control of these aircraft.

3. Red (center-line light type) stop bars or warning signs should be installed at the intersections of the 9R/27L and 14R/32L parallels to prevent aircraft from erroneously taxiing out onto the active runways during low visibility conditions. Installation on the 9R/27L parallel should be east of the intersection and on the 14R/32L parallel south of the intersection. While this installation would be desirable for the current environment it would be mandatory in the future if these parallels became part of a new Outer Circular.

4. The airlines should attempt to develop some procedure that would keep the gate controller advised of whether aircraft departures from the gates will be significantly delayed. This information would be used in advising pilots of arriving flights of the situation in order that they may be able to communicate this information to Inbound Ground. This improvement would be most important during the peak traffic schedule periods.

SECTION 8 - REFERENCES

1. Chicago O'Hare Airport Air Traffic Control Tower Training Manual.

2. Chicago - O'Hare International Airport, Airport Operations Manual Volume I - Operations Manual, November 1972.

3. Chicago - O'Hare International Airport, Airport Operations Manual Volume II - Emergency Plan, November 1972.

4. Federal Aviation Administration, National Aviation Facilities Experimental Center, Catalog of ATC Communications and Controller Activity Data, September 1971.

5. Federal Aviation Administration, Systems Research and Development Service, Climatological Summaries, Visibilities Below 1/2 Mile and Ceilings Below 200 Feet. Volume 8, Chicago, Illinois O'Hare International Airport, SRDS Report No. RD-69-22 Vol. 8, June 1969.

6. Northern Research and Engineering Corporation, The Potential Impact of Emissions Upon Air Quality, Report No. 1167-1, December 1971.

7. Aviation Daily, Airline Statistical Annual, 1973.

8. Federal Aviation Administration, Systems Research and Development Service, Airport Surface Traffic Control Systems Deployment Analysis, Report No. FAA-RD-74-6, January 1974.