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EXAMINATION OF AIR TRAFFIC FLOW AT A MAJOR AIRPORT

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ABSTRACT

A GPSS model is developed for simulating air traffic flow at a major metropolitan airport. It simulates scheduled and non-scheduled flights; and incorporates Official Airline Guide flight schedules, Department of Transportation delay statistics, and additional data obtained from all airlines operating out of Detroit Metropolitan Wayne County Airport. Simulation outputs include: capacity and delay statistics which can be tabulated by runway, gate, and air carrier. This model can be used to study the effect of weather conditions, scheduling patterns, and runway utilization modes on airport congestion and flight delays.

1. INTRODUCTION

According to recent forecasts made by the Federal Aviation Administration (FAA) for fiscal years 1990-2001 [FAA 1990c], a significant increase in the number of airline passengers is expected in the next decade: 64.4% increase to 743.5 million people by the year 2001 . To meet this ever-increasing demand, airlines are using the hub and spoke system at more than 40 airports, scheduling additional flights during peak hours, and seeing increased commuter airline business. These actions by the airlines coupled with the slow increase of airport capacity have contributed to air traffic congestion at major airports.

The FAA estimates that air traffic congestion together with bad weather account for 93% of the delays in 1989 [Thomassie 1990]. Such delays are expected to escalate unless an expansion in airport capacity, an increase in the efficiency of using existing airport capacity, and modernization of air traffic control facilities are forthcoming. According to Labich [1990], the Department of Transportation (DOT) estimates that delays cost the airlines and US businesses at least $5 billion each year in fuel costs and wasted time.

Finding solutions for the delays caused by airport congestion and bad weather have been the objective of numerous simulation models. Many of these models include the airport's airspace, runways, taxiways, and in some cases gates [Willis 1969; Baxter et al. 1970; Seeman 1970; Sutherland et al. 1971; Joline 1971; Yu et al. 1974; Low 1977; Thormet 1983; and the FAA's SIMMOD 1989]. Low's model treats the airport as an integrated system, where in addition to including the terminal's airspace, runways, taxiways, and gates, the airports landside and ground access are also included. Of these models, the FAA's SIMMOD model, Thormet's AIRMOV model, and Joline's ASM-2 model are distinguished by the inclusion of animated graphics.

In most of these models, aggregate hourly counts are used in simulating arriving and departing flights. This approach, although reflecting the variation among hourly flow rates, implies uniform scheduled operations within each hour. As a result, congestion caused by the way airlines schedule their flights cannot be accurately reflected in the simulation. In addition, most of these studies do not include the segment an aircraft spends at the gate, and when they do, it is not reflected accurately. More specifically:

a. Gate assignment to arriving aircraft is assumed to be based on its proximity to the runway used for landing [Low 1977]. No consideration is given to the gates allocated to each airline, or to the fact that each airline makes its gate assignment when its flight schedule is issued and assigned gate change is made only if assigned gate is not expected to be available for an extended period while another gate is available. As a result, simulated delays due to the unavailability of assigned gates are likely to be under-estimated; and
b. Gate holds, imposed by FAA controllers due to weather problems or saturation at the destination airport, initial fixes, and/or departure airport, are not isolated from other types of delays. Hence, simulated departure delay statistics cannot be related to the cause of the delay.

In this study, a GPSS model is developed to simulate the arrival, departure and turn-around segments of scheduled and non-scheduled flights at a major hub airport for one week. This 7-day period makes it possible to simulate peak operating conditions of different days of the week, and to reflect flights which remain overnight (RON) at the gate. In developing this simulation model, special efforts are made to reflect gate assignments, gate holds, and turn-around segments in ways consistent with those reflected in the gathered data. This model can be used to evaluate the effect of changes in runway configuration and utilization mode, weather patterns, and aircraft operation level on airport congestions and delays. Detailed data of individual flights are included to simulate the scheduled arrivals and departures.

This simulation model is being developed in a multi-phased effort. The purpose of this paper is to discuss the first phase which includes the model's design, with a number of simulation runs, relating to peak and off-peak hours of the day for different days of the week, visual (VFR) and instrument (IFR) approaches, and runway closures. Output of these simulation runs includes various capacity and delay statistics which are tabulated, using a statistical package, according to time, air carriers, runways, and gates. Within each sector, aircraft speed, length of sector, and separation minima are assumed to be constant. Variations in the values of these parameters are incorporated in the next phase of this study.

This model is being developed using GPSS/H, Version 2, by Wolverine Software Corporation. New features in Version 2 added programming flexibility, and ease in debugging the program and in manipulating the output for further analysis. This program, in its present form, includes about 1200 lines of code. It is run on the VAX 8650/VMS Version 5.2. To simulate scheduled flights for one week, the program processed 3198 records, each of which includes 35 fields reflecting attributes of different scheduled flights. Non-scheduled flights (general aviation, military, and others) as well as flights which enter the DTW terminal control area (TCA) without landing (secondary IFR, Overflights IFR, and Overflights TCA) are also included.

In this study, the Detroit Metropolitan Wayne County (DTW) Airport is selected because it is a major hub airport and because of its proximity to the authors. It should be mentioned, however, that this model could be modified for use in relation to other airports. In the following section, a brief description of the configuration of the DTW Airport is given. Next, details of the arrival, departure, and turn-around segments are discussed. A summary of the assumptions and data used is included, followed by analysis of the results of the simulation runs.

2. THE DTW AIRPORT

The DTW Airport has three parallel runways (21R/3L, 21C/3C, and 21L/3R) and one crossing runway (9/27) - see Figure 1. Runway 9/27 is used 3% to 6% of the year during high wind conditions. Normally, the preferred runway for takeoff is the center runway, 21C/3C. However, most heavy and some large aircraft require the use of one of the longer runways (21R/3L and 21L/3R) for takeoff. The preferred runways for landing are 21R/3L and 21L/3R.

At present, there are three terminals: the International, North and South terminals. Concourses A and B are in the South terminal, and C, D, E, F and G are in the North terminal. Ninety two gates are available for aircraft parking in the three terminals. Northwest Airlines is the dominant air carrier in the hub. Over two-thirds of the available gates are currently used by Northwest. The remaining gates are mostly used by ten other carriers. Distribution of arrivals and departures among the air carriers are given in Table 1.

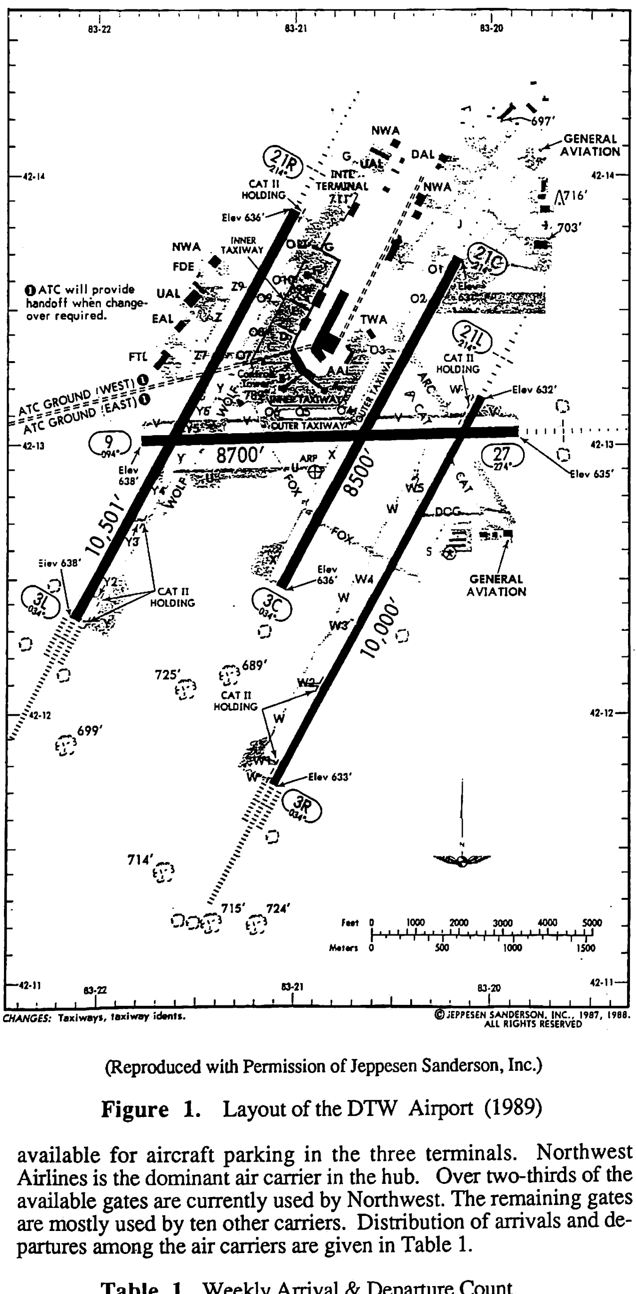

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Figure 1. Layout of the DTW Airport (1989)

Table 1. Weekly Arrival & Departure Count DTW Airport (November 1989)

Airline	No. of Flights	% of Total
Northwest	2,120	66.29
US Air	186	5.82
Delta	155	4.85
American	105	3.28
Southwest	86	2.69
United	85	2.66
Continental	85	2.66
Other	376	11.75
Total	3,198	100.00

Master plans are being developed and some parts are being implemented to expand the capacity of the DTW Airport. These plans include: adding a second East/West runway, a fourth North/South runway, extension of existing runway 21R/3L, adding another terminal, and enhancement of some the taxiway and access roadways [FAA et al. 1988].

3. MODEL DESCRIPTION

As mentioned earlier, this simulation program simulates the arrival, turn-around and departure segments of scheduled and non-scheduled flights at the DTW Airport. Three categories of flights are included: scheduled flights (air carriers and air taxis); non-scheduled flights (general aviation and military); and other flights using the DTW Airport terminal control area without landing (secondary IFR, overflights IFR, and overflights TCA). Data used for simulating all three types of flights are gathered for November, 1989.

3.1 Model Input

In developing the database used in this simulation program, numerous kinds of data are collected. The following is a summary of the data being used.

a. Official Airline Guide's (OAG) data of scheduled arrival and departure flights;
b. Delay statistics of individual flights included in the Airline Service Quality Performance File obtained from the DOT;
c. Hourly arrival and departure counts of scheduled and non-scheduled flights at the DTW Airport (e.g., general aviation, military, and satellite airports);
d. Hourly counts of the flights that entered the DTW Airport TCA, without landing (i.e., secondary IFR, overflight IFR, and overflights TCA);
e. Minimum separations for IFR and VFR;
f. Runway configuration and the mode of operation (i.e., runways designated for takeoff only, runways designated for landing only, and runways designated for both);
g. Gate configuration for each concourse and the specification of the airlines using them;
h. Other data obtained directly from individual air carriers which included: gate assignments, and a departing flight number corresponding to each arriving flight;
i. Estimates of distances and speeds for the arrival and departure segments at the DTW Airport; and
j. Maps of the DTW Airport and airspace, including arrival and departure fixes.

Scheduled flights data are generated using the OAG's data, the DOT's delay statistics, and the airlines' data mentioned above. These flights enter the simulation at a point in time which take into consideration the scheduled arrival time at DTW Airport, expected departure delay at the originating airport, and the minimum time needed to reach the assigned gate from the beginning of the low altitude sector. Non-scheduled and other flights are generated using the hourly arrival and departure counts. These flights progress via the low altitude sector, the approach paths and landing segment, and the taxiing to gate segment. After the turn-around time period, they become departure flights at which point they follow the procedures related to the departure segment.

3.2 The Arrival Segment

The Arrival Segment (Figure 2) begins when the aircraft enters the low altitude sector, which is approximately 100 nautical miles (NM) from the Airport, and ends when it reaches the assigned gate. After entering the low altitude sector, it remains in it until it reaches one of the four arrival fixes (Rhyme, Tripe, Moter and Pinto) which are approximately 50 NM from the DTW Airport. For each of these fixes, an initial approach sector is defined. The length of the initial approach sectors varies from 15 NM to 44 NM, simulating instrument approach (IFR) conditions, and from 11 NM to 30 NM, simulating visual approach (VFR) conditions.

The four initial approach sectors funnel aircraft into two final approach sectors. These two sectors vary in length from 11 NM to 15 NM, depending on the direction from which the aircraft approaches the terminal control area (TCA), and whether IFR or VFR

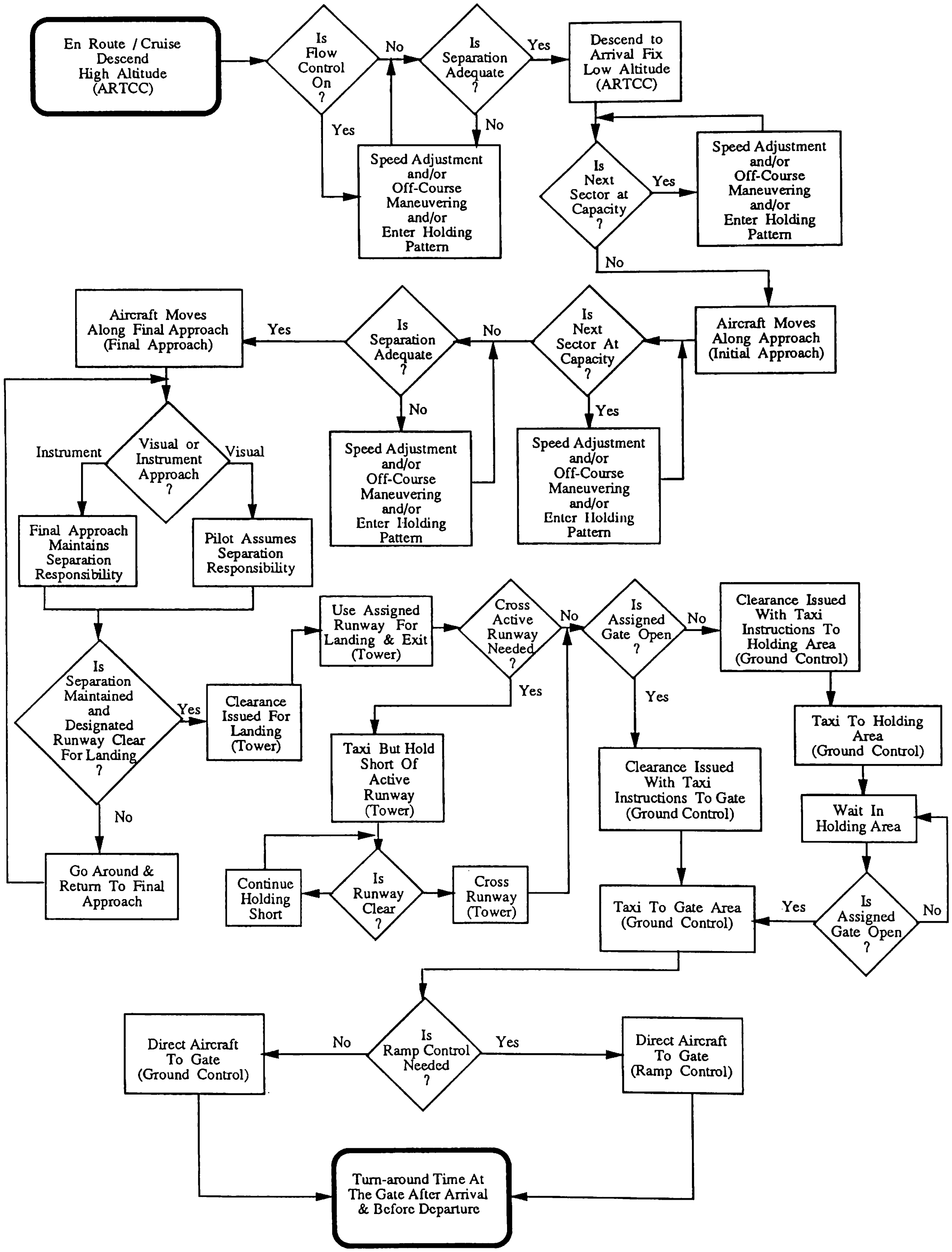

Figure 2. The Arrival Segment

approaches are being used. Final approach ensures that the required separations are maintained before switching the aircraft over to tower. The pilot then receives clearance from tower to land. During the IFR approaches, separation minima and flying distances increase while aircraft speed decreases. As a result, when IFR approach is used, the capacity of this part of the system decreases which translates into congestions and flight delays.

Once the arriving aircraft lands, it exits the runway, taxis to the assigned gate following instructions issued from ground control. In using a common alleyway, an arriving aircraft takes a lower priority than a departing aircraft. Once the aircraft reaches the assigned gate, the Arrival Segment is concluded and the Turn-Around Segment begins.

3.3. The Turn-Around Segment

After the arriving aircraft reaches its designated gate, it remains there for a period of time (turn-around period) after which it leaves to another destination. The length of period the arriving aircraft spends at the gate depends not only on the aircraft type (heavy, large, small) but also on whether it is a through flight (i.e., leaves to another airport with the same flight number) or a terminating flight (i.e., leaves as an originating flight with a different flight number).

During the turn-around period: arriving passengers leave the aircraft and their baggage is unloaded; the cabin is cleaned lightly, if it is a through flight, or fully, if it is a terminating flight; the aircraft is refuelled before departure; and departing passengers board the aircraft and their baggage is loaded. At the end of the Turn-Around Segment, the flight crew start preparing for departure.

3.4. The Departure Segment

The Departure segment (Figure 3) begins when the flight crew arrives at the aircraft to prepare for departure, and ends when the aircraft reaches a departure fix, which is about 50 NM from the Airport. During this segment, the pilot requests and receives several types of clearances: departure clearance, push back from gate clearance, taxiing to assigned runway clearance, and takeoff clearance.

All departure clearances include a Standard Instrument Departure (SID) procedure, route of flight, initial level-off altitude, final expected altitude, departure control frequency and transponder setting. Information regarding gate hold delays is also included in the clearance.

If needed, the flight crew must obtain clearance to push back from ramp control or ground control. The area directly behind the aircraft (common alleyway or taxiway) must be clear before a push-back can take place. If it is not, the departing aircraft must wait at the gate until the aircraft blocking it clears the way. If an arriving and a departing aircraft are in competition for the same alleyway, the departing aircraft is given a higher priority over the arriving aircraft.

After push back is complete, clearance, assigned runway, and taxi instructions are issued by ground control. Ground control maneuvers all aircraft taxiing to the same runway into logical sequence for departure, taking into consideration the direction of the flights. Generally, takeoff priority is on a first-come-first-served basis, but ground control will make modifications on this sequence to accommodate various other operational requirements, such as wake turbulence separation, departure control saturation, and separation of aircraft over the departure fixes.

The sequence for departure is adjusted to spread out aircraft departing in the same direction after takeoff, and/or to accommodate controlled takeoff times. At DTW Airport, all aircraft utilize runway 21C/3C for departure unless they have an operational requirement to use a runway other than the preferred departure runway. Most heavy and some large aircraft must use one of the longer, outer runways, 21L/3R or 21R/3L, because of weight restrictions. Usually, if the pilot requires a runway other than the preferred runway, he must inform ground control prior to requesting taxi clearance.

Tower personnel expect that an aircraft is ready for takeoff when it is number one in the departure queue. Prior to issuing takeoff clearance, tower ensures that the approach course for the departure runway is clear. Tower must also ensure that no other aircraft (landing or taking off) is still on the runway, and that all wake turbulence separation standards are met.

Shortly after takeoff and prior to switching the aircraft over to ARTCC, the aircraft contacts departure control which assumes the responsibility to vector the aircraft to one of the departure fixes, and ensures that the enroute separation requirements are established

3.5. Model Parameters

In what follows, more details concerning the three segments discussed above are given. Major changes are currently taking place in the DTW Airport's traffic pattern..

a. Length, speed, and separation minima for all sectors included in this model are given in Table 2:

Table 2. Length, Speed & Separation Minima For All Sectors At DTW Airport

Arrival & Dep. Sectors	Length (NM)	Speed (Knots)	Separation Minima (NM)
Low Altitude	50	300	(i)
Initial Approach:			
VFR	11-30	250	(i)
IFR	15-44	210	(ii)
Final Approach:			
VFR	11	180	(i)
IFR	15	170	(ii)
Tower:			
VFR	6	140	3
IFR	6	140	5
Departure Control	50	250	(i)

(i) Separation minima under Visual (VFR) Approach:
5 NM If Heavy followed by large or small
4 NM If Heavy followed by heavy
3 NM Others

(ii) Separation minima under Instrument (IFR) Approach:
6 NM If Heavy followed by large or small
5 NM If Heavy followed by heavy, or large followed by small
4 NM Others

b. Runway assignment procedure is assumed to be as follows:
Runway 21R/3L is used for: (a) "landings" for flights arriving from the west side fixes (Pinto and Moter); (b) 90% of heavy "takeoffs"; and 10% of large "takeoffs".
Runway 21C/3C is used only for takeoffs: (a) 100% of small "takeoffs"; (b) 90% of large "takeoffs"; and 10% of heavy "takeoffs".
Runway 21L/3R is used for "landings" for flights arriving from the east side arrival fixes (Rhyme and Tripe).

c. Runway use for landings and takeoffs follows the procedure used in Low's study [1977] with minor modifications of speed and distance. In our study, it is assumed that when an arriving aircraft reaches the final 3 NM of the approach path for the assigned runway, no departures are allowed to take off, and when it reaches the last 1.25 NM it prevents any other arrival from landing. Once this arriving aircraft lands and exits the runway, this runway becomes available for landings but not for takeoffs, unless there are no other arriving aircraft in the final 3 NM of the approach path. In order for an aircraft to take off, there must not be an arriving aircraft within the last 3 NM of the approach path for the assigned runway, and the wake turbulence separation standards must be complied with.

d. Forty-five seconds is assumed to be sufficient, for all categories of aircraft, to clear the runway after landings (or takeoff). This estimate is obtained by observation of aircraft at DTW Airport.

e. Taxiing time between runway and gate is dependent on which runway is used for landing or takeoff and the location of the gate. At the DTW Airport, aircraft contact east ground control (EGC), or west ground control (WGC), or both, according to the following table. The simulated taxiing time for each ground control segment is between 2 and 4 minutes.

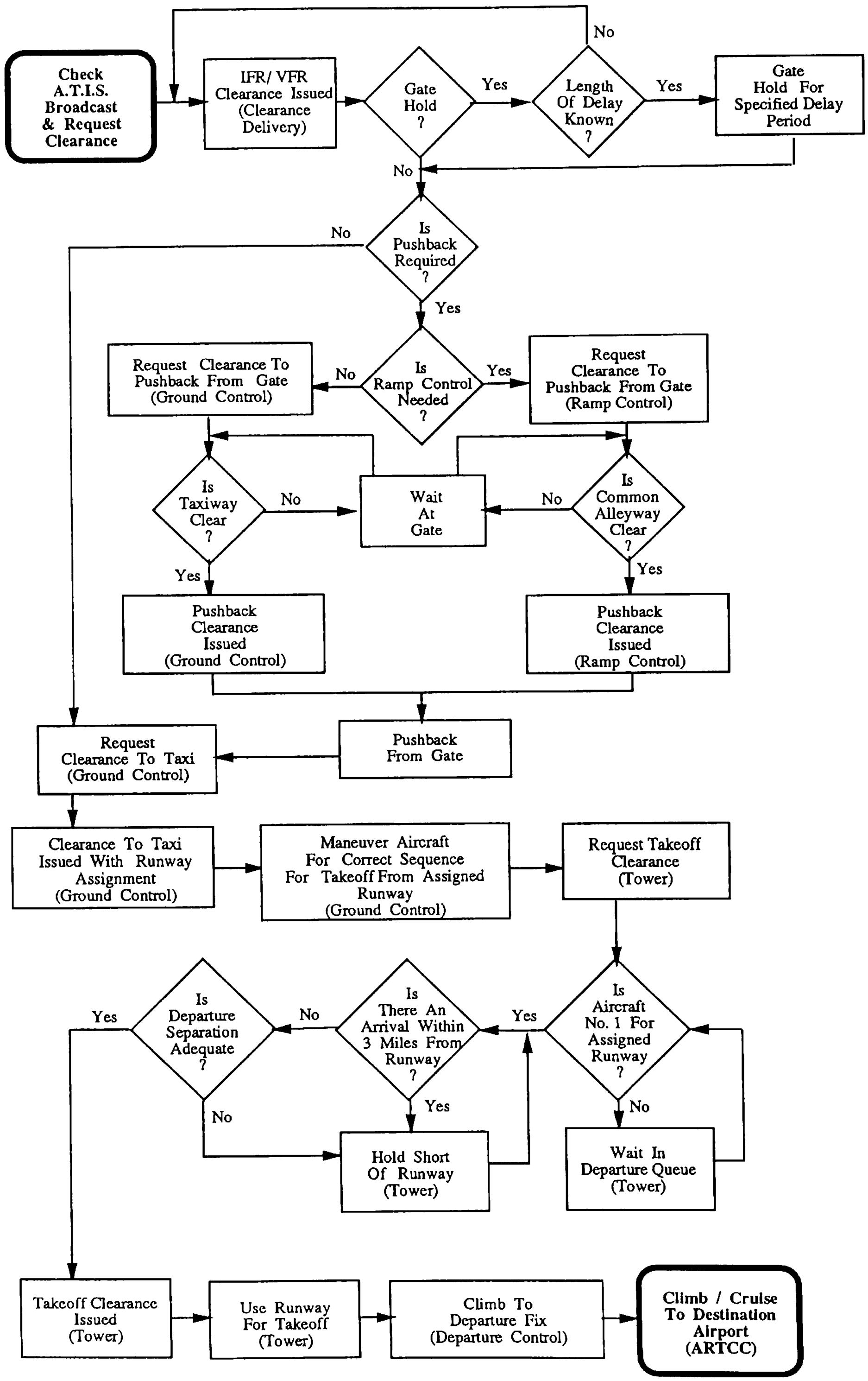

Figure 3. The Departure Segment

Table 3. Ground Control Communication with Pilots by Runway and Gates at DTW Airport

Airlines	Gates At Concourse	Runway 21R/3L		Runway 21C/3C		Runway 21L/3R	
		EGC	WGC	EGC	WGC	EGC	WGC
Northwest Airlines	C North		x	x	x	x	x
	D		x	x	x	x	x
	E		x	x	x	x	x
	F		x	x	x	x	x
	G		x	x	x	x	x
Other Airlines	A	x	x	x		x	
	B	x	x	x		x	
	C South	x	x	x		x	
	Ramp	x	x	x		x	

f. In using a common alleyway, a departing aircraft pushing back from its gate is given a higher priority than an arriving aircraft which is waiting to get to its gate.

g. Minimum turn-around time is assumed to be:
   (i) For through flights:
      55 minutes for heavy,
      35 minutes for large, and
      20 minutes for small.
   (ii) For non-through flights:
      60 minutes for heavy,
      45 minutes for large, and
      30 minutes for small.

h. Gate hold delay (GHD) is computed for DTW departures as follows:
   GHD = max {0 , **or** (Sim. Departure Time - Sched. Departure Time - Sim. Arrival Delay)}

i. It is assumed that an arriving aircraft will wait for its assigned gate, if it is occupied by another aircraft and the expected waiting time does not exceed 15 minutes for a heavy aircraft, and 30 minutes for a large or small aircraft, otherwise, a new gate is assigned.

3.6. Model Output

For each simulation run, the computer output includes the following statistics, for peak and off-peak periods.

a. For each runway : number of flights using it; percent utilization during that period; percent of departure flights which do not have to wait prior to takeoff; average and maximum waiting time before taking off; and average and maximum number of departure flights in the runway queue.

b. For each arrival and departure sector's fix (delay storage): number of flight entering the sector; average time per flight; and maximum content.

c. For each arrival and departure sector: summary and detailed statistics of the time it takes various flights to go through the sector.

d. For each gate: number of flights using the gate; average time per flight; percent utilization during that period; percent which don't have to wait for its assigned gate; average and maximum waiting time for the assigned gate; and gate hold statistics which are analyzed further using a statistical package.

3.7. Model Validation

In the process of the development of the simulation model, considerable effort is made to ensure the validity of the model. During this continuous validation process, many modifications are made in the data base, program and scope of the study. Below is a summary of the four types of validations conducted in developing this study following the validation process discussed in Cheslow's paper [1988].

a. In the development of the model, FAA regulations are examined, discussions with FAA and airport officials have taken place to clarify regulations as well as operational procedures at the DTW Airport. Data used regarding lengths of sectors, speed, and separations under varying weather patterns are checked against data gathered from the field. All these efforts are necessary to ensure that the logic incorporated in the model is an accurate representation of the real system.

b. The most involved and time consuming part of this study is the development of the data base. Although the OAG's monthly schedule is invaluable, it does not include actual arrival and departure times, delay statistics, and airline gate assignments. Additionally, information concerning runway preference, and air traffic sequencing is necessary. These limitations are minimized by: including actual arrival, departure, and delay statistics included in the data obtained from the DOT'; using additional information gathered from the airlines regarding their November 1989 schedule modifications and gate assignments; checking the totals computed using OAG's data with the hourly arrival and departure counts for air carriers and air taxis; and by using data gathered during various flights. Additional information is obtained through conversations with various airport and FAA officials.

c. In validating the computer simulation model, the new debugging capabilities of GPSS/H are used to check for logical errors at various stages of model development.

d. The final phase of validating the model is verifying the results obtained from the simulation runs. This is accomplished by comparing simulated results with actual data which include: hourly arrival and departure counts, actual flying time data for each sector, and delay statistics compiled by the DOT.

4. ANALYSIS OF SIMULATION RESULTS

Several simulation runs are conducted to evaluate the effect of operation level (i.e., number of hourly arrivals and departures), visibility, and runway closures on airport congestions and flight delays.

The purpose of the first set of simulation runs is to measure the effect of the airport's operation level on congestions and delays. Preliminary examination of the results of the simulation runs indicate that congestions and delays are more of a problem on week days than on weekends, and that there is no significant difference among different week days. Further analysis of some of the takeoff queue statistics of runways 21R/3L and 21C/3C (see Table 4), suggests the following:

a. For runway 21R/3L, the percent of departing flights which have to wait before takeoff and their average and maximum waiting time before takeoff are higher during peak periods than off-peak periods. This situation can be explained by the facts that this runway is used for both landings and takeoffs and that landings take higher priority over takeoffs; and

b. For runway 21C/3C, the situation is different. In fact, some of these statistics are lower during some peak periods than some off-peak periods. The reason for that is that, during peak periods, the "No Landing" rule is rigorously adhered to for this runway.

As for arriving flights, average delays in all arrival sectors are noticeably higher during peak periods than off-peak periods (see Table 5). In addition to time of day, the average delays for arriving flights vary by direction from which an aircraft approaches the Airport. For instance, the average delays in the arrival sectors, for flights arriving from the eastern sectors (Rhyme and Tripe) are relatively higher, during peak periods, than for flights arriving from the two west sectors. On the other hand, flights arriving from the west sectors experience more delays in the arrival sectors during off-peak periods than those arriving from the east sectors. This is a subject which requires further analysis.

Table 4. Takeoff Queue Statistics By Time Of Day & Runway Using Visual (VFR) Approach *

QUEUE STATISTICS	PERIOD						
	0:00 - 7:00	**7:00 - 9:00**	9:00 - 11:30	**11:30 - 13:00**	13:00 - 16:00	**16:00 - 20:00**	20:00 - 24:00
21R / 3L RUNWAY:							
Maximum Content (Aircraft)	1	**3**	2	**2**	4	**3**	1
Average Content (Aircraft)	0.00	**0.46**	0.10	**0.50**	0.17	**0.32**	0.14
% Waited Before Takeoff	0.0%	**50.0%**	44.4%	**83.3%**	58.3%	**66.7%**	38.5%
Av. Wait. Time / Who Waited (min.)	0.0	**7.8**	3.9	**9.0**	4.4	**6.4**	6.8
Max. Wait. Time / Who Waited (min.	0.0	**17.0**	4.0	**29.0**	8.0	**22.0**	28.0
21C / 3C RUNWAY:							
Maximum Content (Aircraft)	1	**2**	4	**3**	2	**3**	2
Average Content (Aircraft)	0.00	**0.10**	0.25	**0.13**	0.08	**0.18**	0.05
% Waited Before Takeoff	0.0%	**66.7%**	51.7%	**60.5%**	69.0%	**55.9%**	75.3%
Av. Wait. Time / Who Waited (min.)	0.0	**0.6**	0.9	**0.7**	0.5	**0.7**	0.5
Max. Wait. Time / Who Waited (min.	0.0	**2.0**	3.0	**2.0**	2.0	**3.0**	2.0

*** Note: Bold characters signify peak periods**

Table 5. Average Delay By Time Of Day & Arrival Sector Using Visual (VFR) Approach (in Minutes) *

	PERIOD						
ARRIVAL SECTORS	0:00 - 7:00	**7:00 - 9:00**	9:00 - 11:30	**11:30 - 13:00**	13:00 - 16:00	**16:00 - 20:00**	20:00 - 24:00
INITIAL APPROACH							
E1 (Rhyme)	0.00	**0.88**	0.07	**0.31**	0.02	**0.52**	0.02
E2 (Tripe)	0.03	**0.07**	0.06	**0.06**	0.06	**0.23**	0.00
W1 (Pinto)	0.00	**0.12**	0.29	**0.01**	0.40	**0.06**	0.53
W2 (Moter)	0.01	**0.12**	0.51	**0.28**	0.49	**0.10**	0.90
FINAL APPROACH							
East	0.03	**1.37**	0.06	**1.34**	0.13	**0.98**	0.02
West	0.02	**0.97**	1.40	**0.84**	1.13	**0.29**	1.51
TOWER							
East	0.03	**0.57**	0.13	**0.68**	0.19	**0.58**	0.04
West	0.02	**0.59**	0.66	**0.58**	0.54	**0.29**	0.65
TOTAL							
E1 (Rhyme)	0.06	**2.82**	0.26	**2.33**	0.34	**2.08**	0.07
E2 (Tripe)	0.09	**2.01**	0.25	**2.08**	0.37	**1.78**	0.06
W1 (Pinto)	0.04	**1.68**	2.36	**1.43**	2.06	**0.64**	2.69
W2 (Moter)	0.05	**1.68**	2.57	**1.70**	2.16	**0.68**	3.06

*** Note: Bold characters signify peak periods**

The next set of simulation runs are performed to examine the effect of reduced visibility on time spent in the arrival sectors. Service times and average delays, for each and all of the arrival sectors, are compared under simulated visual (VFR) and instrument (IFR) approaches during one of the peak periods (16:00 - 20:00). As might be expected, service times and average delays are longer during IFR approaches than VFR (see Table 6). This increase is a direct result of increased separation minima between aircraft and reduced speed which are enforced when poor visibility exists.

The third set of simulation runs are conducted to examine the effect of closing runway 21L/3R, for two hours in the morning and three hours in the evening on arrival and departure delays. As seen in Table 7, when runway 21L/3R is closed, delays in the arrival sectors are increased. In addition, values of the average and maximum departure queue length, and the average and maximum waiting time before takeoff are increased.

Table 6. Effect Of Weather Patterns On Time Spent In Arrival Sectors (in Minutes)

Arrival Sector	Av. Service Time		Av. Arrival Delay		Tot. Av. Time in Sector	
	VFR	IFR	VFR	IFR	VFR	IFR
Initial Approach						
E1 (Rhyme)	2.63	4.21	0.52	0.92	3.15	5.13
E2 (Tripe)	5.35	13.53	0.23	1.69	5.58	15.22
W1 (Pinto)	5.37	10.62	0.06	3.37	5.43	13.99
W2 (Moter)	7.03	12.07	0.10	3.27	7.14	15.34
Final Approach						
East	4.42	5.22	0.98	2.66	5.40	7.88
West	4.54	5.16	0.29	4.11	4.83	9.26
Tower						
East	1.28	1.28	0.58	1.26	1.86	2.54
West	1.26	1.27	0.29	1.61	1.56	2.88
Total						
E1 (Rhyme)	8.33	10.71	2.08	4.84	10.41	15.55
E2 (Tripe)	11.05	20.02	1.78	5.61	12.83	25.63
W1 (Pinto)	11.17	17.05	0.64	9.08	11.81	26.13
W2 (Moter)	12.83	18.50	0.69	8.98	13.52	27.49

Table 7. Effect of Runway Closure On Delay Statistics (in Minutes)

Runway 21L/3R Status	Delays in Arrival Sectors				Takeoff Queue for Runway			
					Queue Length		Waiting Time	
	E1	E2	W1	W2	Avg	Max	Avg	Max
Open	0.34	0.37	2.06	2.16	0.17	4	4.36	8
Closed	4.34	3.97	4.18	4.17	0.36	5	6.56	15

Finally, delay statistics related to gate unavailability and gate holds are stored in a file for further analysis. The objective of this analysis is to try to identify some of the main factors which contribute to these types of delay. These factors may include: originating airports, weather patterns, and airlines scheduling.

As is usually the case, the study raises as many questions as it answers. With some modifications of the model, a number of areas of possible examination in the next phase of this study are:

a. Evaluating alternative runway utilization modes for minimum delays.
b. Stochastic changes in variables such as aircraft speed and routes.
c. Flight cancellations.
d. Including other airports in the model.

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