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THE CITY UNIVERSITY

Department of Aeronautics

TERMINAL AREA UTILISATION AT MAJOR AIRPORTS

Thesis submitted for the Degree of Doctor of Philosophy to The City University, St. John Street, London.

Based on research work performed with the City University in association with British Airways, European Division.

By: Muir A. Parker, B.Sc.,
British Airways, European Division.

1974.

A B S T R A C T

Terminal Area Utilisation at Major Airports

The central purpose of this thesis is to provide a means of planning the use of aircraft parking positions (stands) at major airports, to the mutual benefit of airlines and airport authorities.

The methods used to relate capacity and demand in any context, depend to a large extent on the time scale being studied and the detail in which the relationship must be defined.

The terminal area capacity, or number of stands, which must be provided to satisfy a given flight schedule obviously depends on the Utilisation which can be achieved on each stand. This, together with projected flight arrival rates can provide a long term guide to the total requirement, which can be used by the airport authority in its long term investment programme.

From an airline point of view, much more detail is required and the problem is transposed so that it tends to become "What effect does the availability of X number of gates have on our projected schedule?"

The flight schedule is easily translated into a ground timetable and the minimum stand requirement can be calculated. If this is more than X, an amendment to the schedule or to X is unavoidable, but when the requirement is less than, or equal to X, the answer to the above question has remained unquantified.

This is due in the main to a lack of knowledge concerning the effect of unpunctual flight movements on stand requirements.

The thesis attempts to quantify this effect and to ascertain the optimum allocation policies to be used when converting a scheduled ground time into an operational stand plan.

Parameters are identified to enable such stand plans to be defined and compared. The effect of flight disruptions are estimated by simulation and the effect of different stand plans on the overall operation is estimated.

As a result, airlines have the capacity of estimating the real effect of a given number of stands, and the airport authority can set realistic utilisation targets for the areas under its control.

ACKNOWLEDGEMENT

I have received help and full co-operation from many people in both the academic and the Air Transport industry. To all I express my sincere gratitude.

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[redacted] : [redacted].

[redacted] : O.R. Manager, [redacted].

[redacted] : O.R. Project Manager, [redacted]

[redacted] : In his capacity as Servicing Manager, [redacted].

[redacted] : In his capacity as Line Maintenance Manager, [redacted].

[redacted] : General Manager, [redacted].

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[redacted] : Vice-President - [redacted].

[redacted] : Senior Vice-President - [redacted]

Messrs: [redacted] : Senior Vice President - [redacted]

[redacted] : Manager Transportation - [redacted]

Much of the work involved observing operational methods and recording data in Airlines and Airport Authorities. This inevitably caused a degree of disruption to operational staff. I thank them for their forebearance and co-operation.

To my wife Rhona, special appreciation for her loyalty and enthusiasm throughout the project.

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Appendices are attached to the end of the following chapters and contain relevant tables and graphs:

6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 18.

1 INTRODUCTION AND SUMMARY.

This research work is concerned with the utilisation of aircraft parking positions at major commercial airports, and more particularly with the manner in which it is achieved.

1.1 The work was originated by the Chief Engineer of British Airways, European Division, (the late BEA, which it is hereafter called). His concern was that flight delays were being caused by Engineering Division, some of which were attributable to the location of parked aircraft in relation to the Engineering Control Points.

The brief given to the author was consequently very general, and one which enabled the study to encompass aspects of airport planning and utilisation which are not normally associated with the Aircraft Maintenance Organisation of an airline. It was simply to study the problem as a whole and if possible, develop a policy which would satisfy the operational requirements of airlines and provide a level of terminal area utilisation acceptable to the Airport Administration.

1.2 At first sight, the problem is basically common to any allocation problem in transport or production control. Arriving elements require to be assigned to a finite set of locations, using a pre-determined allocation-value matrix.

The utilisation of a stated length of motorway, rail track and platform, or air corridor presents similar problems, especially when a minimum distance between moving entities is required on safety grounds.

Similarly, the flow of items down a production line depends on the process time at each machine and the items arrival rate at each of them.

However, there is a subtle difference between these problems and that of aircraft parking. Although the allocation value in both cases depends predominantly on the pre-assigned sequence of element departure needs, only in the aircraft parking case does the value also depend on the relative position and quantity of servicing or support elements.

Subtle though the difference may be it is of sufficient significance to warrant an in-depth study of the particular problems at our major airports. As a result, no further reference is made in this work to comparable problems and the applicability to them of conclusions deduced from the specialised study is not researched.

1.3 An attempt is made in this paper to relate the operational and organisational problems of airlines to some theoretical aspects of gate utilisation. The methods developed and used by the airlines are studied in general and in the case of five major operators a detailed report is made. On a much broader front, theory alone is used to consider different methods of estimating required gate capacity, and of measuring their eventual usage and the service level which they provide.

1.4 A considerable amount of work has been published on the estimation of total airport capacity, which includes both runway and terminal areas.

Simulations, models and analytical methods have been devised for this purpose, but all relate to a total airport project and not to the operational needs of the user airlines. It is the latter's performances which will determine the success or failure of a given airport, irrespective of whether the facility as a whole is operating to its planned capacity or not.

The effectiveness of an airport cannot be judged by traffic volume alone with little or no reference made to the satisfaction level of its customers, the airlines.

They must be satisfied that their operation can be efficiently handled and will not accept a situation under which airport utilisation assumes more importance than their local interest. Little work has been undertaken to ascertain how these two interests can best be met. This project is intended to go some way towards that end.

1.5 The basis on which the research was to be built was considered in two separate forms.

Firstly, a purely airline attitude could be adopted. The research would then be channelled towards the identification of airline requirements on the ramp areas, assuming no interference or limitation by the airport authority. Different types and sizes of airline operation could be analysed and the results combined to provide an overall demand level. This could then be compared with the facilities which would otherwise have been provided using the established methods of forecasting airport resource requirements.

Alternatively, the resource level could be assumed to fixed and the research could be directed towards quantifying the service level which the facility could provide. This could take the form of the facility's contribution to punctuality performance and its ability to handle disrupted and delayed flights. An estimate could then be made of

1.5 the maximum number of flight movements which could be processed, to the satisfaction of both the airlines and the airport authorities.

It is considered that the first method will apply infrequently since it assumes that capacity can be matched to demand, within the time span of a schedule change. This is neither physically possible nor economically viable, and in fact occurs in its true form only when an airport is being constructed initially. The infrequency of such an event is evidenced by the continuing third London Airport Saga.

However it is felt that the second approach is too restrictive since resource levels can be and are altered within existing airports to provide extra capacity in anticipation of forecasted traffic increases.

The decision was made to concentrate on identifying the best method of scheduling a given flight programme on to a fixed number of gates and on estimating the effect on the operation of slightly altering the capacity of the total available gate area. It is necessary to translate a flight schedule into parameters which can be related to terminal area capacity in order to ascertain the probable service level. It is then the airlines prerogative to accept this level or to press for minor capacity or schedule changes.

1.6 A timetable of ground times can be obtained from any integrated flight schedule very simply. This can be converted into a series of timetables for each gate, with the individual plans depending on the allocation policy being applied and the number of available gates. The effect of these last two factors on the airlines' operational performance begs measurement.

The problem as a whole is far too complex and interactive to give any hope of an analytical solution. Simulation offers possibilities provided it can be designed realistically and with sufficient flexibility so that it can apply to any airline at any airport, irrespective of small differences in local operating procedures.

It is claimed that considerable success has been achieved in this direction by developing the simulation GATESIM, described in detail in later chapters. Parameters which quantify the effectiveness of a gate plan are evaluated by GATESIM and enable comparisons to be made between gate plans constructed under different policies from the same flight schedule and vice-versa.

1.7 In summary, therefore, the project is divided into three main components. These are:

i) The design, programming and testing of the simulation GATESIM.

ii) Collation and analysis of results obtained from GATESIM.

iii) Study of operating procedures of major airlines with particular reference to gate allocation and aircraft turnround control.

CHAPTER 2

SCHEDULE CONSTRUCTION.

2.1 Outline of Activities.

2.2. Long Term Planning (more than five years ahead).

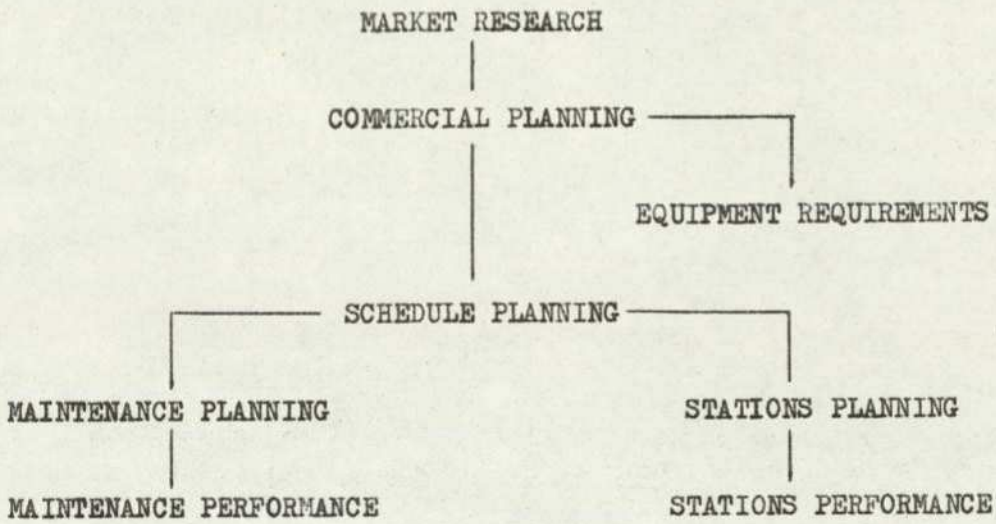
2.3 Medium Term Planning (between two and five years ahead).

2.4 Short Term Planning.

2.5 Scope of this Project.

2.1 Outline of Activities

An outline of the activities in planning an airline schedule could be:



2.2 Long Term Planning (more than five years ahead)

2.2.1 Market Research indicates the demand for a service on a currently unserved area or for any alteration to present services between airport pairs. It predicts the nature, density and frequency of occurence of such demand, indicating the optimum timings of any new flights.

2.2.2 The Equipment Requirement function is study of the spectrum of aircraft which may be available, considering the data produced by Market Research and the existing fleet configuration, leading to recommendations as to type and quantity of aircraft required to fulfil the programme.

2.2.3 Commercial Planning produces projected timetables, trying to provide for any traffic demand peaks while keeping a high aircraft utilisation. No attempt is made to formulate a pattern of sequential flights to be performed by one aircraft (an "integration"), except on a purely experimental basis.

2.2.4 Where new routes or frequency alterations on existing routes are involved, the procedure for obtaining or amending the route licence is initiated.

2.2.5 Where large changes of type and number of aircraft are contemplated, stations and maintenance planners work with commercial planners to ensure that the aircraft can be handled.

2.3 Medium Term Planning (between two and five years ahead)

2.3.1 The long-term planning of routes and aircraft comes under close scrutiny in Schedule Planning to comply with the limitations imposed by:

(i) traffic demand
(ii) aircraft performance
(iii) station facilities
(iv) maintenance requirements
(v) air traffic control and noise restrictions

2.3.2 Aircraft integrations are produced, and these are used by station and maintenance planners to calculate the manpower and facilities required for the day-to-day operation of the schedule.

2.3.3 When considering the turnrounds at the major airport of an airline (e.g. Heathrow for BEA), there are normally more than one aircraft which could operate on a specific departure, the availability of an aircraft being defined by a minimum turnround period. The choice of a specific aircraft is defined by the policy under which the schedule is being constructed. Two such policies are listed in 2.3.4 and 2.3.5.

2.3.4 "Last in, first out" (LIFO).
This policy specifies that, of the aircraft available for a given departure, the one last to arrive (i.e. with the shortest ground time) is selected. This results in a series of short turnrounds and a few very long ones. This is useful to highlight aircraft time which is available for extra non-scheduled flights, charters and maintenance.

2.3.5 "First in, first out" (FIFO).
This specifies that the aircraft selected for a departure is the one with the longest ground time. This minimises

the number of very short turnrounds but also eliminates most of the very long ones.

2.3.6 Both FIFO and LIFO policies produce integrations or cycles to which one aircraft will be allocated. The aircraft is not defined, except by type, but the routing is.

2.3.7 Examples of aircraft integrations may be represented in bar chart form, thus:

Cycle 1 LHR —— ORY —— LHR ——— GVA ——— LHR ———— TRN

Cycle 2 LHR ———— STO ———— LHR ———— ATH ———— LHR

Cycle 3 LHR ——— LBG —— LHR ———— ROM ———— LHR —— ORY

In these bar charts, horizontal displacement represents passage of time.

2.4 Short Term Planning

2.4.1 The final form of the integrations is settled by constant liaison between maintenance, station and schedule planners.

2.4.2 The actual operational performance is, of course, the measure of success, and includes such factors as:

(i) profitability
(ii) safety
(iii) schedule reliability
(iv) punctuality

These are each fed back to the planning activities.

2.5 Scope of this project

2.5.1 This study is applicable to the Schedule Planning, Stations Planning and Station Performance activities.

2.5.2 At the schedule planning stage, the computer simulation helps to determine the station facilities to cater for projected schedules.

2.5.3 Stand requirements and gate utilisation are estimated by

the simulation for the use of station planners.

2.5.4 The study of four domestic airlines in the USA, together with BEA, highlights the different methods used in the day-to-day operation of a large airport.

Chapter 3

Concept of a Gate Timetable

3.1 Basic Theory of a Gate Timetable

3.2 Significant Factors in the Preparation of a Gate Timetable

3.3 Advantages Gained by Use of a Gate Timetable

3.4 Requirements for Practical Operation of a Gate Timetable

3.5 Disadvantages of Using a Gate Timetable

3.6 Gate Timetable Reliability

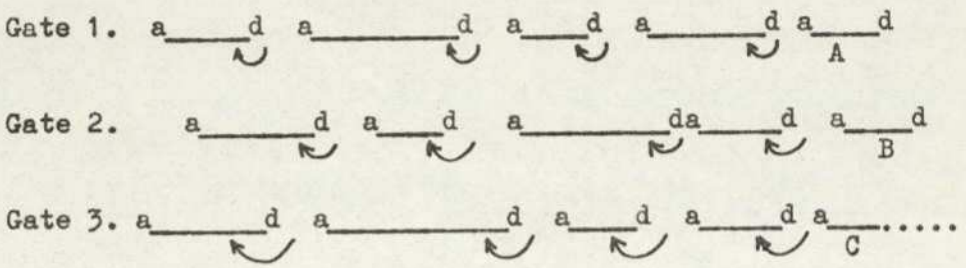
3.7 Alternative to a Gate Timetable

3.8 Reasons for Using Alternative Methods

3.1 Basic Theory of a Gate Timetable

When the aircraft integration plans, as defined in Chapter 2, are finalised, each flight movement has a scheduled ground time associated with it. These ground times can be integrated so that each available gate, (i.e. passenger loading position), has a plan of occupancy. When performed for every flight, this plan is called a gate timetable and can be represented in bar chart form as follows:

3.1.1 Examples of Gate Timetables



a - arrival of aircraft

d - departure of aircraft

The solid lines indicate occupancies of gate areas.

3.1.2 The arrival of an aircraft need not be synonymous with a flight arrival. The aircraft could have been towed to the gate from a non-operational parking area. Similarly, the departure times on a gate timetable need not always reflect flight departures.

3.2 Significant Factors in the Preparation of a Gate Timetable

3.2.1 Separation Time is defined as the time interval between a scheduled departure and the next scheduled arrival on the same gate. Furthermore, a separation time is, by definition, associated with the previous occupancy, as indicated schematically by the arrows in the chart of 3.1.1. Thus if occupancies A, B, and C are last to occupy Gates 1, 2 and 3 respectively, the last significant separation times are those which end at the arrival of A, B and C in turn.

3.2.2 Minimum Occupancy Time refers to the situation when an aircraft, for gate utilisation reasons is planned to be moved from its arrival gate to a parking area or another gate before its next departure. It does not apply when the whole of an aircraft's scheduled ground time between

flights is spent on one gate.

An aircraft must be positioned on a gate, after a towing movement, at least X minutes before its scheduled departure. In the case of a tow-off, the towing movement cannot commence until Y minutes have elapsed since its arrival. X and Y are set by the individual airline, but reasonable values are 45 and 30 respectively.

3.2.3 Gate Restrictions

Some gates may be unsuitable for certain types of aircraft in operation, due possibly to length or ground manoeuvrability. A gate which can accommodate any aircraft is spoken of as being "homogeneous".

3.2.4 Different Policies in Gate Timetable Formulation

(i) Aircraft may be positioned on gates according to their type, i.e. the available gates may be classified into groups, each of which accommodates only one type of aircraft.

(ii) The timetable may be prepared with high theoretical utilisation the prime concern.

(iii) The timetable may be planned with theoretical utilisation less than the optimum, by increasing the minimum separation time. This requires more gates than (ii) in theory, but in practice could have better reliability. This concept is further discussed in 3.6.

(iv) The restriction of (i) could be applied to (ii).

(v) Similarly, the restriction of (i) could be applied to (iii).

3.2.5 In the airlines studied, policy (i) above was accepted as good theoretically, but, in practice was impossible to adhere to because the number of gates available to the airlines was insufficient for its implementation.

3.3 Advantages Gained by Use of a Gate Timetable

3.3.1 The feasibility of accommodating a projected schedule from a given number of gates can be seen.

3.3.2 Utilisation of gate areas is planned and consequently local control centres may be set up within the gate complex, each having a known degree of congestion, and staffed accordingly.

3.3.3 Facilities and staff with necessary technical skills can be positioned according to the aircraft types planned for each area.

3.3.4 Airline ramp personnel, (i.e. those working within the aircraft parking area) know the flights and turnround times which must be catered for within their area.

3.3.5 The division of the total unskilled ramp labour force into separate entities, as is usually done with engineers, may foster healthy inter-area rivalry, and tend to reduce the apathy which is sometimes apparent when a large labour force is controlled from one location.

3.3.6 Staff meal breaks can be realistically planned according to the distribution of movements in each area.

3.3.7 Passengers have a higher degree of convenience in that:

(i) regular passengers or commuters know the gate of their departure;

(ii) gate allocation may be publicised earlier

(iii) check-in may be transferred to the gate areas

3.3.8 It can be ascertained immediately whether any extra service can be accommodated on a gate, and if not, what alteration to the flight time is necessary.

3.4 Requirements for Practical Operation of a Gate Timetable

3.4.1 Aircraft scheduled integrations must be adhered to as closely as possible.

3.4.2 Good estimates of arrival, departure and return to serviceability must exist.

3.4.3 The movement of aircraft in the gate area must be under the complete control of a ramp controller and his

authority should not be subject to over-ruling by the maintenance department, except obviously where danger is possible.

3.4.4 The aircraft integrations are formulated with the assumption that all flights operate on time. However, in the event of late arrivals occurring in practice, the planned integrations are altered to minimise the delay, creating turnrounds which are not provisioned for in the gate timetable. It is essential that any such changes are made as soon as reliable arrival estimates are available, allowing alterations to the gate timetable to be made. Delaying the decision to alter an integration until the actual arrival of the late flight can cause unnecessary large disruptions to the gate plan.

3.4.5 Unserviceability discovered after landing is a factor that must be accepted in practice, so aircraft changes will occur at this stage. Then it is necessary to perform an aircraft reallocation, and amend the gate timetable.

3.4.6 At some airports, the operational control of the gate areas rests with the airport authority, while at others each major airline leases specific gates and has complete control over them. The latter is essential for the operation of a gate timetable so that any alteration to the planned availability of gates is made by the airline concerned, and is not affected either by other airlines' gate problems or by the inopportune closure of a gate, for maintenance work, by the airport authority.

3.4.7 The airline must be able to contact an arriving aircraft's crew between touch-down and arrival on the gate. Preferably the gate number should be transmitted at this stage, but if that is required to be done earlier, at least the facility for altering the gate and informing the crew should exist.

3.4.8 Good communication must exist between the ramp controller and the personnel working within the gate area.

3.5 Disadvantages of Using a Gate Timetable

3.5.1 An aircraft positioned on a gate for departure may be found to be unserviceable, making it necessary to seek an aircraft change. If the snag rectification time is such that the presence of the "sick" aircraft on the gate would cause unacceptable disruptions to subsequent gate occupancies, the aircraft must be towed to a non-operational parking area. This increases the off-service time.

3.5.2 Estimates of times of arrival, departure and return to serviceability are not 100% accurate, and this may result in a gate being still occupied after the actual arrival of the next occupying aircraft. This could lead to gate changes affecting passengers already assembled at the original gate areas.

3.5.3 Owing to the fact that staff are positioned according to the planned occupancies, a deviation from the plan may necessitate temporary transfer of personnel. Thus flexibility of manpower and good communications must exist.

3.6 Gate Timetable Reliability

This is defined as the percentage of flight departures which leave from the gate specified by the original gate timetable. The reliability is dependent on:

(i) gate separation time.

(ii) distribution of actual arrival times around the scheduled arrival times.

(iii) unserviceability.

(iv) departure delays which occur on the station and are independent of arrival time of the aircraft. These are referred to as "station delays".

(v) alterations to aircraft integration plans create turnrounds for which no provision is made in a gate timetable. These are referred to as "unscheduled turnrounds" and their occurrence can affect the reliability.

3.7 Alternative to a Gate Timetable

The concept of a gate timetable is accepted by all five airlines studied, but not operated by one of them (BEA) and is only in limited operation with another (Western Air Lines, Inc.)

3.7.1 BEA has a ramp controller who allocates gates according to the existing conditions of gates, aircraft etc.,

There is no continuity from day to day so far as concerns specific flights on specific gates.

3.7.2 Western has a similar controller who formulates a gate time-table at the start of each day's operation. Here there is a greater element of continuity than with BEA, and it is also more flexible than a rigid pre-plan. However, it is only because the number of departures does not exceed about 80 or 90 per day that it does not become too large a task to perform daily.

3.8 Reasons for Using Alternative Methods

3.8.1 In Western's case, the operation is sufficiently small to permit a plan to be drawn up daily. This can result in the best utilisation since small local disturbances (e.g. gate maintenance) or any extra flights can be catered for.

3.8.2 BEA has a Ground Operations Planning section which prepares gate timetables, but, to date, has found them impossible to implement. The reasons given by the airline for this failure are based mainly on the fact that BEA has a radial type of operation, London (Heathrow) Airport being the hub, with most aircraft performing only two flight sectors between departure and subsequent return to London. Consequently any disruption experienced early in a day, has reactionary effects later in the same day. This effect is not so marked with an airline with longer sector times, but it is the author's view that BEA's failure is not explained simply by reference to its route structure.

3.8.3 It is necessary to study not only the differences in route structure, but also punctuality, schedule reliability and operating methods (especially relating to changes of the planned integrations) between airlines before it can be categorically stated that airlines with hub-and-spoke type operations (e.g. BEA) cannot, in practice operate a gate timetable at the hub, but those which have more evenly distributed flight movements throughout their route networks, can.

3.9 Use of simulation to validate gate timetables.

3.9.1 Gate timetables are seen to provide a method of ascertaining the number of gate positions required to accommodate a given flight schedule assuming 100% punctuality. In the medium and long term planning stages as defined in 2.2 and 2.3 this is probably sufficient to allow airport capacity requirements to be estimated.

However, in the short term stage, (2.4) and for operational station planning, flight disruptions must be considered. The total resource level likely to be required for a given arrival rate can be estimated by the Erlang Method, but this provides only a global resource level. Individual allocations of flights to gates cannot be produced by this approach.

3.9.2 Simulation provides a realistic way of ascertaining the effect of flight disruptions on a gate plan. In addition it should be possible to identify which if any, of the gate policies described in 3.2.4 produces the most effective plan in terms of operational feasability. This is more fully discussed in chapter 7.

Alternatively, the simulation may be designed to create a gate plan having first ascertained the likely arrival and departure punctuality distributions which a given schedule will produce. This approach suffers from three main faults, namely:-

i) Logic must be provided to enable the simulation to create the gate plan. This assumes that the optimum policy from 3.2.4 can be identified. Gate plans produced under these different policies can vary dramatically, even assuming constant resource availability. There is no reason to believe that their operational use will have no effect on punctuality, or the same effect.

ii) In order to produce realistic estimates of punctuality probabilities by flight number, the simulation must be capable of performing aircraft changes. Thus although a good forecast of the required separation time between a departure and the following gate arrival may be obtainable, the occupancies themselves need not be those shown on the original flight schedule.

3.9.2 iii) No facility would exist to estimate the reliability of the final plan because of ii).

3.9.3 It is considered that because of the lack of knowledge in this field of Air Transport the primary function of this project simulation is to define if possible, the optimum policy to be used in constructing a gate timetable. This policy should maximise its reliability and minimise any adverse effect on punctuality which its implementation may cause.

This approach allows the gate plan to form part of input data, which can also include details of flight disruptions to be used in generating delays and aircraft changes.

The effect of operating different gate plans under the same input delay data can be measured. Similarly, by altering the delay data, the ability of each plan to withstand differing punctuality characteristics can be estimated.

3.9.4 Chapter 4 considers the input data required for such a simulation and one way in which the flight and gate plans can be represented. A method of defining aircraft changes is also considered.

Chapter 5 describes the program procedures which were written to amend the schedule details after the occurrence of aircraft or gate changes. The details of the simulation are shown in chapter 6.

Chapter 4

Data Required as Input for the Simulation

4.1 Input of Schedule in Cycle Form

4.2 Flight Numbers

4.3 Gate Timetable

4.4 Gate Timetable Flight Numbers

4.5 Cross-reference to Link Flight with Gate Number

4.6 Cross-reference to Link Gate Occupancy with Aircraft

4.7 "Clean-run" Simulation

4.8 "Grubby-run" Simulation

4.9 "Dirty-run" Simulation

4.10 Towing Movements

4.11 Overnight Station Maintenance Inputs

4.1 Input of Schedule in Cycle Form

4.1.1 An aircraft cycle or integration has been defined as the sequential flights which, it is planned, will be performed by one aircraft. The integration may be calculated on a daily basis with no planned correlation between the last arrival of each aircraft at any one station and the first departures of the following day. Conversely, the integrations may be constructed showing the complete planned routings of each aircraft for a whole season's operation.

4.1.2 In this simulation, the integrations are considered to be on a daily basis. This has been done for the following reasons:-

(i) The integration for a complete season is not available for BEA.

(ii) The computer core store required would be excessive. For BEA, one day's information is held in two 100 x 8 arrays. For a period of 30 days, the array would be 100 x 8 x 30 in size.

(iii) The data preparation time would be excessive.

(iv) The program run time would be too long to be acceptable.

(v) It would be necessary to record all details of time-controlled maintenance items.

4.1.3 The scheduled movement times are stored in the computer as two-dimensional arrays. Only the movements at the station under study are required. Any intermediate stops between departure from this station and return to it are not required as input.

4.1.4 The arrival times are stored in an array named TA. Each row contains, in chronological order, the planned arrival times of one aircraft. The departure times are similarly stored in array TD.

4.1.5 Thus, taking the arrays together, one row represents the integration for that specific aircraft at the station under scrutiny. Aircraft A, arriving at time TA(A,B) departs on its next outbound flight at TD(A,B), which in turn arrives back at time TA(A,B+1), to depart again at TD(A,B+1), provided the elements TD(A,B), TA(A,B+1), TD(A,B+1) have significance as actual movements.

4.1.6 The elements in the arrays have significance unless their values are 0 (zero) or 3000. This limitation is necessary because each cycle may have a different number of segments, causing the rows to have differing numbers of significant elements. The following code was adopted:

(i) TA(A,1) (the first arrival of aircraft A) is set to zero if the aircraft has a departure from the station as its first flight.

(ii) Having made a departure at time TD(A,B), the aircraft A may not return to the station on the same day. This is shown by setting TA(A,B+1) and subsequent elements in row A of TA array to zero, and all subsequent elements in row A of TD array after TD(A,B) to 3000.

(iii) Having made an arrival at time TA(A,B), the aircraft A may not depart from the station again on the same day. This is shown by setting TD(A,B) and all subsequent elements in row A of TD array to 3000. All subsequent elements in row A of TA array after TA(A,B) are set to zero.

4.2 Flight Numbers

4.2.1 Flight numbers are stored in exactly the same way, and using the same code, as the flight arrival and departure times. ARRNO and DEPNO are the array names. Hence:-

(i) an arrival at time TA(A,B) has flight number ARRNO(A,B);

(ii) a departure at time TD(A,B) has flight number DEPNO(A,B);

assuming that the elements have significant values.

4.3 Gate Timetable

4.3.1 The planned movements for each gate area are stored in a similar manner to flight movements. The activity times (either arrival or departure on a gate) are held in the arrays GTA and GTD, each row holding information about one specific gate.

4.3.2 All gate movements are included, and, for example in the GTA array, the value of an element does not indicate whether the arrival is from an inbound flight or is derived from the towing of an aircraft to the gate in preparation for an outbound service.

4.3.3 The times are stored in such a way that a departure at time GTD(A,B) is followed by an arrival at time GTA(A,B) which in

turn departs at GTD(A,B+1). Each gate may have a differing number of occupancies so, as with the TA and TD arrays, the number of significant elements in GTA and GTD arrays may vary from row to row. Hence a code similar to that in 4.1.6 is adopted. It is as follows:

(i) If the first movement on gate A (say) is a departure then this time is stored in GTD(A,1) and the next arrival in GTA(A,1). However, if the gate is empty overnight and the first movement is an arrival, then GTD(A,1) is set to zero and GTA(A,1) is set to the arrival time.

(ii) If the last movement on gate A is an arrival at time GTA(A,B), then all elements from GTA(A,B+1) to the end of row A are set to 3000, and all elements in GTD array from GTD(A,B+1) to the end of row A are set to zero.

(iii) If the last movement on gate A is a departure at time GTD(A,B), then all elements in GTD from GTD(A,B+1) to the end of row A are set to zero and all elements in GTA from GTA(A,B) to the end of row A are set to 3000.

4.4 Gate Timetable Flight Numbers

4.4.1 Gate timetable flight numbers are stored in exactly the same way, and using the same code as the gate activity times, with one extra significant number. If a gate movement is the commencement or termination of an aircraft towing movement, then this movement is given the flight number 2000.

4.4.2 The array names are GARRNO and GDEPNO.
Assuming that neither GARRNO(A,B) nor GDEPNO(A,B) has the value 2000, then:-

Flight number GARRNO(A,B) arrives on gate number A at time GTA(A,B) and departs from the same gate on flight number GDEPNO(A,B) at time GTD(A,B).

4.5 Cross-reference to Link Flight with Gate Number

4.5.1 At this stage, there is no quick way of connecting an outbound flight DEPNO(A,B), (say) at time TD(A,B) with its departure gate. It is necessary to search the complete GDEPNO array until the flight number given by GDEPNO(I,J) equals DEPNO(A,B). A similar search is required to ascertain the arrival gate of an inbound flight.

4.5.2 To accelerate this process, two arrays GARR and GDEP have been declared. These have the same dimensions as the arrays TA and TD and are given values such that for aircraft A,

i) GARR(A,B) contains the gate number of flight ARRNO(A,B) scheduled at TA(A,B).

ii) GDEP(A,B) contains the gate number of flight DEPNO(A,B) scheduled at TD(A,B).

4.5.3 If aircraft A (say), departs from the same gate as it arrived on, then GARR(A,B) = GDEP(A,B), however if the ground time is sufficiently large, it may be removed to a parking area before departure from a different gate, when GARR(A,B) $\neq$ GDEP(A,B).

4.5.4 If aircraft A has a departure as its first movement of the day and is towed on to its gate then GARR(A,1) is given the value 2000 while GDEP(A,1) contains the departure gate number. If the aircraft is already on Gate A at the start of the day, then GARR(A,1) is given the value of the aircraft cycle number. Similarly, if the last movement of aircraft A is an arrival, flight number ARRNO(A,B) after which it is towed off the gate, then GDEP(A,B) is set to 2000.

4.5.5 The non-significant elements of GARR and GDEP are given the values 0 and 3000 respectively in accordance with the code for TA and TD detailed in 4.1.6.

4.6 Cross Reference to Link Gate Occupancy with Aircraft Cycle Number.

4.6.1 The identification of an aircraft cycle number when studying a gate arrival requires a search through the ARRNO array until the equality GARRNO(A,B) = ARRNO(I,J) is satisfied when the value of I gives the cycle number of the gate arrival. Similarly, for a gate departure the search is for GDEPNO(A,B) = DEPNO(I,J).

4.6.2 As in 4.5.2, to accelerate this process, two arrays ARRG and DEPG were declared, serving a similar purpose to GARR and GDEP foregoing.

Thus:

i) ARRG(A,B) contains the aircraft cycle number of inbound movement GARRNO(A,B) at time GTA(A,B) on Gate A.

ii) DEPG(A,B) contains the aircraft cycle number of outbound movement GDEPNO(A,B) at time GTD(A,B) from Gate A.

4.6.2 If gate A is empty at the start of the simulated day, then DEPG(A,1) is set to zero, and ARRG(A,1) is set to the value of the aircraft cycle number forming the first occupancy.

4.6.3 The non-significant elements of DEPG and ARRG are given the values of 0 and 3000 respectively in accordance with the code for GTD and GTA detailed in 4.3.

4.7. "Clean-run" Simulation.

This is defined as simulation into which no disturbances are injected.

4.7.1 At this stage it is possible to simulate, either manually or on a computer, the arrival and departure of aircraft. The link between arriving and departing flights has been made by TA, TD, ARRNO and DEPNO arrays. The gate occupancies are known by the arrays GTA, GTD, GARRNO and GDEPNO.

4.7.2 The link between a flight movement and a gate is given by arrays GARR and GDEP.

4.7.3 The link between a gate occupancy and a cycle number is given by arrays ARRG and DEPG.

4.7.4 It is seen that there is a 100% arrival and departure on-time performance. This is not realistic but, nevertheless, certain important results are produced, as follows:

i) the gate timetable analysis,
ii) the distribution of movements on an hourly basis,
iii) the frequency of tows and the number of tractors needed.

4.8 "Grubby-run" Simulation.

This is defined, in this context, as the simulation into which delays to aircraft movements are injected, but in which no action is taken to reduce the disruption. It was used primarily to test the sampling procedures and to select input delay distributions for use in the main simulation.

4.8.1 Originating departures have actual departure times formed by sampling from a distribution.

4.8.2 Actual arrival times are built up from a distribution of the deviations from planned flight times, used in conjunction with immediately previous departures from the same station.

4.8.3 Non-originating actual departure times are computed as follows:

i) If the scheduled departure time minus the actual arrival time is less than the minimum turnround time, then: actual departure time = actual arrival time + minimum ground time + sample of station delay.

4.8.3 ii) If the actual ground time is greater than the minimum, then:

actual departure time = scheduled departure time + sample of station delay.

4.8.4 No deviation from the aircraft integrations or the gate timetable is permitted and flights due to arrive on a gate which is occupied by a delayed departure must wait for the gate to become vacant.

4.8.5 Clearly a facility must be provided whereby a flight can have its gate altered during the simulation.

4.8.6 It is still assumed that, having been allocated to a cycle, an aircraft will remain on the same cycle until its completion. In practice, even assuming 100% serviceability, this is not the case. When a flight crew estimates a late arrival which would cause an inherent delay to its next planned departure, then an aircraft change is sought, which would reduce and possibly eliminate the projected delay.

4.8.7 Any change to the integrations requires the gate timetable to be correspondingly altered.

4.9 "Dirty-run" Simulation.

This is defined as the stage of the simulation when flights are delayed as in 4.8, and also the facility to alter aircraft integrations and gate timetables is incorporated.

4.9.1 In this project, aircraft changes have been classified into four categories. These are called:

i) DIRECT SWAP

ii) NIGHT-STOP DIRECT SWAP

iii) INDIRECT SWAP

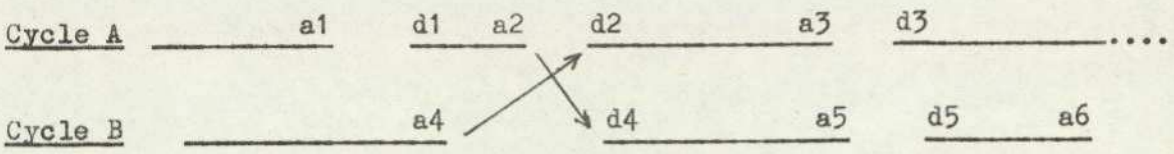
iv) NIGHT-STOP INDIRECT SWAP

These are now described in turn.

4.9.2 DIRECT SWAP.

This is defined as a change sequence which involves only two aircraft and which eliminates the projected delay. The aircraft

involved are not required to return to their original cycles, with the result that there are two unscheduled turnrounds. This can be represented schematically by:



a - represents an arrival

b - represents a departure

Horizontal displacement represents the passage of time.

In the original aircraft allocation, it is specified that the flights to be performed by aircraft A and B should be:

a1, d1, a2, d2, a3, d3

and a4, d4, a5, d5 and a6 respectively.

By using a DIRECT SWAP these have been changed to:

a1, d1, a2, d4, a5, d5, a6

and a4, d2, a3, d3 respectively.

Both d2 and d4 have turnrounds equalling or exceeding the minimum required for an on-time departure.

4.9.3 NIGHT-STOP DIRECT SWAP (N/S DIRECT SWAP)

This change sequence is similar to 4.9.2 with the added limitation that at least one of the aircraft is restricted, (i.e. it must be returned to its original cycle.) There are therefore four unscheduled turnrounds associated with an N/S DIRECT SWAP. Referring to the figure in 4.9.2, it is necessary for aircraft A and B to return to their original cycles. This can be done by planning for aircraft A to depart at d3, having arrived at a5 and aircraft B to depart at d5 having arrived at a3. This change is referred to as the secondary reallocation whereas the change a2 - d4 and a4 - d2 is referred to as the initial one.

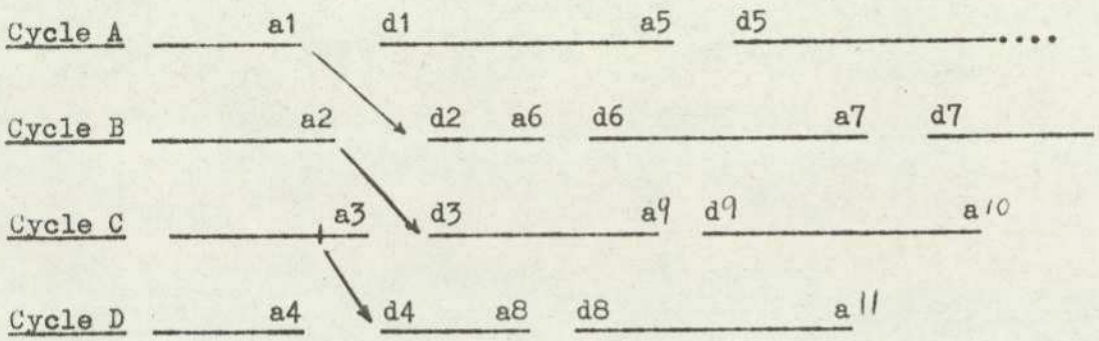
The initial reallocation can by definition, in this type of swap, always be performed with no inherent delay; however, the secondary one may involve a projected delay. Referring to the above example, it would appear that d5 could depart on time but d3 may involve a delay.

Thus when N/S DIRECT SWAPs are being considered, the most important feature is the possible secondary reallocation delay.

4.9.4 INDIRECT SWAP

This change sequence involves a total of at least two aircraft, none of which must be returned to its original cycle. Thus there

is no secondary reallocation. The initial reallocation need not eliminate the original projected delay. When only two aircraft are involved, there is always an inherent delay; otherwise the change would have been classed as a DIRECT SWAP. For more than two aircraft involved, consider the following:



Horizontal displacement represents the passage of time.
Let a represent arrivals, and d represent departures, and with subscripts let them represent the flight times.

In this case, the change involves four unscheduled turnrounds, where:

$d2 - a1 \geqslant M1$ but $d1 - a2 < M1$

$d3 - a2 \geqslant M1$ but $d1 - a3 < M1$

$d4 - a3 \geqslant M1$

For no initial delay, $d1 - a4 \geqslant M1$;

otherwise $d1 - a4 < M1$.

In the above M1 is the minimum turnround time for no inherent delay.

4.9.5 NIGHT-STOP INDIRECT SWAP (N/S INDIRECT SWAP)

This change sequence is similar to 4.9.4 with the added limitation that at least one of the aircraft must return to its original cycle. When a total of X aircraft are involved and of these Y are restricted there will be X+Y+1 unscheduled turnrounds, when $Y < X$. If $Y = X$ the number will be $X + Y$.

Referring to the figure in 4.9.4, assume that cycles A and D are restricted with the result that the flights at d5 and d8 must be operated by the original aircraft. This is possible by performing a secondary reallocation as follows:

aircraft arriving at a5 departs at d8.
" " " a6 " " d5.
" " " a8 " " d6.

This secondary change may result in an inherent delay, in

addition to the possible delay in the initial reallocation. Thus, when considering N/S INDIRECT SWAPS, there could be up to Y + 2 inherent delays, Y again being the number of restricted aircraft involved in the swap.

4.9.6 There are frequently several aircraft change sequences which could be applied to reduce a given delay. The selection of a specific swap is done on the basis of maximum reduction (or elimination) of the projected delay followed by minimum number of unscheduled turnrounds per reallocation sequence. This is done by the procedure ACCHANGE and is described in 5.1.

4.9.7 Gate changes are necessary when unscheduled turnrounds, caused by aircraft changes, occur and also when the gate initially planned for an inbound aircraft will not be vacant to permit its scheduled occupancy. Since a gate timetable and a set of aircraft cycles can be similarly represented in bar chart form, both an aircraft and a gate change involve the manipulation of the "bars" associated with the swap sequence so that the new bar chart thus formed represents the new cycles. Thus any procedures developed for performing aircraft changes can equally well be used to perform simple gate changes where no aircraft reallocation occurs as well, i.e. where there are no unscheduled turnrounds. Let such a procedure be named ACCHANGE.

A call to this procedure using data representing the aircraft integrations will result in search for an aircraft change to reduce a projected delay. Conversely, if the procedure is called using gate timetable data, then the same logic will result in a search for a gate change to reduce the time for which an inbound aircraft would have to wait for its gate to become vacant.

However, when an aircraft change has been made, an immediate call to ACCHANGE for a gate alteration does not suffice since there are now ground times in the aircraft integrations which do not correspond with the appropriate occupancies in the gate timetable data. This discrepancy must be eliminated before ACCHANGE is called. This process is performed by the procedure ALLCHANGE as described in 5.3.

4.9.8 The change sequences listed in 4.9.2 to 4.9.5 were described in terms of aircraft changes. The significance of each type as a

gate change is now considered.

4.9.8.1 Direct Swap.

Gate 1 ____ d1 a1 ____ d ____ a ____ d3 a3 ____ d5

Gate 2 ____ d2 a2 ____ d ____ a ____ d4 ____ a4 ____ d6 a ____

d - represents the departure of an aircraft from a gate.
a - represents the arrival of an aircraft onto a gate.

This type of change if accepted, results in all the occupancies originally on Gate 1 from a1 onwards to be moved to Gate 2. Similarly all movements originally on Gate 2 from a2 onwards are now planned for Gate 1.

4.9.8.2 N/S Direct Swap.

In the above diagram if the occupancy a3-d5 could not be accommodated on gate 2 because of gate/aircraft limitations, it is necessary to perform a secondary allocation such that:

a3 follows d4 on gate 1
a4 follows d3 on gate 2.

Occupancies after d5 and d6 remain on their original gates.

4.9.8.3 Indirect Swap.

This change involves a total of at least two gates on one of which at least, a gate hold will be experienced because of interfering occupancies. None of the gates have aircraft type limitations so secondary changes are not required.

Referring to the chart in 4.9.4, cycle A, B, C and D should be regarded as gates A, B, C and D. The identifiers a( ) represent the end of occupancies while d( ) represent their start time.

Thus after INDIRECT SWAP, the gate plan becomes

gate A - occupancies a1, d2-a6, d6-a7, d7.
gate B - occupancies a2, d3-a9, d9-a10.
gate C - occupancies a3, d4-a8, d8-a11.
gate D - occupancies a4, d1-a5, d5.

4.9.8.4 N/S Indirect Swap.

This is similar to the above with the added condition that certain occupancies are limited to certain gates because of gate/aircraft restrictions. This results in a secondary set of gate changes as described in 4.9.5 under aircraft reallocation.

4.10 Towing Movements.

4.10.1 In this simulation, towing is performed purely in the interest of gate utilisation, i.e. to avoid having long gate occupancies. Such long occupancies can be reduced by setting up an overspill area which can be used to park aircraft but which cannot cater for passengers. It is simply an off-line non-operational parking area with reasonable access to the operational gate areas.

4.10.2 A gate timetable shows the planned occurrence of movements between this area and the gate areas. In practice, the towing of an aircraft between these areas is affected by the maintenance state of the aircraft and by the availability of towing vehicles. When engineering personnel are working on an aircraft positioned on a gate, they are unwilling to stop to permit the aircraft to be towed to the parking area. The simulation does not permit such a tow to be cancelled for this reason and it will accept the reduction in ground time available to the engineers. However, tows can be cancelled when it is seen from arrival estimates that there will be insufficient time to move the aircraft, reposition it and make an on-time departure. The gate timetable is altered in compliance with the new planned occupancies.

4.10.3 Within BEA, there are two sources of information relating to towing movements. One is the towing crew supervisor who records the time of hitch-up and completion of each tow providing accurate tow duration times. The second source is the

controller of ramp movements who records the time at which he requested the tow and again the completion time. However, the tow is often called for earlier than necessary in an attempt to provide the towing supervisor with a work programme. Thus the tow commencement may occur some considerable time after the initial request either because of the above reason or simply because of a tug shortage. It is therefore more realistic to form a distribution of actual towing times and to limit the number of tugs available, rather than to use the "Time requested - time completed" distribution with no formal limitations on the number of tugs in use at any one time. The delays caused by tug shortage can be estimated. When a request for a tow is made, the simulation checks for a free tug and sets the tow to commence five minutes later. If no tug is free, then the tug availability check is repeated every minute until one is free, five minutes after which the tow commences.

4.10.4 Tug shortage can affect the gate timetable and punctuality in two ways. Firstly, it can delay the arrival of an aircraft on a gate, after a tow from an external parking area, thus delaying the outbound flight. Secondly, an aircraft waiting on a stand to be towed out, can cause an aircraft inbound to that same gate to hold for the gate to clear, possibly affecting its outbound punctuality. The length of any delay to the start of a tow is recorded and output in histogram form. Such a delay need not necessarily incur a flight delay since the towing time is sampled from a distribution and the actual tow time is frequently less than the length used as a standard when formulating the gate timetable. Any departure delay caused by the late arrival of a towed aircraft at a gate, whether due to tug shortage or large towing time, is recorded and output in a separate histogram.

4.11 Overnight Station Maintenance Inputs

4.11.1 The wisdom of a policy of performing overnight minor maintenance at stations apart from the main maintenance base of an airline such as BEA is not discussed or questioned in this project. However, having accepted the policy, certain limitations to aircraft changes can be incurred. Those aircraft requiring such maintenance must remain allocated to the "maintenance feed" flight unless its maintenance check can be deferred and

another aircraft substituted for the maintenance staff to work on. This decision can be reached only by those who monitor and record such figures as the number of elapsed and flying hours since previous checks, number of landings, component lives, etc. These figures are not recorded or updated in this model for reasons of program complexity and size. It is felt it would therefore be imprudent to allow any deviation from the overnight maintenance plan. Assuming cycle A (say) terminates at an outstation for maintenance on a specific day, then the program will always ensure that the initially allocated aircraft will perform that last sector. It may not have performed all of the earlier flights in its initial cycle, but will certainly be returned for the "feeder" sector.

4.11.2 Similarly it is possible to ensure that a specific aircraft will return to the station being studied on a particular flight. Of the carriers studied, the latter condition is of less importance to BEA than to American, Delta, United or Western, because at Heathrow no mandatory time interval overnight maintenance is planned. The maintenance performed is based on the defect state of the aircraft as found throughout the day's flying. Therefore it is impossible to specify, one night, the precise maintenance requirements for the next. This led to the decision that for BEA, no restrictions, for servicing reasons, would be placed on aircraft with flights terminating at Heathrow.

4.11.3 Conversely, with the other carriers studied, considerable mandatory maintenance is in fact carried out at main stations. Consequently, when simulating these stations, it is imperative that specific aircraft remain mated with specific flights, and the simulation is capable of ensuring this.

4.11.4 The input data indicates those cycles for which the last sectors are maintenance feeds. It is assumed by the program that the aircraft allocated to the first sector of such a cycle must perform the last sector and will accordingly allow no changes to be made to the last. Row I of the arrays TA and TD represents one cycle for which an aircraft is required. The

simulation assumes that aircraft I is planned to perform it and consequently, need not know that aircraft I does, in fact, have the registration G-ARPA.

CHAPTER 5

"PROCEDURES" DEVELOPED FOR USE IN THE SIMULATION

5.1	"Procedure "	ACCHANGE
5.2	"	GATEALTER
5.3	"	ALLCHANGE
5.4	"	INTERSWOP
5.5	"	DEPONGATE and ARRONGATE
5.6	"	DIRECTSWOP
5.7	"	LISTSWOP
5.8	"	SEPARATEDRS
5.9	"	INDSEPARATE
5.10	"	REARRANGE
5.11	"	MULTICHAN
5.12	"	OKDIRECT
5.13	"	INDIRECT
5.14	"	NSDIRECT
5.15	"	NSINDIRECT
5.16	"	FIRSTNSDIR
5.17	"	INDFIRST
5.18	"	NSINDFIRST
5.19	"	ANALYSE

5.1 "Procedure" ACCHANGE

5.1.1 Object of ACCHANGE

This procedure is utilised when a disruption which adversely affects punctuality has occurred. It is not called directly from the simulation but via the procedures ALLCHANGE or GATE-ALTER, which set up the input parameters for ACCHANGE and are described in 5.3 and 5.2 respectively. The disruption may take the form of a late arriving aircraft, which would result in a departure delay to the next outbound flight, making it desirable to perform an aircraft change. Alternatively, an early arrival could find its planned gate not yet vacant, necessitating a gate change. A station delay could similarly require a gate change and if large, also an aircraft change. It was seen in Chapter 4, that a gate timetable and aircraft integrations can be represented in similar ways by use of the arrays GTA with GTD and TA with TD respectively, and that a gate change, which involves no unscheduled turnrounds, is analogous to an aircraft change.

ACCHANGE calls other procedures which list possible changes, classifies them into one of the four types described in 4.9.2 to 4.9.5, and selects the specific change sequence which, it decides is least disruptive using the logic described in 5.1.3. It then compares the effect of this suggested change with the projected effect of the original disruption and selects the better. If any changes from the plan are decided upon, ACCHANGE calls procedures to implement them and assigns values to output parameters reflecting these alterations from plan.

5.1.2 The Formal Parameters of ACCHANGE are:

TA,TD,ARRNO,DEPNO,GARR,GDEP,A,B,M1,AC,X1,Y1,STA,NS,NOCHANGE, TIMETABLE.

5.1.2.1 Input Parameters

TA,TD,ARRNO,DEPNO,GARR and GDEP are integer arrays for which the integers X1 and Y1 define the number of columns and rows in each array.

5.1.2.1.1 When ACCHANGE is called to perform an aircraft change, these arrays contain details of the aircraft integrations:-

i.e. TA and TD contain flight arrival and departure times respectively,
ARRNO and DEPNO contain flight arrival and departure service numbers respectively,
GARR and GDEP contain details of the gates planned for each movement.

It is emphasised that, as formal parameters of a procedure, these arrays do not necessarily contain the same values as do their namesakes described in Chapter 4. When an aircraft change is being sought, the values given to the formal parametric arrays above, will be copied from their namesakes which are declared as global to the whole simulation. Even so, only those elements of the global arrays which could be of interest to ACCHANGE are copied. This process is performed by the procedure ALLCHANGE which is described in 5.3.

5.1.2.1.2 When ACCHANGE is called to perform a gate change, these formal parametric arrays contain details of the gate timetable:-

i.e. TA and TD contain gate departure and arrival times respectively,
ARRNO and DEPNO contain gate departure and arrival flight numbers respectively,
GARR and GDEP contain details of the cycle number of the aircraft which is performing each occupancy.

The values given to these parameters are obtained from the global arrays GTD,GTA,GDEPNO,GARRNO,DEPG and ARRG respectively. The contents and significance of these arrays are given in Chapter 4.

It can be seen, therefore, that irrespective of whether the change being sought concerns gates or aircraft, the values of the arrays in the formal parameter list are such that they represent in bar chart form, the following diagram:

1	2	3	4
TA(C,D)	TD(C,D)	TA(C,D+2)	TD(C,D+2)
ARRNO(C,D)	DEPNO(C,D)	ARRNO(C,D+2)	DEPNO(C,D+2)
GARR(C,D)	GDEP(C,D)	GARR(C,D+2)	GDEP(C,D+2)

where C and D represent any value within the array bounds, and where "bar" 1 signifies either:

i) a flight is due to arrive at time TA(C,D) on service number ARRNO(C,D) at gate GARR(C,D).

or ii) an aircraft belonging to cycle GARR(C,D) is due to leave Gate C at TA(C,D) on service number ARRNO(C,D).

Similarly "bar" 4 signifies either:

i) a flight with number DEPNO(C,D+2) is planned to depart at TD(C,D+2) from gate GDEP(C,D+2), operated by the aircraft on cycle C.

or ii) an occupancy of Gate C which is planned to commence at TD(C,D+2) with the arrival of flight number DEPNO(C,D+2), operated by the aircraft from cycle GDEP(C,D+2).

The input parameter M1 is an integer and is given a value corresponding to the minimum turnround time of an aircraft or the minimum separation time between gate occupancies, dependent on the type of change being sought by ACCHANGE.

The input parameters A and B are integers, having values defining the initial disruption which necessitated the calling of ACCHANGE. i.e. TD(A,B) - TA(A,B) < M1. STA is an integer parameter which contains the value which TA(A,B) would have had, if no deviation from plan had occurred.

AC is a one-dimensional array with Y1 columns, such that AC(I), say, refers to row I of the arrays TA, TD, etc. The values of the elements of AC are such that AC(I) = 1 if row I of TA and TD arrays refers to an aircraft cycle or to a gate which is restricted and which should not form part of a DIRECT or INDIRECT type swap. If row I is not limited, AC(I) is set to zero.

When considering a gate change, it is attempted to keep as many departures as possible on the originally planned gates. This is done because the original gate for the departure may have already been posted on the display board and some passengers may already have congregated at this gate. An alteration of an arrival gate does not result in this problem. Any deviation from the plan should be of short duration, and the original gate allocation should be returned to as soon as possible. This specifies that gate changes should preferably be of type N/S DIRECT or N/S INDIRECT. This is in contrast to aircraft changes where if possible, the new allocation is adhered to, and the preferred changes are of type DIRECT and INDIRECT. By setting the value of all elements of the array AC to 1 when considering a gate change, ACCHANGE classifies all possible changes into the category N/S DIRECT or N/S INDIRECT which is as required for gate changes. For aircraft changes, AC(I) is set to 1 only when aircraft cycle I is a "maintenance feed" cycle, so that all types of changes are possible.

TIMETABLE is a procedure which was used during program development to print intermediate values of array elements. It is not necessary for the execution of ACCHANGE.

5.1.2.2 Output Parameters

NS and NOCHANGE are Boolean quantities to which ACCHANGE assigns the value 'true' or 'false' dependant on the type of change, if any, chosen by the procedure. When it is decided to accept the original delay and not perform any changes, NOCHANGE is given the value 'true' and NS the value 'false'. When a change is decided upon, NOCHANGE takes the value''false' and if the selected change is of type N/S DIRECT or N/S INDIRECT, then NS takes the value 'true'. Otherwise NS is set to 'false'.

The arrays TA,TD,ARRNO,DEPNO,GARR and GDEP, on exit from the procedure, have been altered to incorporate the selected change.

5.1.3 Logic used by ACCHANGE

The steps taken by ACCHANGE are summarized below:

1. Disruption is identified.
2. Possible swaps are compiled.
3. These swaps are categorised.
4. DIRECT SWAPS are considered first and if more than one exist the best is chosen.
5. The INDIRECT SWAPS are studied and if any exist eliminating the projected delay, the best is chosen from these.
6. When all INDIRECT SWAPS involve a delay, the categories N/S DIRECT and N/S INDIRECT are searched for changes which, though more involved, will eliminate the delay. If such swaps exist, the best is selected, with N/S DIRECT swaps being preferred to N/S INDIRECT ones.
7. When all possible changes involve a delay, the best is selected on the basis of average delay per delayed flight, total number of delayed aircraft and the number of aircraft involved in the swap.
8. The necessary changes are made to TA,TD,ARRNO,DEPNO,GARR and GDEP to incorporate the selected change.
9. NS and NOCHANGE are assigned their significant values.

Separate procedures have been developed to select the best change within each swap category. These are described in 5.12, 5.13, 5.14, and 5.15. Similarly other procedures compare the punctuality performance of one category with that of another and select the best. These are described in 5.16, 5.17, and 5.18. Sections 5.10 and 5.11 describe the procedures which are used to manipulate the input arrays in accordance with the selected change.

5.2 Procedure GATEALTER

5.2.1 Object of GATEALTER

This procedure is called from ALLCHANGE or from the main block of the simulation. Its function is to eliminate or reduce projected gate holds by rearranging gate occupancies.

5.2.1.1 Section 4.9 refers to the similarity between gate timetables and aircraft integrations and shows how aircraft and gate changes are similarly defined. Section 5.1 describes the procedure ACCHANGE and how its formal parameters can be used to represent either type of timetable. However, it is important to realise that when studying a gate reallocation problem, ACCHANGE amends only the gate timetable arrays and does not update the flight integration arrays GARR and GDEP. Apart from calling ACCHANGE, this is the function of GATEALTER. Section 5.3 considers the corollary where ALLCHANGE performs similar transactions when considering aircraft changes.

5.2.1.2 The formal parameters of ACCHANGE include six arrays which describe the timetable to be studied and two integer values identifying the specific movements which are apparently incompatible. These parameters must be assigned values by GATEALTER. The gate timetable arrays in particular may be offered to ACCHANGE in either global form i.e all gates may be considered homogenous, or else in local form, i.e the gate timetable is subdivided into gate areas and each occupancy is restricted to the gates within its originally planned area.

In the former case, the parameters of ACCHANGE can be the globally declared gate timetable ones (GARRNO, GDEPNO etc) while the latter approach requires local arrays to be derived from their global counterparts, dependant on the area to which the unacceptable occupancy belongs.

5.2.1.2 (continued)

It was decided to treat all gates as being homogenous so there is no necessity for local arrays to be declared in GATEALTER. The reasons underlying this decision are discussed in section 8.7.

5.2.2 Formal Parameters of GATEALTER

These are GDEPNO, GARRNO, DEPG, ARRG, GTD, GTA, ARRNO, DEPNO, GARR, GDEP, A, B, SEP, ICOL, IMAX, ACCHANGE, TIMETABLE, of which A, B, SEP, ICOL and IMAX are integer variables, ACCHANGE and TIMETABLE are procedures and the remainder are integer arrays.

5.2.2.1 Input Parameters

All are input parameters with the following significance:

GDEPNO, GARRNO)
GTD , GTA) represent a gate timetable in the manner described in Chapter 4. The same variable names are used.
DEPG, ARRG)

ARRNO, DEPNO) represent aircraft integrations as
GARR, GDEP) described in Chapter 4. The same variable names are used.

IMAX — contains the total number of gates available for use, i.e the number of rows in the gate arrays.

ICOL — contains the number of columns in the gate arrays.

SEP — is the planned minimum separation time between succesive gate occupancies.

A and B — are integer variables and identify the occupancies which are incompatible by referring to row and column numbers of the gate arrays.
The incompatible movements are:
gate departure at time GTD (A,B)
gate arrival at time GTA (A,B)

TIMETABLE — is a procedure used during program testing and is not required for the execution of GATEALTER.

ACCHANGE — is the procedure described in section 5.1.

5.2.2.2 Output Parameters.

None of the parameters is used solely to transfer data to the calling point of the program. The results of the procedure are evidenced by the alterations made to the gate and aircraft integration arrays.

5.2.3 Logic Used by GATEALTER.

i) Input parameters of GATEALTER identify two gate movements which are incompatible. These values and the gate timetable arrays form the first eight formal parameters of the procedure ACCHANGE which is called by GATEALTER. If no gate reallocations are possible, a marker is set indicating that no further action is necessary from GATEALTER and that the simulation must accept for the present, that a gate hold is unavoidable for at least one occupancy. Program control returns to the point from which the procedure was called.

The following activities apply when gate changes have been made.

ii) Each gate movement is studied in turn and the cycle number of the operating aircraft is ascertained by reference to the arrays ARRG and DEPG. The value is stored in ROW.

iii) The element of the aircraft integration arrays, which refers to the flight forming the gate movement, is identified by ascertaining the value of its column index COL such that

GDEPNO (I,J) = DEPNO (ROW,COL)

where GDEPNO(I,J) is the gate departure being studied

DEPNO is part of the aircraft integrations

ROW is evaluated as in ii)

COL is increased in steps of one from the value one until the above equality exists.

The same procedure applies to gate arrivals.

iv) Care is taken to ensure that a gate movement caused by a tow-off or a tow-on is not studied in this manner since the equality will never be satisfied. This is so because towing movements are represented on the gate plan as having dummy flight numbers which will not appear in the aircraft cycles.

5.2.3 v) The array GARR or GDEP, whichever applies is updated by the statement

GARR(ROW,COL) or GDEP(ROW,COL): = I

This statement will alter the element value only if the flight identified by ROW and COL has had its gate changed. Otherwise, the element will have the same value before and after assignment.

vi) Activities ii) to v) are repeated for each gate movement.

It would appear wasteful to process every gate movement when in most cases the result will be to overwrite the value of an element in GARR or GDEP with its own value. However, alternative methods achieve speed of execution at the expense of a higher core storage requirement. Backing store was considered but results in a greater time penalty than does the adopted method due to the large number of transfers involved. The alternative methods include:

a) Copying the globally declared gate arrays into locally declared ones for presentation to ACCHANGE. The two can then be compared to isolate gate changes. This implies a further six arrays equal in size to the global ones.

b) Altering ACCHANGE to include an additional output parametric array which could contain a series of pairs of numbers such that:

i) one number of each pair identifies, on the amended timetable, a gate which has been altered.

ii) The second number indicates the column number which refers to the new occupancy.

Since the array size must be defined before it is possible to ascertain the number of significant entries, it must be set to the maximum possible. Though highly unlikely to occur, it would be necessary to set the size such that each gate movement is allocated two elements.

It can be seen that both alternatives involve a high penalty of extra core requirement which is undesirable in view of its already large usage. In addition, although not essential, the adopted method offers a good opportunity to ensure the integrity of the cross reference system.

5.3 'Procedure' ALLCHANGE

5.3.1 Object of ALLCHANGE.

This procedure is called directly from the simulation when it is discovered that an inbound aircraft is estimated to arrive so late as to cause a delay to its planned outbound sector. ALLCHANGE selects aircraft which could be used in a change sequence, and using them, calls procedure ACCHANGE to select the most suitable change.

If no alteration to the integrations can be found to improve the situation, a gate change may still be necessary, GATEALTER is called for this purpose.

However, when an aircraft change is required, there now exist turnrounds which are not catered for in the gate timetable. ALLCHANGE studies these unscheduled ground times in sequence and, unless the aircraft in question is already on the ground, it leaves the outbound flight on its original gate and transfers the new inbound flight to this gate, if it will be vacant in time. Otherwise a further gate change for the complete occupancy is required. When one of the aircraft involved is already on a gate, the associated outbound flight is transferred to this gate. If this causes the following occupancy on the same gate to be affected, then a gate change for that occupancy is carried out. This process of altering the gate timetable to suit the new aircraft integrations is repeated for each unscheduled turnround.

5.3.2 The Formal Parameters of ALLCHANGE are:

X1, A and AC.

ALLCHANGE is declared inside the block where the arrays TA, TD, etc., are declared. Thus any use of these array names refers to the global variables and not to formal parameters as was the case with ACCHANGE. An array XX (say) could be declared as a formal parameter, but since ALLCHANGE is always used in the same context, operating on data representing the same type of situation, the array TA (say) will always occur in the XX position when the procedure is called. There is therefore no requirement for a long list of formal parameters as exists in ACCHANGE.

5.3.2.1 Input Parameters.

X1 and A are integer quantities which contain respectively the number of columns in the TA and TD arrays, and the row number of the originally disturbed cycle. AC is an integer array which has the same significance and values as the globally declared array NSAC (see 6.9.1.5).

5.3.2.2 Output Parameters.

There are no specific output parameters as such, due to all operations being performed on global variables.

5.3.3 Logic of ALLCHANGE.

In this section, unless otherwise stated, the identifiers TA, TD, ARRNO, DEPNO, GARR, GDEP, GTA, GTD, GARRNO, GDEPNO, DEPG and ARRG refer to the globally declared arrays as described in Chapter 4 and not to the formal parameters of procedures.

5.3.3.1 The arrays IN, OUT, FLIN, FLOUT, GIN and GOUT are declared to have Y1 rows and X1 columns with the exception of IN which has row numbers from 0 (zero) to X1. Initially all the elements in IN, FLIN and GIN are set to zero, while all elements in OUT, FLOUT and GOUT are set to 3000. These arrays correspond to the arrays TA, TD, ARRNO, DEPNO, GARR and GDEP respectively, and the values which their elements assume are derived from their global counterparts. These newly declared arrays, when assigned values, are then used as the first six parameters of procedure ACCHANGE. This is done so that those aircraft which cannot possibly be used in a swap are not even considered by ACCHANGE. Such aircraft could include one which in practice:-

(i) has departed from the station not to return on the same day,

or (ii) is allocated to a departure, for which everything is prepared with the passenger aboard,

or (iii) is allocated to a departure which if altered would incur a separate delay, due to the proximity of departure time, even though the passengers were not aboard.

5.3.3.1 The number of rows of the TA and TD arrays which ACCHANGE must study is significantly reduced. When an aircraft is considered eligible for inclusion in the ACCHANGE parameters, it is not necessary to include details of its activities previous to its preceding activity time. This results in the arrays IN,OUT,etc., having fewer significant columns than their global counterparts, again speeding the execution of ACCHANGE. In addition, arrays TA and TD are not updated to include arrival and departure delays because their elements are compared with actual activity times when computing punctuality. ACCHANGE must be presented with actual, or at worst, estimates of actual, times, so that a realistic change sequence may be found. This realism can be provided by use of arrays IN and OUT, but not by TA and TD.

5.3.3.2 Assignment of values to elements of arrays IN,OUT, FLIN, FLOUT, GIN and GOUT.

Row 1 of these arrays contains details of the aircraft cycle for which a change is sought, this being defined by integers A and B such that, when M1 is the minimum turnround time,

TD(A,B)-(TA(A,B)+DELAY) < M1.

IN(1,1) is given the value of the actual or estimated arrival time on a gate.

OUT(1,1)	is	given	the	value	of TD(A,B)
FLIN(1,1)	"	"	"	"	" ARRNO(A,B)
FLOUT(1,1)	"	"	"	"	" DEPNO(A,B)
GIN(1,1)	"	"	"	"	" GARR (A,B)
GOUT(1,1)	"	"	"	"	" GDEP(A,B)

The remainder of the rows of the global arrays occurring after column B, is copied into row 1 of their corresponding local arrays with ascending column number. Thus each local array has its first row identical with part of the corresponding row of the relevant global array, with the exception of IN(1,1) which does not equal TA(A,B).

5.3.3.2 A similar process is used to form the subsequent rows of the local arrays, in which will be listed details of aircraft which could conceivably form part of an aircraft change sequence. Least disruption is caused if there is an aircraft which has completed its planned flights for the day and is available as a standby. Thus ALLCHANGE first searches for such an aircraft and if successful ascertains the values of I and J (say) which specify the last arrival, flight number ARRNO(I,J) which was operated by that aircraft. IN(2,1) is now given the value of the time when aircraft I, having been positioned on a gate, could become available for allocation to a flight. When the aircraft is already on a gate, it is given the value of clock-time, otherwise the towing time average is used to estimate an arrival time which is given to IN(2,1). The remainder of this row of array IN, and the complete row of OUT, FLIN, FLOUT, GIN and GOUT are given values in an exactly similar manner as described for the aircraft number A above. Each unallocated aircraft is treated in this way, with the row number of the local arrays being updated by one each time. When even only one such aircraft is found, there is no attempt to include an allocated aircraft in the arrays at this stage.

However, when there are no unallocated aircraft available, the fleet must be re-studied and possible participants in a swap sequence extracted and listed in the local arrays exactly as above. It is only the first element of any significant row of the array IN which is not copied from the corresponding global array. At the simulation time when the change is being sought, it is the position relative to the gate area and the next activity time which determines the value of IN(I,1).

Considering the aircraft belonging to cycle C of TA array, the different values given to IN(I,1) are shown below:

5.3.3.2

POSITION	NEXT ACTIVITY	VALUE TO IN(I,1) (minutes)
FLYING	DE-BRIEF	TIME OF DEBRIEF + 20
FLYING	LANDING	ESTIMATE OF LANDING TIME
ON GATE	TOW TO PARKING AREA	SIMULATION TIME
ON GROUND	ARRIVAL BY TUG ON GATE	ESTIMATE OF ARRIVAL TIME
ON GROUND	ARRIVAL BY TUG IN PARKING AREA	CLOCKTIME + AVERAGE TOW-TIME FROM PARK TO GATE
IN PARK AREA	DEPARTURE TO A GATE BY TUG	CLOCKTIME + AVERAGE TOW-TIME + 5
ON GATE	DEPARTURE ON FLIGHT	AIRCRAFT CONSIDERED ONLY IF CLOCKTIME + 45 < DEP-ARTURE TIME. IN THAT CASE IN(I,1) = CLOCKTIME.

The zero column of array IN, i.e. IN(I,0), is, in each row, allocated the value of the row number of TA to which the aircraft now in row I of IN belongs originally.

5.3.3.3 Aircraft Changes.

The locally declared arrays, IN,OUT,FLIN,FLOUT,GIN and GOUT form the first six parameters of ACCHANGE. Thus on exit from this procedure, these local arrays contain unscheduled turnrounds if a change sequence has in fact been selected by ACCHANGE. ALLCHANGE studies every turnround in the local arrays and identifies the unscheduled ones by comparing them to those originally planned and still recorded in the global arrays.

The arrival FLIN(A,B), say, was originally planned to be operated by the aircraft on the integration represented in row IN(A,0) of the global arrays, provided B has the value 1. The flight numbers in row I of ARRNO, where I = IN(A,0) are studied until a value of J is found such that FLIN(A,1) = ARRNO(I,J). An unscheduled turnround exists if FLOUT(A,1) ≠ DEPNO(I,J). Similarly, secondary changes are identified by ascertaining for a given arrival, FLIN(A,B) say, the values of I and J for which FLIN(A,B)=ARRNO(I,J) but FLOUT(A,B)≠DEPNO(A,B) In this case, the value of IN(A,0) does not provide the value of I.

5.3.3.3 The identification of unscheduled turnrounds does not permit any immediate alteration to the gate timetable since such occupancies do not exist on the gate plan. However, the elements of the arrays GIN and GOUT were re-arranged during the execution of ACCHANGE in precisely the same manner as were the other integration arrays IN,OUT,FLIN and FLOUT. Consequently the gate number originally planned for flight FLIN(I,J) say, is held in the element GIN(I,J) irrespective of whether FLIN(I,J) is involved in an unscheduled turnround or not. The cross reference between flight departures and originally planned gate numbers is similarly safeguarded by ACCHANGE.

When studying an unscheduled turnround, ALLCHANGE is interested in only two aircraft, viz. the one performing the turnround and the one which should have operated the turnround's departure. The type of change sequence is of no interest to ALLCHANGE; these two aircraft must be identified irrespective of the type of reallocation, be it NSINDIRECT or DIRECT. It is the location of these two aircraft relative to their original gate occupancies which determines the action to be taken by ALLCHANGE.

5.3.3.4 Changes to the Gate Timetable caused by Unscheduled Turnrounds.

As stated in 5.3.1, ALLCHANGE attempts to leave departures on their originally planned gates and to alter only arrival gates to accommodate unscheduled turnrounds. This indicates that the values held in the local array GIN be amended in preference to those held in GOUT. Having identified an unscheduled turnround as described in paragraph 5.3.3, the rigid application of this policy whereby the arrival gate is altered, could result in the following activities:-

i) Ascertain the original gate occupancy which contains the departure of the unscheduled turnround.

ii) Alter the details of the arrival movement of this occupancy to those of the unscheduled turnrounds arrival.

5.3.3.4 iii) Identify the element in array GIN which refers to this arrival and alter its value to that of the new gate.

In general, these activities can be applied to every unscheduled turnround encountered in a swap sequence and will correctly alter gate occupancies provided the simulation has ensured that none of the aircraft involved in the change exhibit any of the following properties:-

a) already positioned on a gate,
b) planned for a double occupancy turnround (i.e. tow-off and tow-on),
c) not allocated to a departure.

Clearly these conditions must be allowed for and although the initial concept of altering arrival gates in preference to departure ones is valid, it must be amplified considerably. This is best illustrated by the examples in 5.3.3.5 and 5.3.3.6.

Before proceeding with the more elaborate methods required to alter original occupancies to comply with those incurred by unscheduled turnrounds, it is necessary to highlight an additional amendment necessary to maintain the integrity of the cross reference arrays ARRG and DEPG. On each disturbed cycle, after the initial reallocation, there may remain turnrounds which have not been altered in themselves but which are now being operated under a new cycle number. Consequently, on the gate timetable, even though these turnrounds are represented by original occupancies in terms of flight numbers, the elements of the arrays ARRG and DEPG referring to them contain the value of the original cycle numbers. These must be altered to the new values. The procedure INTERSWOP has been developed for this purpose and is described in section 5.4. It is called after the identification of the two aircraft involved in the unscheduled turnround.

5.3.3.5 Consider only "direct swops", i.e. only two aircraft involved.

Original integration represented by

cycle I1 ——— A1 ——— D1 ———

cycle I2 ——— A2 ——— D2 ———

I1 and I2 are the row numbers in the global arrays.

The re-allocation results in the cycles

cycle I1 ——— A1 ——— D2 ———

cycle I2 ——— A2 ——— D1 ———

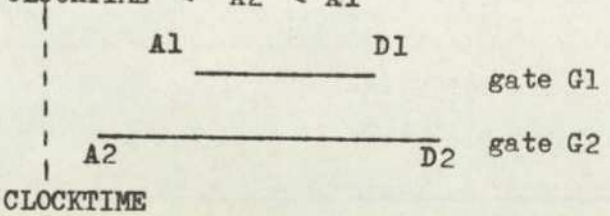
LOCAL ARRAYS:
row C1 cross referred to I1.
row C2 cross referred to I2.

After exit from procedure ACCHANGE, only the local arrays show the amended integrations in rows C1 and C2. Rows I1 and I2 in the global arrays remain unchanged.

The amendments to the gate timetables depend on the relative position of CLOCKTIME to the times of A1 and A2 and also the types of occupancies originally planned for the scheduled turnrounds. Since ALLCHANGE is only called at air-debrief time, the arrival time of A1 must occur later than the current value of CLOCKTIME. For the swap to be accepted by ACCHANGE, the time of A2 must precede that of A1.

Hence a direct swap can be represented by one of the following situations. The diagrams all refer to gate timetable occupancies as originally planned.

i) CLOCKTIME $\leq$ A2 < A1



Neither aircraft has arrived so it is acceptable to replace A2 with A1 and vice-versa. This is done in the sequence:-

5.3.3.5 i) a) Local arrays are scanned to identify unplanned turnrounds. Since they are studied in ascending row order, A1-D2 is always processed before A2-D1.

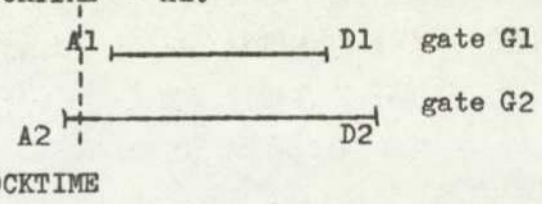
b) Departure gate of D2 is identified as is the element in the gate timetable arrays referring to A2. These values are overwritten by those referring to A1. Thus details of A1 now appear twice in the gate plan and those of A2 not at all.

c) The turnround A2-D1 is next identified as is the departure gate of D1.

d) As in b), the elements referring to the original A1, i.e. on gate G1 are identified and overwritten with details of A2.

The possible interference of the new occupancies with preceding ones is not investigated at this stage.

ii) A2 ≤ CLOCKTIME < A1.



Aircraft as on cycle I2 has already commenced its occupancy A2-D2. Both aircraft are planned to have single occupancy turnrounds. Turnround A2-D1 must be accommodated on gate G2, and if possible, A1-D2 should be planned to succeed it. This is unlikely unless D2 ≫ D1 and the delay on A1 is such that A1 > D1. These comparisons need not be made provided the facility for performing gate changes exists before exit from ALLCHANGE. This is available.

5.3.3.5 ii) The sequence of activities is as follows:

a) Local arrays are scanned and the unscheduled turnround A1-D2 is identified.

b) Arrival A1 is seen to be operated by an aircraft which is not occupying a gate.

c) Further scanning of the local arrays identifies unplanned turnround A2-D1.

d) Arrival A2 is seen to be operated by an aircraft already positioned at its gate.

e) Departure D2 is overwritten by departure D1.

f) The occupancy A1-D1 on gate G1 is deleted from the gate timetable.

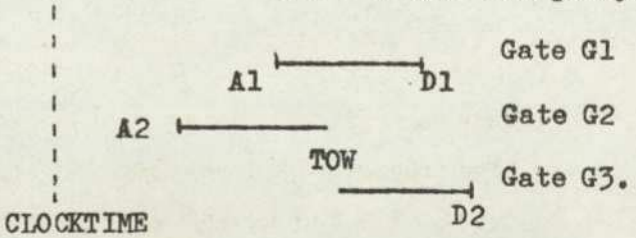
g) Further scanning of the local arrays re-identifies turnround A1-D2.

h) Gate G1 is identified but the absence of arrival A1 on it indicates that a new gate for A1-D2 must be found.

i) Gate G2 is chosen and the occupancy A1-D2 is inserted after A2-D1. Interference between the two is not considered at this point.

iii) A2 and A1 $\leq$ CLOCKTIME.
This situation cannot exist since ALLCHANGE is called only at the point of air-debrief of the aircraft, i.e. before A1 has arrived. Section 6.7 refers.

iv) CLOCKTIME $\leq$ A2 < A1, and the turnround A2-D2 has a double occupancy.



Neither aircraft has arrived so all three arrival gates may be amended if necessary.

5.3.3.5 iv) The turnround ending with departure D2 has a double occupancy and is retained as such even though operated by a different aircraft. The time of arrival A1 may result in insufficient time for such a tow, in which case the gate timetable can be amended before exit from ALLCHANGE. The intention is simply to replace A2 with A1 and vice-versa as in case i) above. This is done as follows:

a) Local arrays are scanned, identifying turnround A1-D2 as being unplanned.

b) D2 is seen to have been part of turnround A2-D2 which is identified as having had a split occupancy.

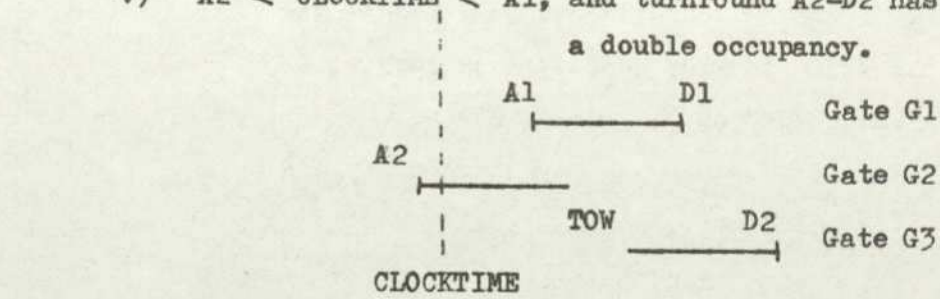
c) Details of A2 are overwritten by details of A1. Tow is allowed to remain.

d) The occupancy TOW-ON - D2 is cross referred to its new aircraft.

e) Further scanning of the local arrays identifies the turnround A2-D1.

f) Details of A1 on gate G1 are overwritten by those of arrival A2.

v) A2 < CLOCKTIME < A1, and turnround A2-D2 has a double occupancy.



The originally delayed aircraft has not arrived but the substituted one may be in one of the following positions:-

1. on arrival gate G2 (as illustrated),
2. under tow from gate G2 to its parking area,
3. positioned in the parking area,
4. under tow from parking area to gate G3,
5. positioned on departure gate G3.

5.3.3.5 v) Condition 1 and Condition 5 above.

a) Unscheduled turnround A1-D2 is identified but not processed since the operating aircraft is not in position.

b) A2-D1 is identified and processed because the operating aircraft is already positioned on a gate.

c) As in ii) above, the occupancy A1-D1 is deleted from the gate timetable.

It is now necessary to ascertain whether condition 1 or 5 applies. The planned arrival gate for A2 is identified as G2 and if unoccupied condition 5 applies. If G2 is occupied condition 1 only applies if the last arrival on G2 had the value A2. Otherwise 5 applies again.

If 1 applies:-

d) The tow off is overwritten with details of departure D1.

e) Turnround A1-D2 is studied.

f) The original arrival for D2 is identified as A2, as is the occupancy commencing in A2. It is known that A2-D2 is split, but the occupancy identified, though commencing with A2 does not terminate with a tow. It is therefore deduced that this occupancy has been altered and cannot be overwritten again. A new gate must be found for A1 which is allowed to retain the tow originally planned for aircraft C2. For ease of programming A1-tow off is inserted after A2-D1 in the knowledge that if the tow is possible, this occupancy will probably be repositioned to gate G1 where a known vacancy exists. If the ground time precludes a tow then the turnround A1-D2 will be re-planned as a single occupancy on gate G3.

5.3.3.5 v) If condition 5 applies:-

g) Gate G3 is identified as being the gate occupied by the aircraft now on turnround A2-D1.

h) D2 is overwritten with D1.

i) Turnround A1-D2 is studied.

j) As in step f) above, A2-D2 is known to be a split occupancy turnround but the A2 tow off segment is found to be intact on gate G2. This, together with the knowledge that aircraft C2 is on a gate, indicates that this occupancy has been completed and therefore cannot be amended as in condition 1.

k) Gate G3 is identified as the original planned departure gate for D2 so A1-D2 is inserted after tow on - D1. The physical possibility is not checked at this stage. A1-D2 is inserted as one occupancy and not as A1- tow-D2 as adopted for example iv) and condition 1 of this example.
In this example there is no chance of A1 arriving in sufficient time to permit a towing movement before departure, since A1 must occur after the current simulation time which itself, in this instance, exceeds the time of tow on of the original aircraft for D2.

Conditions 2,3 and 4.
These are similar to condition 5 in that the occupancy A2-tow off has occurred and is therefore not amendable. The part of the split occupancy on gate G3 has not commenced, so the logic used in example i) above can be utilised with minor amendments:-

a) The gate number G3 is held in the array GOUT only.

b) If the aircraft is being towed to a parking area, it must be deleted from the set TOCPARK and added to TOGATE, and have its gate arrival time estimated.

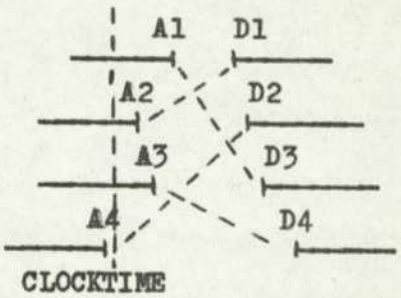
5.3.3.5 v) c) If the aircraft is already parked awaiting a tow to its gate, then the time of the tow planned start is updated to CLOCKTIME + 5.

Under all three conditions, the result is that details of A1 overwrite, those of the tow on to gate G3 and the occupancy A1-D1 on gate G1 is amended to tow-on - D1.

5.3.3.6 Indirect Swaps.

Many more permutations exist when considering indirect swaps and as most of the logic is contained in the above examples, it is not proposed to describe gate changes following an indirect swap in any detail. The reader is referred to the following worked example.

Initial Integrations

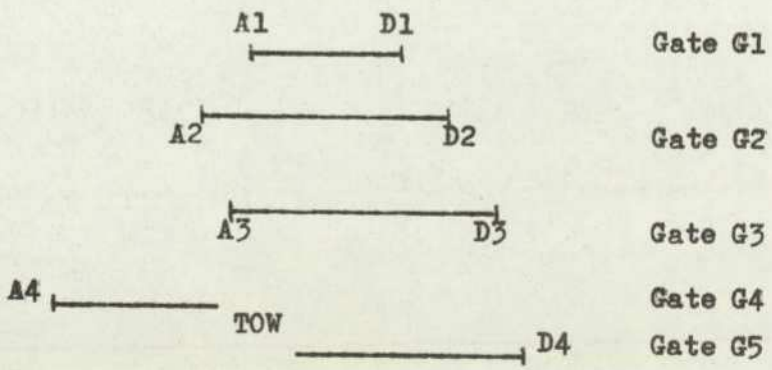


	Global Arrays		Local Arrays (after ACCHANGE)	
	Row No.	Turnround	Row No.	Turnround
	11	A1-D1	1	A1-D3
	6	A2-D2	6	A2-D1
	8	A3-D3	8	A3-D4
	15	A4-D4	11	A4-D2

An - flight arrival

Dn - flight departure.

Assume the original gate timetable be as follows:-



5.3.3.6 The amendments to the gate timetable would be performed in the sequence:

1) The tow of aircraft 15 from gate G4 is cancelled.
2) Occupancy A2-D2 is removed from the timetable.
3) The tow-off from gate G4 is replaced by details of departure D2.
4) Arrival A3 is overwritten with details of arrival A1.
5) Arrival A1, details of which are still held on gate G1, is overwritten by Arrival A2.
6) An occupancy A3-tow off is inserted on gate G4 after occupancy A4-D2.

If A4-D4 had been planned as a single occupancy on G4, then A3-D4 would have been allocated to G4 in the same manner.

5.3.3.7 In all cases, the elements of the local arrays GIN and GØUT and of global arrays ARRG and DEPG referring to altered occupancies are updated at the time of the occupancy alteration. As described in 5.3.3.4 and 5.4, other elements of ARRG and DEPG referring to unaltered turnrounds are amended by calling procedure INTERSWOP after the identification of each unscheduled turnround.

5.3.3.8 After all unscheduled turnrounds have been processed in turn, the gate timetable is fully compatable with the new integrations, but may be practically non feasible due to interference between amended occupancies and original ones. It would be very restrictive to consider gate changes for the new occupancies only since a less disruptive alteration may be possible by reallocating the gates of unchanged occupancies. This requires the gate timetable arrays to be studied in conjunction with the global integration arrays rather than the local ones. Before the gates are studied, the global arrays are updated to reflect the aircraft changes by overwriting the relevant rows with values from the local arrays.

Any gate occupancy, which on the basis of estimated movement times is found to be the cause of a possible gate hold in excess of the input maximum, is submitted to procedure GATEALTER. As indicated above, the occupancies

5.3.3.8 whose gates are altered by this procedure call, need not be those involved in the aircraft change sequence. GATEALTER is described in section 5.2.

Aircraft turnround times are not studied at this stage of the program so impractical tows cannot be cancelled. This is more effectively done from the simulation proper when the best estimates of arrival times are available. Section 6.7.8 refers.

5.4 Procedure INTERSWOP.

5.4.1 Object.

Aircraft changes of type DIRECT and INDIRECT permit disruption to the original aircraft integrations only at the time of initial re-allocation. By definition, no secondary changes are possible. Consequently the turnrounds and associated gate occupancies which occur after the initial changes belong to new cycle numbers although they themselves remain unaltered. Turnrounds exhibiting the same property can be found in swop types NSDIRECT and NS INDIRECT between the initial and secondary re-allocations and after the secondary ones.

Although such occupancies figure in the arrays GTD, GTA, GDEPNO and GARRNO, the relevant elements of ARRG and DEPG contain the cycle number to which the turnrounds originally belonged. The function of INTERSWOP is to identify in a given row of the local arrays any such turnrounds, to locate the corresponding occupancy in the gate timetable arrays and to update the value held in the located elements of ARRG and DEPG.

5.4.2 Formal Parameters.

These are four integer variables, C,E,I and J, none of which is altered during the execution of the procedure but which are used to identify the integrations and turnrounds to be studied.

5.4.2.1 INTERSWOP is declared within the procedure ALLCHANGE and as such can reference any variable name declared within ALLCHANGE and also those declared in the block containing ALLCHANGE. i.e. Any variable which can be accessed from within ALLCHANGE can also be referenced from INTERSWOP by using the same variable name without it being included as a formal parameter.

5.4.2.2 C,E,I and J are assigned values by ALLCHANGE such that the first two identify in the local arrays the unscheduled turnround represented by FLIN(C,E)-FLOUT(C,E) which is being studied by ALLCHANGE. The second two parameters refer to integrations as held in the global arrays and are assigned values such that FLOUT(C,E) = DEPNO(I,J). Thus if no further unscheduled turnrounds exist in row C, the new integration as defined in row C from column E + 1 onwards will coincide with the original integration as listed in row I of the global arrays from column J + 1 onwards.

By comparing these two rows, unaltered turnrounds are identified. The gate occupancy is located by first ascertaining the planned gate from arrays GIN and GOUT and by searching this row number of the arrays GARRNO and GDEPNO until the correct gate arrival or departure movement is discovered. The cycle numbers are then updated.

Since unscheduled turnrounds are processed by ALLCHANGE itself, no action is taken on them by INTERSWOP since the occupancy will not appear in the timetable. In addition, since INTERSWOP is called after the discovery of every re-allocation, there is no point in this procedure amending the cycle numbers of unaltered turnrounds which occur after a secondary change if it was called originally because ALLCHANGE was considering an initial re-allocation. This updating will be done by a subsequent call to INTERSWOP when the secondary phase is being studied in its own right.

5.4.2.3 Output Parameters.

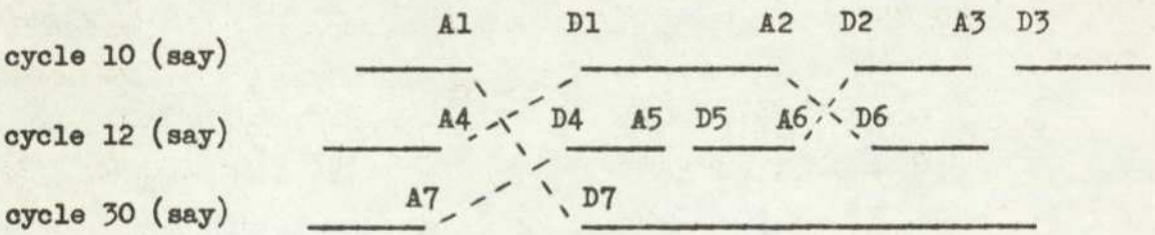
There are no specific output parameters since the procedure's activities are directed towards amending the gate timetable arrays ARRG and DEPG which are globally declared.

5.4.3 Example on the use of INTERSWOP.

Diagram and array contents are shown below.

If INTERSWOP is called to study row 5 of the local array, parameters C and I would have values 5 and 12 respectively. By comparing row 5 of the local arrays with row 12 of the global ones, the turnround A5-D5 is found to be scheduled. This is located in the gate timetable and the appropriate elements of ARRG and DEPG would be altered to show that the cycle number of the operating aircraft had changed from 12 to 30. However, the next turnround in row 5, A6-D2, is seen to be unscheduled and of no direct interest to INTERSWOP. Similarly, A3-D3 is not studied and program control returns to ALLCHANGE. After completing the processing of A7-D4, A6-D2 will be the next unscheduled occupancy identified by ALLCHANGE. INTERSWOP will be re-called and A3-D3 processed at this stage.

Consider the change sequence:-



The entries in the global and local arrays representing the before and after change situation may be:

Global		Local	
Row No.	Turnrounds	Row No.	Turnrounds
10	A1-D1, A2-D2, A3-D3	1	A1-D7
12	A4-D4, A5-D5, A6-D6	3 (say)	A4-D1, A2-D6
30	A7-D7	5 "	A7-D4, A5-D5, A6-D2, A3-D3.

This would ensure that the aircraft initially allocated to cycle 12, returned to it in time for flight D6.

5.5. Procedures ARRONGATE and DEPONGATE.

These procedures perform similar functions and so are more easily considered together.

5.5.1 Object of ARRONGATE and DEPONGATE.

During the processing of an unscheduled turnround as listed in the local flight arrays, ALLCHANGE identifies gate occupancies in which either the gate arrival or the gate departure movement forms one part of the unscheduled turnround. As described in section 5.3, it is necessary to overwrite the details of either the gate occupancy start or of its finish, dependent on the conditions at the time of the aircraft change.

5.5.1.1 Procedure ARRONGATE overwrites the details of a gate departure with those relating to the flight departure of the unscheduled turnround under scrutiny. The planned arrival on the gate remains unaltered.

5.5.1.2 Procedure DEPONGATE overwrites the details of a gate arrival with those relating to the flight arrival of the unscheduled turnround under scrutiny by ALLCHANGE. The departure from the gate remains unaltered.

5.5.2 Formal parameters of ARRONGATE and DEPONGATE.

Both procedures are declared within ALLCHANGE and as such enjoy the same reference facilities to ALLCHANGE.variables as is described for INTERSWOP in section 5.4. Thus the formal parameters merely identify the elements in the global and local arrays to be referenced.

5.5.2.1 Formal parameters of ARRONGATE.

These are X, I, J, A and B all being of integer type with the following significances:-

i) A and B identify the unscheduled turnround being processed by ALLCHANGE. viz. FLIN(A,B) - FLOUT(A,B).

ii) I and J identify a planned gate occupancy such that GARRNO(I,J-1)= FLIN(A,B).

iii) X contains the estimated movement time of FLOUT(A,B).

5.5.2.2 Formal parameters of DEPONGATE.

These are X, Y, I, J, A and B, all being of type integer with the following significancies:-

i) A and B identify the unscheduled turnround being processed by ALLCHANGE. viz. FLIN(A,B) - FLOUT(A,B).

5.5.2.2 ii) I and J identify a planned gate occupancy such that GDEPNO (I,J) = FLOUT(A,B).

iii) X and Y contain estimates of the movement of times on gate number I of the aircraft performing the unscheduled turnround.

5.5.3 Amendments made by ARRONGATE and DEPONGATE.

5.5.3.1 ARRONGATE alters the following elements in the gate timetable arrays:-

i) GDEPNO(I,J) is given the value of FLOUT(A,B).

ii) GTD(I,J) is assigned the value of X, the estimate of the gate clearing time.

iii) DEPG(I,J) is given the value of IN(A,0), in which the global array is the row number containing FLOUT(A,B). i.e. the new cycle number.

iv) The gate number of FLOUT(A,B) is altered from its original value to that of I by the statement GOUT(A,B):=I.

The movement which commences the occupancy remains as planned, but if it is a tow on, the value held in ARRG(I,J-1) would refer to the pre-change aircraft cycle number. It is therefore necessary under this circumstance to alter its value to that of IN(A,D), the new cycle number of the planned aircraft. If FLOUT(A,B) has the value 3000, indicating that the aircraft is unallocated after flight FLIN(A,B), then GDEPNO(I,J) is given the value 2000 to ensure that the aircraft may be towed off the gate if required. The reason for this is described in section 6.8.8.

5.5.3.2 DEPONGATE performs similar transactions to the movement which commences the occupancy. These are:

i) GARRNO(I,J) is assigned the value of FLIN(A,B).

ii) GTD(I,J) and GTA(I,J-1) are given the values of the estimates of the aircraft departure and arrival times on the gate.

iii) ARRG(I,J-1) is given the value of IN(A,0).

iv) The new gate number of FLIN(A,B) is altered from its original value to that of I by the assignment GIN(A,B):=I.

5.5.3.2 Although the movement which ends the gate occupancy remains as planned, the value of DEPG(I,J), which contains the cycle number of the operating aircraft, will refer to the original integrations if the movement is a tow-off. It is therefore necessary in this case to ensure that DEPG(I,J) is assigned the value of IN(A,0).

In addition, if FLIN(A,B)=0, aircraft I has a departure as its first movement. Since its gate has been altered, its arrival to its new gate must be by means of a tow-on, either from its old gate or from its parking area. Under this condition, the value of GARRNO(I,J-1) is altered to 2000 to indicate a tow-on.

5.5.4 After exit from ARRONGATE or DEPONGATE, the gate occupancy identified by ALLCHANGE is in accord with the unscheduled turnround being studied.

5.6 'Procedure' DIRECTSWOP

5.6.1 Object of DIRECTSWOP

This procedure compares two pairs of numbers and gives values to output parameters according to the relationship of these four numbers. In the context of this simulation, each pair represents one arrival and one departure time. DIRECTSWOP ascertains if the departure times are separated from their respective arrival times by at least M1 (say), where M1 is given a value before entry to the procedure.

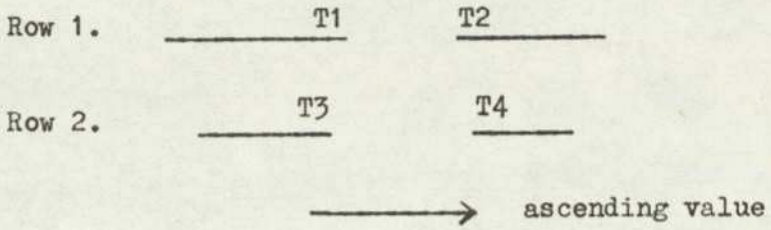


FIG.1.

The procedure primarily compares T1 with T4 and T2 with T3. It can be seen that rows 1 and 2 could represent either part of a gate timetable or else part of an aircraft fleet integration.

5.6.1.1 Part of a Gate Timetable

T1 and T3 represent flight departure times and T2 and T4 are flight arrival times. By comparing T4 with T1 the possibility of positioning arrival T4 on the same gate as departure T1 is being studied. Similarly T2 and T3 are tested for the feasibility of moving arrival T2 on to the same gate as T3.

5.6.1.2 Part of an Aircraft Fleet Integration

In this case, T1 and T3 represent flight arrivals, while T2 and T4 represent departures. The comparison of T4 and T1 now tests the possibility of the aircraft arriving at T1 departing again at T4. Similarly, the reallocation of the departure at T2 to the same cycle as the arrival at T3 is studied by comparing T2 and T3.

5.6.2 Formal Parameters of DIRECTSWOP

These are T1,T2,T3,T4,M1,INDEX,A1,A2,M,L,X.

All are 'integer' quantities with the exception of A1 and A2 which are of type 'Boolean'.

The input parameters are T1,T2,T3,T4,M1,M,L and X.

5.6.2.1 Significance of the Input Parameters

T1,T2,T3 and T4 are as described in 5.6.1.

L and M contain the row and column number respectively, of the arrays from which T1,T2,T3 and T4 were obtained prior to entry into the procedure.

M1 is given a value dependent on the context in which the procedure is called. When a gate change is being investigated, it is given the value of the minimum permissable separation time between successive aircraft occupancies on a gate. When considering an aircraft change, it is given the value of the minimum turnround time, the value always being expressed in minutes.

X is given the value 0 (zero) or 1 prior to entering the procedure, indicating, when X = 0, that the change being studied forms part of the initial reallocation and, when X = 1, that the change is part of the secondary reallocation. In the former case, T2 always has a significant value so that for T3 and T4 to be of any use, the value of T4 must be such that T4 > T2. Otherwise, even though the relationship T2-T3 > M1 holds, the other turnround given by (T4-T1) will be as short or shorter than (T2-T1) and no advantage will be gained. However, if this specific call to DIRECTSWOP is being made as part of a secondary reallocation, then T2 need not have a significant value, (i.e. it may be 3000). The comparison T4 > T2 does not now apply, and by giving X the value 0 it is indicated to the procedure that T2 should be replaced with T1, so that the requirement for T4 becomes T4 > T1.

5.6.2.2 Significance of the Output Parameters

INDEX is an integer and can have value 1,2 or 3.

A1 and A2 are Boolean quantities.

The following combinations of values can exist:

(i) INDEX = 1)
A1 = false) indicates that: T2-T3 $\geq$ M1 and T4-T1 $\geq$ M1
A2 = false)

i.e. the swap defined by T1,T2,T3 and T4 can be performed with no delay incurred.

(ii) INDEX = 2) T2-T3 $\geq$ M1 and T4-T1 < M1
A1 = false) or
A2 = false) T4-T1 < M1 and T2-T3 $\geq$ M1

i.e. the swap defined by T1,T2,T3 and T4 involves a delay to one cycle.

(iii) INDEX = 3)
A1 = false) T4 $\leq$ T2 when T2 has a significant value.
A2 = true) or T4 $\leq$ T1 when T2 has not a significant value.

i.e. T3 and T4 occur too early to be of use and so the next elements in the same row of the arrays should be studied.

(iv) INDEX = 3) T2 < T3
A1 = true) or
A2 = false) T3 = 0 and T4 = 3000

i.e. T3 and T4 relate to a turnround which either occurs too late in the day to be of any use or else to one which does not have significant values. Thus the row of the array containing T3 and T4 is of no value and the next row should be studied, since the elements occurring earlier in the same row have already been considered.

5.7 'Procedure' LISTSWOP.

5.7.1 Object of LISTSWOP.

For a given disruption to an aircraft or gate timetable this procedure lists possible changes to the relevant plan which could reduce any inherent delays. It utilises the procedure DIRECTSWOP and, dependent on the values of the output parameters from it, either stores details of the comparison or else rejects it as being inapplicable. DIRECTSWOP is re-entered until all the significant elements in the arrays TA and TD or GTD and GTA have been studied.

5.7.2 Formal Parameters of LISTSWOP.

These are ARR,DEP,CAUSE1,CAUSE2,CAUSE3,CAUSE4,PROB1,PROB2, POSS2,FIRSTDELAY,M1,X,Y,DIRECTSWOP.

5.7.2.1 Input Parameters.

DIRECTSWOP is a procedure used by LISTSWOP.
The arrays ARR and DEP form input as integer arrays and contain the values of either TA and TD arrays or GTD and GTA respectively, dependent on whether an aircraft or a gate change is being studied.

CAUSE1,CAUSE2,CAUSE3,CAUSE4 and M1 are input in integer form and have been given values before entry to LISTSWOP such that the inequality

$$ARR(CAUSE1,CAUSE2)-DEP(CAUSE3,CAUSE4) \geq M1$$

is not true, where M1 has the same significance as in 5.6.

X and Y contain the number of columns and rows respectively in ARR and DEP arrays.

5.7.2.2

The output parameters are the integer arrays PROB1, PROB2,POSS2 and the integer FIRSTDELAY.

FIRSTDELAY is given the value of

$$M1-(DEP(CAUSE3,CAUSE4)-ARR(CAUSE1,CAUSE2)\ ).$$

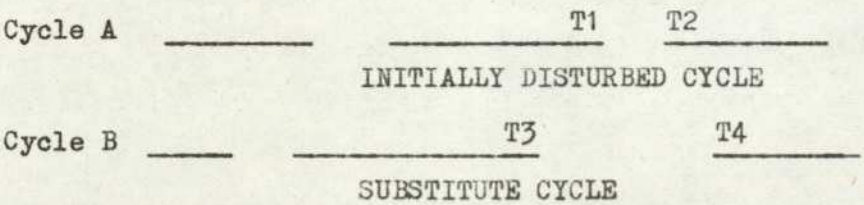
i.e. It contains the minimum delay which the entity, identified by CAUSE3, will incur if its activity is to be subsequent to the activity of the entity identified by CAUSE1.

The array PROB1 contains details of the cycle changes which fall into the category DIRECT SWAP and N/S DIRECT SWAP.

The arrays PROB2 and POSS2 contain details of the possible cycle changes in the category INDIRECT SWAP and N/S INDIRECT SWAP.

In all cases, all the details concerning one change sequence are stored in one row of the arrays, which initially had all its elements set to zero. Thus when X rows of PROB1 have non-zero elements, there is a total of X possible DIRECT or N/S DIRECT SWAPs. Similarly Y rows in POSS2 containing some non-zero terms, indicate that there are Y INDIRECT or N/S INDIRECT SWAPs possible. There is no link between entries in the PROB1 array and the other two arrays. However, row Y (say) of PROB2 refers to the same change sequence as does the corresponding row in POSS2. Row Y of PROB2 contains a non-zero element only if the INDIRECT SWAP defined in row Y of POSS2 can be performed with no associated delays; otherwise the elements in that row remain set at zero.

5.7.2.3 Consider the change sequence which is possible between cycles A and B below:



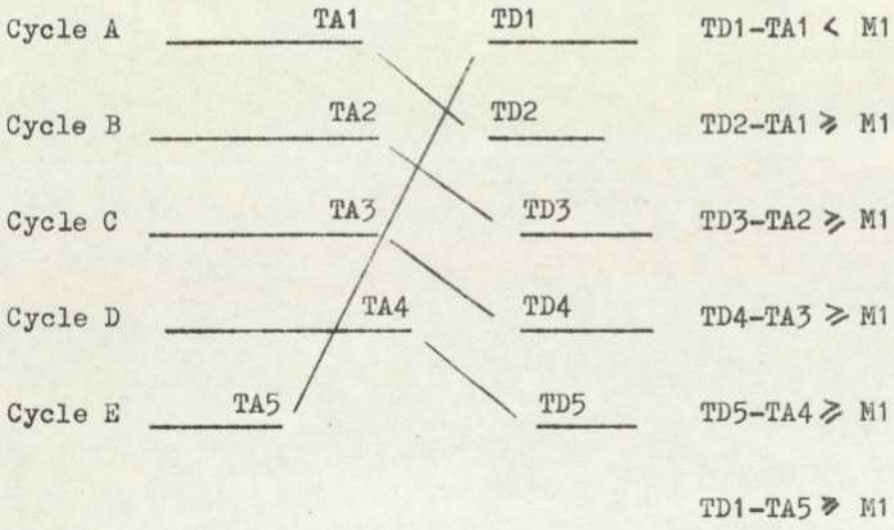
The values of T1,T2,T3 and T4 were presented to procedure DIRECTSWOP and the output parameters, INDEX, A1 and A2 were found to have the values 1,'false' and 'false' respectively, indicating the feasibility of a DIRECT SWAP. T3,T4 and associated flight numbers are recorded by setting the first element of the first non-zero row of PROB1 (row X say) to the value of the array row to which T3 and T4 belong. The second element of the same row of PROB1 is given the column index which identifies T3 and T4 in their respective arrays. i.e. the values would be such that,

T2 = ARR(PROB1(X,1),PROB1(X,2))

T3 = DEP(PROB1(X,1),PROB1(X,2))

5.7.2.4 Consider the change sequence which results in an INDIRECT SWAP as follows.

Assume that there is a total of five aircraft found to be involved in the swap and that this is the Xth INDIRECT or N/S INDIRECT SWAP to be found.



The parameters T1 and T2 of procedure DIRECTSWOP are first given the values TA1 and TD1. The arrays ARR and DEP are now searched for two elements ARR(i,j) and DEP(i,j) such that, when their values are given to the parameters T3 and T4 of DIRECTSWOP, the value of the output parameter INDEX equals one or two. When T3 and T4 take the values TA2 and TD2, INDEX assumes the value two, indicating that cycle B could form part of an INDIRECT or N/S INDIRECT SWAP. The values of i and j are stored in the array POSS2 so that

TA2 = ARR(POSS2(X,1),POSS2(X,2))
TD2 = DEP(POSS2(X,1),POSS2(X,2)).

The parameters T1 and T2 are now given the values TA2 and TD1 since they are separated by less than M1 minutes. A further search of ARR and DEP is required to find a reallocation which could eliminate this projected delay. The values of elements ARR(i,j) and DEP(i,j) are given to parameters T3 and T4 and eventually cycle C is studied and found to further reduce the delay. This is noted by storing the values of i and j in POSS2 array such that

TA3 = ARR(POSS2(X,3),POSS2(X,4))
TD3 = DEP(POSS2(X,3),POSS2(X,4)).

The values of T1 and T2 are reset to TA3 and TD1 respectively and a further search is made to further reduce the delay still inherent at T2. This is found when the values of the parameter

T3 and T4 are TA4 and TD4, but the delay is still only reduced, not eliminated. The contribution made by cycle D is stored as above, such that

TA4 = ARR(POSS2(X,5),POSS2(X,6))

TD4 = ARR(POSS2(X,5),POSS2(X,7)).

Since the delay is still not eliminated, the search of ARR and DEP continues until cycle E is found in which TA5 and TD5 are such that the delay could be eliminated by one further swap since

TD5-TA4 $\not\geq$ M1 and TD1-TA5 $\geq$ M1.

This final change is called the TERMINATING SWAP and the indices i,j of TA5 and TD5 in ARR and DEP are stored in the PROB2 array such that

TA5 = ARR(PROB2(X,1),PROB2(X,2))

TD5 = DEP(PROB2(X,1),PROB2(X,2)).

This swap being now complete, X is updated by one, and a further separate change sequence, which commences with a cycle number differing from B, is sought. When none exists, an exit is made from LISTSWOP.

In the case described above, had cycle E not existed, then the sequence would have stopped at cycle D and row X in PROB2 would have remained zero, indicating that the delay had only been reduced.

5.8 'Procedure' SEPARATEDRS.

5.8.1 Object of SEPARATEDRS.

This procedure studies the possible swaps which the procedure LISTSWOP has stored in array PROB1, i.e. those swaps involving a total of only two aircraft, and separates them into the two types of changes known as DIRECT SWAPS and N/S DIRECT SWAPS, both of which are described in 4.9.

The numbers of the cycles which are restricted form part of the input and any swap which involves any of these cycles is classed as a N/S DIRECT SWAP.

5.8.2 Formal Parameters of SEPARATEDRS.

These are AC,PROB1,NIGHTPROB1,A,PO,X1 of which the first three are each integer arrays and the last three are each integers.

5.8.2.1 Input Parameters.

These are AC,PROB1,A and X1.
On entry, PROB1 is identical to the array of the same name which was set up by procedure LISTSWOP and which contains details of possible DIRECT or N/S DIRECT SWAPS.

The integer array AC is one dimensional and its elements are given the value 0 or 1. AC(i) refers to cycle number i in the arrays TA and TD or GTA and GTD. AC(i) set to one indicates that cycle i is a restricted one and therefore cannot form part of a DIRECT or INDIRECT SWAP. The values of the elements in AC are provided by data cards.

The integer A contains the value of the initially disturbed cycle, while the integer X1 contains the number of cycles which were available for LISTSWOP to study.

5.8.2.2 Output Parameters.

PROB1 is amended so that only DIRECT SWAPS remain in it and the integer array NIGHTPROB1, of the same dimensions, contain details of the swaps, originally in PROB1, which are found to be of type N/S DIRECT.

If the cycle A is such that AC(A) = 1 then all elements in PROB1 are copied, to similar positions in

NIGHTPROB1 and the PROB1 elements set to zero.

If AC(A) = 0 then the first element of each row of PROB1, i.e. PROB1(P,1), is individually studied.

If AC(PROB1(P,1)) = 1 then row P of PROB1 is copied into the first row of NIGHTPROB1 which has zero values.

Then, in PROB1, each row from row P to the penultimate one is overwritten by the following row. The last one is set to zero. This process is repeated for each non-zero-valued row in PROB1. The number of N/S DIRECT SWAPS is stored in P0.

5.9 'Procedure' INDSEPARATE

5.9.1 Object of INDSEPARATE

This procedure studies the possible swaps which the procedure LISTSWOP has stored in arrays PROB2 and POSS2, i.e. those which either involve more than two aircraft or else do not eliminate the delay, and separates them into the types known as INDIRECT SWAPS and N/S INDIRECT SWAPS. Using the same logic as in SEPARATEDRS, any swap which involves a restricted cycle is classed as a N/S INDIRECT SWAP.

5.9.2 Formal Parameters of INDSEPARATE

These are AC,PROB2,POSS2,NTPR,NTPS,A,PO,X1, of which the first five are integer arrays and the last three integers.

5.9.2.1 Input Parameters

On entry, PROB2 and POSS2 are identical in value to the arrays of the same name set up by procedure LISTSWOP and which contain details of possible indirect or N/S INDIRECT SWAPS.

The array AC, and integers A and X1 have the same significance as in 5.8.

5.9.2.2 Output Parameters

PROB2 and POSS2 are amended so that only INDIRECT SWAPS remain stored in them, while the arrays NTPR and NTPS, of the same respective size, are given details of the N/S INDIRECT SWAPS, which are deleted from the two former arrays. This is done in a way similar to that in SEPARATEDRS, with the addition that there are possibly more than two cycles in each change sequence.

PO contains the number of N/S INDIRECT SWAPS stored in NTPS and NTPR.

5.10 'Procedure' REARRANGE

5.10.1 Object of REARRANGE

This procedure rearranges the elements of two rows of two arrays as defined by input parameters. Consider the two arrays ARRNO and DEPNO which contain flight numbers with each row corresponding to one integrated aircraft cycle. Aircraft arriving on flights ARRNO(I,J) and ARRNO(A,B) are planned to depart on flights DEPNO(I,J) and DEPNO(A,B) respectively. An aircraft change may require this to be altered so that the aircraft operating ARRNO(I,J) is required to depart on DEPNO(A,B) and that on ARRNO(A,B) to depart on DEPNO(I,J). This is represented in these two arrays by switching the values of DEPNO(I,J) with DEPNO(A,B), and ARRNO(I,J+1) with ARRNO(A,B+1). Aircraft number I is now scheduled to depart on the original cycle number A. If aircraft I is to complete cycle A and aircraft A is to complete the original cycle I then the above switching sequence is repeated by increasing J and B by 1 until the array limit is reached. However, when restricted cycles are involved the aircraft must be returned to their original cycles for specific flights. In this case the switch repetition is halted when these flights are encountered, thus leaving the original aircraft allocation for the remaining sector(s).

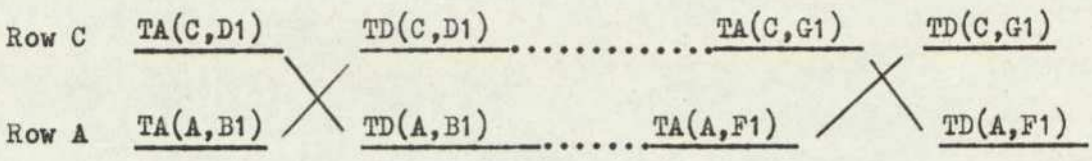
5.10.2 Formal Parameters of REARRANGE

These are TA,TD,A,C,B1,D1,F1,G1,X1 and Y1, of which TA and TD are integer arrays, the remainder being integers.

5.10.2.1 Input Parameters

X1 and Y1 contain the number of rows and columns respectively in TA and TD.

The other integers define elements of the two rows A and C of TA and TD which are to be rearranged. The significance of the parameters can be seen by considering the following diagram:



horizontal displacement represents the passage of time

Consider the case when TA and TD represent flight arrival and departure times respectively, in cycle form.

It is seen in the diagram that, due to a cycle change, the aircraft arriving at TA(C,D1) is now departing at TD(A,B1). It continues on this cycle until arrival at TA(A,F1) when it reverts to its original cycle to depart at TD(C,G1). This is represented in the TD array by transferring the value of the elements TD(A,B1) to TD(A,F1-1) inclusive into positions TD(C,D1) to TD(C,D1+F1-B1-1) inclusive. The original values of the elements from TD(C,G1) to TD(C,Y1) are preserved on entry to REARRANGE and are now re-located into positions TD(C,D1+F1-B1) to TD(C,Y1). The original values of TD(C,D1) to TD(C,G1-1) are transferred to row A.

Similarly: the original values of TA(A,B1+1) to TA(A,F1) are re-located into the relevant positions in row C.

and: the original values of TA(C,D1+1) to TA(C,G1) are re-located into the relevant positions in row A.

If aircraft C and A were to remain on their new cycles, i.e. with the secondary reallocation shown above omitted, then G1 and F1 would be set to the value of Y1 before entry, resulting in every element of rows A and C which refers to events occurring after TA(C,D1) and TA(A,B1) being switched from one row to the other.

5.10.2.2 Output Parameters

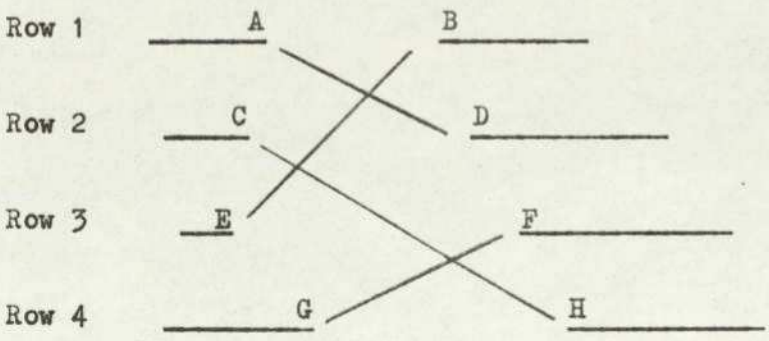
TA and TD arrays, now containing two modified rows, form the only output.

5.11 'Procedure' MULTICHAN

5.11.1 Object of MULTICHAN

Certain swap sequences involve more than two rows of the arrays in which case the procedure REARRANGE must be called several times, operating on two rows at a time. In this case MULTICHAN sets up the input parameters for REARRANGE according to the INDIRECT or N/S INDIRECT swap which is to be performed.

Consider the indirect swap, represented by the diagram:



where A,C,E,G are arrival times

B,D,F,H are departure times

In this case, the sequence of calling REARRANGE decided upon by MULTICHAN would be

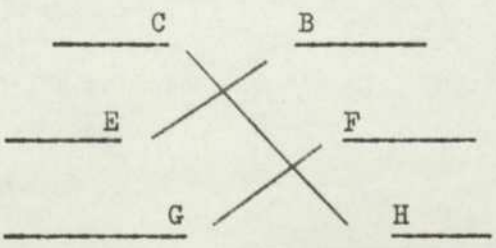
i. from B and D onwards, swap rows 1 and 2.

ii. from B and H onwards, swap rows 4 and the new values in row 2.

iii. from F and B onwards, swap row 3 with the new values in row 4.

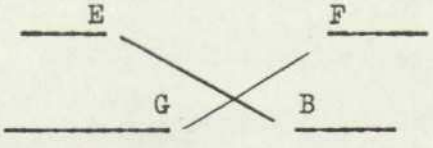
The intermediate values held in these rows would be,

after (i) A ✓ D

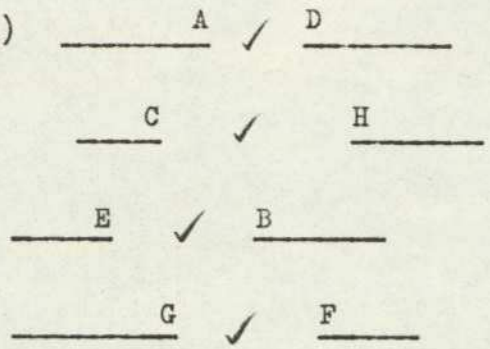


after (ii) A ✓ D

C ✓ H



after (iii)



which is as required.

5.11.2 Formal Parameters of MULTICHAN

These are TA,TD,A,B,PS,PR,ARRNO,DEPNO,GARR,GDEP,P,M1, DELAY,X1,Y1 and REARRANGE of which A,B,P,M1,DELAY,X1 and Y1 are integers, the remainder being integer arrays. REARRANGE is the procedure described in 5.10.

5.11.2.1 Input Parameters

The arrays TA,TD,ARRNO,DEPNO,GARR and GDEP contain details of either integrated aircraft cycles and associated planned gates or else of a gate timetable and associated identification of aircraft.

(a) In the former case:

(i) TA and TD contain flight times in cycle form.

(ii) ARRNO and DEPNO contain flight numbers in cycle form.

(iii) GARR and GDEP provide the cross-reference to link the flights defined by (i) and (ii) with the planned gate.

(b) In the latter case:

(iv) TA and TD contain aircraft movement times in the form of a gate timetable.

(v) ARRNO and DEPNO contain flight numbers in the form of a gate timetable.

(vi) GARR and GDEP provide the cross-reference to link a gate occupancy as defined by (v) and (vi) with a specific aircraft.

The arrays PS and PR contain details of an INDIRECT SWAP or of the initial reallocation which forms part of a N/S INDIRECT SWAP. They are analogous to POSS2 and PROB2 respectively as used

in LISTSWOP. The integer P identifies the row of PS and PR defining the swap to be performed by MULTICHAN. Any change in TA and TD must be accompanied by a similar change in ARRNO,DEPNO and in GARR,GDEP.

M1,X1 and Y1 have the same significance as with REARRANGE in 5.10.

5.11.2.2 Output Parameters

The arrays TA,TD,ARRNO,DEPNO,GARR and GDEP have been rearranged so that in their new form they incorporate the change which was defined by row P of PS and PR.

The integer DELAY contains the value of any delay which may be inherent to the reallocation. It has the value zero when PR(P,1) is greater than zero.

5.12 'Procedure' OKDIRECT

5.12.1 Object of OKDIRECT

This procedure studies the changes of type DIRECT SWAP and selects the best on the basis of ground time. For each change sequence the following is performed:

1. Let T1 and T2 be the length of the two unscheduled turnrounds.
2. Let M1 be the minimum turnround time.
3. The swaps giving unscheduled turnround times each equalling or exceeding (M1+10) minutes, are separated from those which have at least one in the range $M1 \leqslant T \leqslant M1+10$.
4. If any such long turnround swaps exist, the one selected is that with the maximum (T1+T2).
5. When no such swaps exist, the one selected is that with the maximum (T1+T2), in which case one or both turnrounds lie in the range $M1 \leqslant T \leqslant M1+10$.
6. When this fails to isolate one swap, the one selected is that which was first found by LISTSWOP.

5.12.2 Formal Parameters of OKDIRECT

These are PROB1,ALPHA,A,B,TA,TD,M1 and X1, of which PROB1,TA and TD are integer arrays, while ALPHA,A,B,M1 and X1 are integers.

5.12.2.1 Input Parameters

A and B identify the initially disrupted movement in the arrays TA and TD which contain details of aircraft integrations or of a gate timetable. Correspondingly, M1 contains the value of either the minimum turnround time of an aircraft or else the minimum separation time between gate occupancies. X1 has the value of the Number of rows in TA and TD. The array PROB1 contains details of possible DIRECT SWAPS, as produced by LISTSWOP and amended by SEPARATEDRS.

5.12.2.2 Output Parameters

ALPHA is assigned a value such that row number ALPHA in PROB1 identifies the change sequence which has been selected by OKDIRECT as being the best

available. Therefore the aircraft on the flight arriving at TA(A,B) now departs at TD(PROB1(ALPHA,1),PROB1(ALPHA,2)) and the one on the arrival at TA(PROB1(ALPHA,1), PROB1(ALPHA,2)) now departs at TD(A,B).

5.13 'Procedure' INDIRECT

5.13.1 Object of INDIRECT

This procedure studies all the changes of type INDIRECT SWAP and selects the best on the basis of punctuality and/or ground time:

1. Let the total number of aircraft (including the initially disturbed one) involved in a swap sequence be N. There are now N turnrounds of length T1,T2,T3...T(N).
2. Swaps which eliminate the original delay are separated and studied first.
3. Of these swaps, the ones with T1,T2...T(N) all equalling or exceeding (M1+10) minutes are further separated. M1 contains the value of the minimum turnround time.
4. Of these swaps, the one with (T1+T2+...T(N))/N a maximum is chosen.
5. If all of the swaps which eliminate the delay have at least one turnround in the range M1$\leq$ T$\leq$(M1+10) then the swap with the highest value of (T1+T2+...T(N))/N is selected.
6. When no swaps which can eliminate the delay exist, the one with the minimum delay is selected.
7. When several swaps incur the same minimum delay, the one involving the fewest number of cycles is chosen.
8. If this still fails to isolate one change sequence, then the one which was first found by LISTSWOP is chosen.

5.13.2 Formal Parameters of INDIRECT

These are POSS2,PROB2,TA,TD,A,B,M1,EVEP,DEL,X of which the first four are integer arrays, the remainder being integers.

5.13.2.1 Input Parameters

TA,TD,A,B and M1 have the same significance as their namesakes in procedure OKDIRECT. X contains the number of rows in TA and TD. POSS2 and PROB2 contain details of possible INDIRECT SWAPS as produced by LISTSWOP and amended by

INDSEPARATE.

5.13.2.2 Output Parameters

Using the logic described in 5.13.1, INDIRECT selects a specific change sequence and stores in EVEP the row number of POSS2 which relates to this particular change sequence. The value of any delay inherent to this swap is stored in DEL. This of course has the value zero if PROB2(ALPHA,1) is greater than zero.

5.14 'Procedure' NSDIRECT.

5.14.1 Object of NSDIRECT.

This procedure studies all the change sequences of type N/S DIRECT SWAP which were initially found by LISTSWOP and then amended by SEPARATEDRS. The latter procedure provides NSDIRECT with details of the initial reallocations in all the N/S DIRECT SWAPS. The secondary reallocations are not defined and must be formulated by NSDIRECT. Any delays incurred in this secondary phase are recorded together with details of the swap, if in fact it is possible to return to the original allocation at all, even by accepting a delay. However, when both cycles are restricted, it is permissible to omit the requirement for a secondary reallocation provided that at least one of the initially disrupted turnrounds is the last planned movement of that cycle. Some of the listed changes are thus rejected because of the failure to be able to perform the necessary secondary reallocations. Of the remaining changes, the best is selected on the basis of the lengths of the four turnrounds involved.

The priorities used are as follows:

1. Any changes which do not require a secondary reallocation are input to procedure OKDIRECT which selects the best.
2. Let the unscheduled turnrounds be of length T1, T2, T3, and T4.
3. Swaps which have no reactionary delays are separated.
4. Of these the ones which have T1, T2, T3 and T4 all equalling or exceeding M1+10 minutes are further separated.
5. If any of these longer-turnround swaps exist, the one with the largest (T1+T2+T3+T4) is selected and has its details assigned to output parameters.
6. If no such changes occur, but there are some non-delay ones listed, the one selected is again that with maximum (T1+T2+T3+T4).
7. If all swaps involve a secondary delay, the one which has the minimum delay is selected.

8. If more than one swap involves the same delay, then the one occurring first in the input listing parameters is selected.

5.14.2 Formal Parameters of NSDIRECT

These are TA,TD,PROB1,NIGHTPROB1,AC,A,B,BESTL,BESTM, BESTB4,BESTM2,DELNS,PO,M1,X1,Y1,OKDIRECT,DIRECTSWOP.

5.14.2.1 Input Parameters

The integer arrays TA and TD contain in cycle form the details of a gate timetable or of aircraft integrations.

The integer array NIGHTPROB1 contains details of the initial reallocations of the possible N/S DIRECT SWAPS as found by LISTSWOP and amended by SEPARATEDRS.

The integers A,B,M1 and X1 have the same significance as their namesakes in OKDIRECT, section 5.12.

The integer Y1 contains the number of columns in TA and TD arrays.

DIRECTSWOP and OKDIRECT are the procedures described in 5.6 and 5.12 respectively.

The integer PO contains the number of N/S DIRECT SWAPS listed in NIGHTPROB1 on entry to the procedure.

5.14.2.2 Output Parameters

Using the selection procedure listed in 5.14.1 the best swap is selected and is defined by assigning values to the output integers BESTL,BESTM,BESTB4 and BESTM2 such that it can be represented by:

Cycle A TA(A,B) TD(A,B) ..... TA(A,BESTB4) TD(A,BESTB4)

Cycle BESTL TA(BESTL,BESTM) TD(BESTL,BESTM) ..... TA(BESTL,BESTM2) TD(BESTL,BESTM2)

Any delay inherent in the secondary reallocation is stored in the output integer parameter DELNS.

If TD(A,B) or TD(BESTL,BESTM) represent the last movement on their respective cycles and both of the cycles are restricted, thus eliminating the necessity for return to the original cycles, DELNS is set to zero and BESTB4,BESTM2 both assigned the value of Y1. When no such swaps exist and it is impossible to perform the necessary secondary changes on the remainder, DELNS is given the value 100,000 which would ensure that no swaps of type N/S DIRECT would be finally selected by ACCHANGE.

5.15 Procedure NSINDIRECT.

5.15.1 This procedure studies the possible change sequences which were identified by LISTSWOP and subsequently classified as being of type N/S INDIRECT by the procedure INDSEPARATE. On entry to NSINDIRECT, the possible initial re-allocations are known but the secondary ones are undefined. It is the function of this procedure to identify them and to select the least disruptive total change sequence.

Output parameters are set to identify the selected alterations.

5.15.2 Formal Parameters.

These are: TA,TD, ARRNO, DEPNO, GARR, GDEP, M1, AC, NTPS, NTPR, BESTI, INDICES, BESTAVDLY, X1, Y1, MULTICHAN, LISTSWOP, REARRANGE and DIRECT SWOP.

The last four parameters are procedures called from within NSINDIRECT but which are not local to the procedure block. They are described in sections 5.6., 5.7, 5.10 and 5.11.

The parameters M1, BESTI, BESTAVDLY, X and Y1 are integers, the remainder being integer arrays.

5.15.2.1 Input parameters.

The parameters TA, TD, ARRNO, DEPNO, GARR and GDEP are integer arrays which represent either aircraft integrations or a gate timetable. In the former case, they are given the same values and have the same significance as their globally declared namesakes, described in section 4. When representing a gate timetable, they assume the values and significance of the global arrays GTD, GTA, GDEPNO, GARRNO, DEPG and ARRG respectively. These are also discussed in section 4.

The integers M1, X1 and Y1 together with the integer array AC have the same significance as their namesakes described in section 5.14.2 under procedure NSDIRECT.

The integer arrays NTPS and NTPR contain details of the possible initial re-allocations. The reader is referred to section 5.7 where the procedure LISTSWOP is described. Each significant row of NTPS and NTPR (which correspond to the LISTSWOP formal parameters POSS2 and PROB2) defines one sequence of initial changes in which at least one cycle is restricted.

5.15.2.2 Output Parameters.

The integer BESTI is assigned the value of the row number, which in the arrays NTPS and NTPR, describes the initial change sequence chosen by NSINDIRECT as being the least disruptive. In order to reach this decision, the required secondary re-allocation needs identification and is defined in the array INDICES as described below.

The integer BESTAVDLY is assigned the value of the mean delay per disrupted departure (in the case of aircraft changes). It is not the mean delay per delayed aircraft.

5.15.2.3 Definition of the secondary re-allocation.

The elements of the array INDICES are assigned values which refer to the state of the parametric integration arrays after the selected initial changes have been performed. The secondary changes are not defined in precisely the same manner as that employed during the formulation of the arrays NTPS and NTPR. Rather than an identification of the swap itself, INDICES defines the order in which computed parameters should be presented to REARRANGE such that the end result will be the desired new integrations.

The elements are grouped so that the odd ones refer to row numbers of the parameter integration arrays and the subsequent even numbered elements refer to the column number of the same row.

i.e. P is odd.

INDICES (P) and INDICES(P+1) identify two movements -

ARRNO(INDICES(P), INDICES(P+1)) and DEPNO (INDICES(P), INDICES(P+1)).

In addition, commencing with the first element (i.e. P=1), the parameters for each successive call to REARRANGE are grouped into blocks of four elements.

i.e. P = 1 - 4 defines the parameters for the first call.

P = 5 - 9 defines the parameters for the second call.

etc.

5.15.2.3 The integration arrays described in the input parameters are altered during the execution of NSINDIRECT, but are restored to their input value before exit from the procedure.

The manner in which the complete change sequence will be occasioned (by ACCHANGE) is by referring to NTPS, NTPR, BESTI and INDICES as follows:-

i) Call MULTICHAN to perform initial changes as defined by row BESTI of NTPS and NTPR.

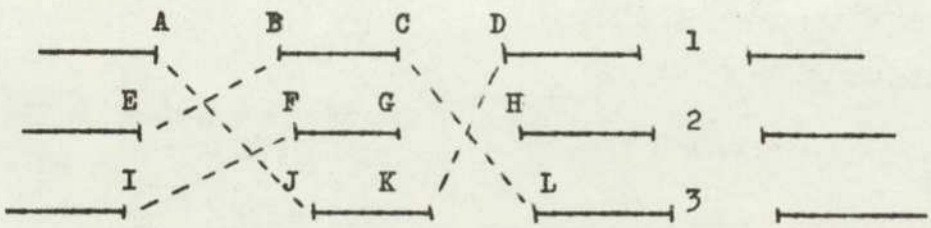
ii) Call REARRANGE to replace row number INDICES(P) of the integration arrays, from column INDICES(P+1) with row number INDICES(P+2) from column INDICES(P+3), and vice-versa.

iii) Increase P by 4 and repeat from ii) until no significant elements of INDICES remain.

Non significant elements have the value zero.

5.15.3 Logic used by NSINDIRECT.

As stated in 5.15.1, the initial re-allocations are defined on entry to the procedure, but the secondary ones are not. Thus, the first task of NSINDIRECT is to ascertain for each change sequence those cycles which must be terminated with its originally planned movement. It is not essential to perform the mirror image of the initial re-allocation since not all disturbed cycles need be restricted ones. Consider the following example:



initial re-allocation

secondary re-allocation.

Let this bar chart represent aircraft cycles with the arrivals being denoted by A, E, I, C, G and K. The departures are B, F, J, D, H, L. If the aircraft originally scheduled for flights A, B, C and D is on the only restricted cycle, then the secondary

5.15.3 re-allocation shown is acceptable. The mirror image of the initial change would result in the turnrounds C-H, G-L and K-D. This is clearly more disruptive and is less likely to be found possible in practice without incurring avoidable delays. If however, all cylces were restricted, it is necessary to attempt such a change. In addition, it may be possible to delay the secondary changes until turnrounds 1, 2 and 3.

It is therefore apparent that for a given initial change, it is reasonable to expect more than one secondary re-allocation. NSINDIRECT therefore lists all of them and selects the optimum on the basis of minimum cycle disruption. Having done so, the procedure may now contain several initial swaps with the corresponding secondary ones defined. The final combination is selected using the following guides:-

i) Select sequence with minimum average incurred delay per departure.

ii) If two or more combinations have the same average delay, select the one involving the fewest number of aircraft.

iii) If several remain, select from them the one first processed by NSINDIRECT.

5.16 'Procedure' FIRSTNSDIR

5.16.1 Object of FIRSTNSDIR

This procedure is entered after a decision has been made by ACCHANGE that, of the possible change sequences, the best is of type N/S DIRECT SWAP. The effect of this change is now compared to the effect of allowing the original allocation to remain. The choice is made on the basis of minimum inherent delay, or, when the projected delays are identical, on minimum disruption to the integrations.

5.16.2 Formal Parameters of FIRSTNSDIR

These are TA,TD,ARRNO,DEPNO,GARR,GDEP,A,B,BESTL,BESTM, BESTB4,BESTM2,DELNS,M1,FIRSTDELAY,X1,Y1,NS,NOCHANGE,REARRANGE.

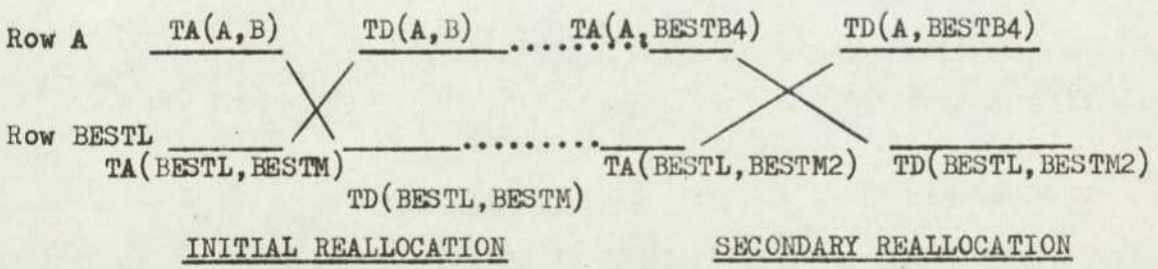
5.16.2.1 Input Parameters

REARRANGE is the procedure described in 5.10.

TA,TD,ARRNO,DEPNO,GARR and GDEP are integer arrays, while M1,X1 and Y1 are integers, all with the same significances as their namesakes in MULTICHAN in 5.11.

The integer FIRSTDELAY contains the delay which would be incurred if no changes were made to the cycles.

The integer DELNS contains the value of the delay inherent in the N/S DIRECT SWAP which is defined by the integers A,B,BESTL,BESTM,BESTB4 and BESTM2 as shown below:



The delay DELNS will be incurred in total during the secondary reallocation phase.

5.16.2.2 Output Parameters

If DELNS is less than FIRSTDELAY, the N/S DIRECT SWAP is selected and the necessary changes are made, using REARRANGE, to TA,TD, and ARRNO,DEPNO and GARR, GDEP.

The Boolean quantities NS and NOCHANGE are given the values 'true' and 'false' indicating that a restricted cycle has been altered and that a change has taken place.

Otherwise the above arrays remain untouched, and NS and NOCHANGE are given the values 'false' and 'true' indicating that no cycles have been altered and more specifically that the restricted ones remain intact.

5.17 'Procedure' INDFIRST

5.17.1 Object of INDFIRST

This procedure is similar to FIRSTNSDIR with the exception that the change sequence selected by ACCHANGE is of type INDIRECT SWAP. The comparison to be made here is therefore between the delay inherent to this reallocation and the projected delay if no changes were made at all.

5.17.2 Formal Parameters of INDFIRST

These are TA,TD,ARRNO,DEPNO,GARR,GDEP,A,B,NTPS,NTPR, POORP,M1,FIRSTDELAY,DEL,X1,Y1,NOCHANGE,MULTICHAN,REARRANGE.

5.17.2.1 Input Parameters

The integer arrays TA,TD,ARRNO,DEPNO,GARR, GDEP, have the same significance as in FIRSTNSDIR, as have the integers A,B,M1,X1, and Y1 and FIRSTDELAY.

MULTICHAN and REARRANGE are the procedures described in 5.10 and 5.11.

The integer arrays NTPS and NTPR contain details of all INDIRECT SWAPS as found by LISTSWOP and amended by INDSEPARATE. They are analogous to POSS2 and PROB2 in LISTSWOP.

The integer POORP contains the row number of NTPS and NTPR which defines the change sequence being studied here.

DEL contains the value of the delay inherent to the INDIRECT SWAP defined by row POORP.

5.17.2.2 Output Parameters

If FIRSTDELAY is less than or equal to DEL, no change is made to the integrations and the delay on cycle A is accepted. The Boolean quantity NOCHANGE is given the value 'true' to signify this.

However, if DEL is less than FIRSTDELAY, the cycles are altered in accordance with row POORP of NTPS and NTPR, using procedure MULTICHAN. NOCHANGE is given the value 'false' indicating, on exit, that changes have occurred.

5.18 'Procedure' NSINDFIRST

5.18.1 Object of NSINDFIRST

This procedure is similar to INDFIRST and FIRSTNSDIR in deciding whether the reallocation, chosen by ACCHANGE as being the best one, is used in preference to accepting the original delay and making no changes at all. In this case the reallocation chosen is of type N/S INDIRECT SWAP and is one which cannot be performed without an inherent delay.

5.18.2 Formal Parameters of NSINDFIRST

These are TA,TD,ARRNO,DEPNO,GARR,GDEP,NTPS,NTPR,A,B, M1,FIRSTDELAY,BESTI,INDICES,NSAVDLY,X1,Y1,NS,NOCHANGE, REARRANGE,MULTICHAN.

5.18.2.1 Input Parameters

The integer arrays TA,TD,ARRNO,DEPNO,GARR, GDEP have the same significance as in FIRSTNSDIR and INDFIRST, as have the integers A,B,M1,X1,Y1 and FIRSTDELAY.

MULTICHAN and REARRANGE are the procedures described in 5.10 and 5.11.

The integer arrays NTPS and NTPR contain details of the initial reallocations of all the N/S INDIRECT SWAPS as found by LISTSWOP and amended by INDSEPARATE. The integer BESTI contains the row number of NTPS and NTPR which defines the change sequence selected by ACCHANGE for study here.

The array INDICES contains details of the secondary reallocation necessary to complete the change sequence. This array is a copy of the array of the same name which is produced by the NSINDIRECT procedure, described in 5.15.

The integer NSAVDLY contains the mean delay per delayed flight incurred by this N/S INDIRECT SWAP.

5.18.2.2 Output Parameters

If FIRSTDELAY is less than or equal to NSAVDLY, no change is made to the integrations and the delay on cycle A is accepted. The Boolean quantities

NS and NOCHANGE are given the value 'false' and 'true' respectively to signify this decision.

However, when NSAVDLY is less than FIRSTDELAY, the cycles are altered in accordance with row number BESTI of NTPS and NTPR and with INDICES, utilising the procedures REARRANGE and MULTICHAN.

NS and NOCHANGE are assigned the values 'true' and 'false' respectively, indicating that cycle changes have occurred and that restricted cycles are involved.

5.19 'Procedure' ANALYSE.

5.19.1 Object of ANALYSE.

This procedure performs an analysis on a gate timetable producing histograms of gate occupancy and separation times, both for the individual gates and for the station as a whole. In the program GATESIM, ANALYSE is called before the start of the simulation to provide an analysis of the planned gate timetable.

5.19.2 Formal Parameters of ANALYSE.

These are GTD,GTA,X,GMT,HISTOGRAM,ADDTO,WRITEDOWN.

5.19.2.1 Input Parameters.

GTD and GTA are integer arrays which contain details of the gate timetable to be analysed. The significance of the value of the elements in GTD and GTA is described in 4.3.1.

The number of rows in these arrays, i.e. the number of gates being studied, is contained in the integer X.

HISTOGRAM,ADDTO and WRITEDOWN are procedures which were provided by ICL as part of the SIMON simulation package. The declaration, manipulation and printing of histograms and related statistics are performed by these procedures which are more fully described in section 6.10.2.

GMT is a procedure which converts an integer representing a time in minutes to two integers representing that time in hours and minutes.

5.19.2.2 Output from ANALYSE.

The only output of ANALYSE is done on the line printer using WRITEDOWN and no output parameters are required.

For each gate area the following is printed:

i) gate number
ii) number of occupancies considered
iii) average gate occupancy time in minutes
iv) average gate separation time in minutes.

(v) variance and standard deviation of the distribution of the gate separation times

(vi) variance and standard deviation of the distribution of the gate occupancy times

A summary is provided showing the frequency of occurrence in specific time bands, of occupancy times and separation times.

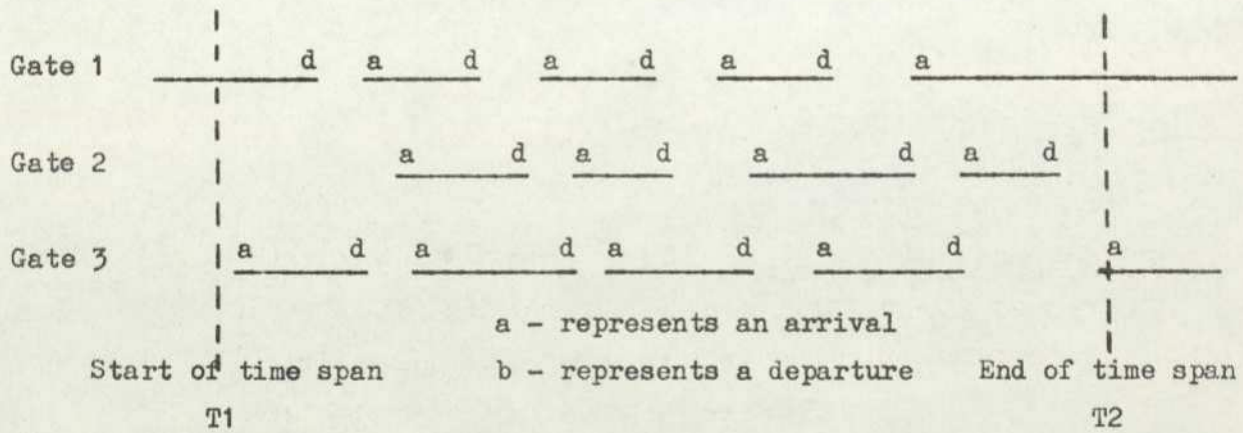
Finally the mean, variance and standard deviation of the station occupancy and station separation time distributions are printed.

5.19.3 Details of the analysis

It is possible to calculate factors (ii) to (vi) in 5.19.2.2 for the twenty-four hour period commencing at midnight at the start of the day to be studied, or for any selected time span during the day. This time span may be taken to be identical for each gate or to vary from gate to gate. The difference between using the constant time span and the variable one is as follows:

5.19.3.1 Using the constant time span

Consider the following chart representing the occupancies of three gates:



On Gate 1, there are five occupancies and only four separation times during the time span. The lengths of the first and last occupancies and thus of the mean occupancy, are determined purely by the choice of T1 and T2 and in this example would result in a high mean occupancy time and a high standard deviation, reducing the significance of the mean as a useful parameter.

Conversely, in Gate 2, the same time span includes

five vacancies, of which only 3 are separation times by definition, and four occupancies. In this case the mean separation time has its significance reduced.

In Gate 3, there are five vacancies, only four of which are true separation times. In addition, the occurrence of the last arrival so close to T2 will reduce the value of the mean occupancy to below the value which is representative of the period containing most activities.

5.19.3.2 Using the variable time span

The start of the time period can be chosen so that it coincides with the arrival of an aircraft on the gate being considered; and the end, so that it coincides with the arrival of another aircraft. Thus, each occupancy has a separation time associated with it, there being the same number of vacancies as occupancies.

ANALYSE utilises this method and selects as the starting point, the arrival of the first aircraft with an occupancy time of less than ninety-one minutes. This is done in an attempt to eliminate the effect of aircraft arriving in the early morning and remaining on the gate for several hours before departure. The end of the time span is taken to be the arrival of the last aircraft on the gate, thus eliminating the long evening occupancies exemplified in Gate 1 above.

CHAPTER 6

Introduction to Simulation Program GATESIM

6.1 The Simon Package.

6.2 Concept of entities, attributes in Simon.

6.3 Listing by attributes.

6.4 Listing by sets.

6.5 Simulation time.

6.6 Entities used in GATESIM.

6.7 Sets used in GATESIM.

6.8 Initial conditions.

6.9 Input data.

6.10 Output of results.

6.11 Control variables.

6.1 The Simon Package.

Many languages or "packages" have been developed to simplify the programming of specialised simulations. The majority tend to be designed for use with particular machines and compilers. CSL, for example, is a Fortran based language which is processed by a translator program before being compiled normally.

The Simon package, however, consists of a series of procedures, written in basic Algol, which can be incorporated into any Algol program. It was selected for this project for two main reasons:-

i) Program testing was performed on an ICL 1900 machine but the complete simulation was run on a CDC one. The Simon procedures were acceptable to the compilers of both installations.

ii) The procedures can be amended to suit particular program requirements. Only those used by the program need be compiled in to it, thus minimising program size.

6.2 Any model formulated using SIMON consists of a number of individual components or ENTITIES the state of which can be recorded in two ways:-

i) Each entity may have several properties or ATTRIBUTES associated with it, each attribute being represented by a number designated by the programmer. For example, AIRCRAFT1 could be an entity with attributes such as: flying, on a gate, unserviceable, fuelled, etc. Each attribute is declared to be an integer and is assigned an integer value chosen by the programmer.

ii) Alternatively, those entities, all of which are in a particular state, may be listed under the state name. This state name is called a SET. Once again the set name is declared as being of type integer.

i) and ii) may be summarised as follows:
Consider four entities, A,B,C and D, each capable of existing in any or all of the four states w,x,y,z.

Using i), the states would be listed under each entity as below:

ENTITY	A	B	C	D
STATES	w		w	
	x	x		x
		y		y
		z	z	

Alternatively, using ii), the entities may be listed by the state:

STATES	w	x	y	z
ENTITIES	A	A		
		B	B	B
	C			C
		D	D	

Both these methods are used in GATESIM.

A number of entities with the same set of attributes may be defined collectively as a GROUPENTITY. Individual entities may still be referred to and processed as a single entity.

In SIMON, a group entity is represented by a two-dimensional integer array, each row representing a single entity and each column an attribute, common to all entities. Element 0 (zero) of each row is reserved for a value assigned by the groupentity declaration procedure.

6.3 Listing by Attributes

A fleet of 20 aircraft, each with four attributes (e.g. flying, loaded, serviceable, fuelled) could be represented by the array declaration:-

```
'INTEGER' 'ARRAY' AIRCRAFT(1:20,0:4)
```

In this array the entity states are stored as integer values, which are set by the programmer. Let us assume that the programmer requires that:

column 1 refers to the operation being carried out by the aircraft.
column 2 " " " payload state of the aircraft.
column 3 " " " maintenance state of the aircraft.
column 4 " " " fuel state of the aircraft.

The following words have been declared as integers and given the values as shown:

for use in column no. 1: FLYING=1 TAXYING=2 OFFSERVICE=3 PREPARING=4
" " " " no. 2: LOADED=1 EMPTY=2 LOADING=3
" " " " no. 3: SERVICEABLE=1 SNAGGED=2
" " " " no. 4: FUELLED=1 FUELLING=2 DEFUELLING=3

Assignment statements can now be made describing the state of an entity - aircraft number I:-

```
AIRCRAFT(I,1):=PREPARING
AIRCRAFT(I,2):=LOADING
AIRCRAFT(I,3):=SNAGGED
AIRCRAFT(I,4):=FUELLING
```

} A

These statements indicate that aircraft I is

(i) being prepared for a flight

(ii) being loaded

(iii) at present unserviceable

(iv) is being refuelled.

At the beginning of a program the initial states of the entities are set up by statements such as A and are subsequently altered as necessary during execution.

6.4 Listing by Sets

The other way of listing entity states is by forming sets. For example, a set called IN AIR which has been declared as an integer, could be established to contain the names of all entities which are at present flying. Thus using attributes also, any aircraft in this set should have the value of element AIRCRAFT(I,1) set to 1, as defined above. By using this method, the number of entities in a particular state may be found without examining the attributes of each entity.

In SIMON, a set is formed by declaring an integer variable and then defining this variable as the name of a set by means of the SIMON procedure SET. For example:-

```
'INTEGER' INAIR;
SET(INAIR);
```

ensures that INAIR is the name of a set to which entities may be added.

The statement

```
ADDLAST(AIRCRAFT1,INAIR);
```

would result in the entity called AIRCRAFT1 being added to the set called INAIR, in such a way that, if the set is considered to be in the nature of a queue, AIRCRAFT1 is now in the last position. A member is withdrawn from a set by a statement such as

```
DELETE(AIRCRAFT1,INAIR).
```

6.5 Advance of Simulation Time

6.5.1 Having set up a model by defining and declaring the entities, attributes and sets required, the way in which the model changes with time must be considered. At any time, two classes of entities may exist; those which will change autonomously as a result of the passing of time, and those which will change only as a result of changes in other entities. The former are referred to as time dependent entities and the latter as time

independent entities. Each time dependent entity has, at any time, a value associated with it, and this is the time at which that entity will change state. This timevalue may be assigned a number which is either input and not altered by the program or else allocated by the program itself dependent upon prevailing conditions in the model. Simulation time thus advances in discrete jumps from one timevalue of an entity to the next earliest timevalue. At each of these "clocktimes", the associated time dependent entity has its state altered. This alteration may cause state changes in other entities which in turn may affect yet further ones. Thus before the clocktime is advanced to the next activity time as defined by the time-values, tests must be carried out, the results of which determine any further state-changes at this clocktime.

6.5.2 In Simon, all time-dependent entities must be listed in a set. This is not done automatically, and the normal listing procedures must be used to add each time dependent entity to this set. The time value of the entity is assigned using the procedure SETTIME as provided. The number to which it is set, must be an integer quantity and is usually obtained by internal computation, using input data as a base. The first activity is found by searching the time set and advancing the clocktime to the earliest time-value. This is done by the procedure SCAN.

6.5.3 The facility of sampling cumulative percentage probability distributions is provided. This is done by selecting a probability value at random by means of a random number generator (provided in semi-compiled form on cards), by finding the corresponding time from the distribution and interpolating linearly where necessary.

6.5.4 Input and output are carried out by the usual Algol procedures. However, the additional facility of forming and outputting histograms in tabular form is available. These procedures output the mean, variance and standard deviation of the histogram values.

6.6 In GATESIM, three GROUPENTITIES are declared, one representing the aircraft, one the gates available for use and the other the towing vehicles available for inter gate and gate-parking area movements.

6.6.1 The aircraft are represented by the array AIRCRAFT which is defined as having AC rows (starting at 1) and 2 columns (columns 0 and 1). AC is an integer, the value for which forms part of the input data and represents the number of aircraft which in one day will pass through the station being simulated. There are only two attributes associated with each entity. These are represented by the integers ATLHR and AWAY, and are given the values 1 and 2 respectively. Only one of these attributes can be applicable at any one time, so the array AIRCRAFT need only have two columns, the zero column being required by SIMON for internal documentation.

6.6.2 The available gates are represented by the array PARK which is declared as having ST rows (starting at 1) and 2 columns (columns 0 and 1). ST is an integer, the value for which forms part of the input data and represents the number of gates available to the airline at the station being simulated. Once again there are only two attributes, namely FULL and EMPTY, of which only one can apply to a particular gate at a specific time. Thus the array PARK, as with AIRCRAFT need have only two columns. FULL and EMPTY are assigned the values 1 and 2 respectively.

6.6.3 The towing vehicles are represented by the array TUG which has NMAX rows (starting at 1) and 2 columns (columns 0 and 1). NMAX is an integer which is assigned a value by the input data and which represents the total number of tugs which can be in use at any one time. Again there are only two attributes represented by the integers BUSY and FREE, which are assigned the values 1 and 2 respectively.

6.6.4 The attributes related to the towing vehicles and the gates describe their states sufficiently well for the simulation, but much greater detail is required when considering the aircraft. The attributes ATLHR and AWAY merely provide a broad classification. The detail required by the simulation is provided by the other listing device described in 6.4, namely by sets.

6.7 Sets Used in GATESIM

6.7.1 With one exception, the sets relate to the states of the aircraft. This exception is called TOWING and refers to the tractors.

The maximum number of tugs required at any one time forms part of the output and this necessitates a constant check being made of the number of towing vehicles in use. When a tractor represented by TUG(I,0), say, commences a tow, it is added to the set TOWING, from which it is deleted at the end of the tow. Thus the size of TOWING gives the number of tugs in use and this is much easier to evaluate than searching the attributes of each vehicle.

6.7.2 It is essential in SIMON that a set be declared to which are added all the entities which have a timevalue associated with them, the activities of which control the advance of simulation time. In GATESIM, this set is called TIMESET. The only time dependent entities are those in the array AIRCRAFT and each entity from AIRCRAFT(1,0) to AIRCRAFT(AC,0) must be added to TIMESET individually by the procedure ADDLAST. The inclusion of an entity in this set neither indicates the associated time value nor the activities to be performed at that time, but merely that the entity is time dependent. The time value is set by the procedure SETTIME which takes the form

```
SETTIME(AIRCRAFT(I,0),500);
```

The activities to be performed at time 500 will be dependent on the entity state at 500, this, in GATESIM, being defined by the membership of the entity in other sets, independent of TIMESET.

6.7.3 Nine sets (to which only the entities represented by the array AIRCRAFT can be added,) are defined and these govern the next activities to be performed by its members. The names of the sets are:

(i) FLYOUT
(ii) FLYIN
(iii) GATEC
(iv) CGATE
(v) TOCP
(vi) TOGATE
(vii) HOLDING
(viii) ERESTA
(ix) ERESTD

A specific entity can of course, be a member of only one of these sets at any given time.

6.7.4 There are in addition other four sets, namely ONGATE, INCPARK, AWAYLHR and NOTALLOC which are used to provide additional information about the entities of the array AIRCRAFT, but which are not informative as regards the next activity to be performed by their members.

6.7.5 The statements SCAN(TIMESET,MEMBER,LEASTIME);

and CLOCKTIME:=LEASTIME;

cause a search of all entities in the set TIMESET for the one which has the lowest timevalue associated with it. This entity can, in subsequent references, be identified by the use of the integer MEMBER and the timevalue associated with it is stored in LEASTIME. The second of the above two statements advances the simulation time to the value of LEASTIME.

6.7.6 Each of the sets (i) to (ix) listed in 6.7.3 is searched until the one which contains the entity MEMBER, identified by the SCAN procedure, is located. The following nine sections describe the significance of an entity's membership in one of these sets.

6.7.7 Significance of Membership in set FLYOUT

The members of this set are aircraft which are positioned on a departure gate and have been committed to a flight departure. The precise departure time has been computed during a previous activity, (section 6.7.15) but this time is not used by the simulation prior to arriving at it. Instead, if a reference to the impending departure time is necessary, an estimate of that time is used. This estimate is based on either the previous arrival time of the aircraft or the scheduled departure time dependent upon the length of the turnround time. The evaluation of this estimate is described in section 6.7.8 when considering the set FLYIN and also in 6.8 where initial conditions are discussed.

When the procedure SCAN identifies an entity which is found to belong to the set FLYOUT, the simulation time is advanced to its timevalue and the following procedures are followed:

(i) The row number in the TD array to which this entity refers, is identified by the procedure MEMNUM and the value stored in the integer I.

(ii) The column number J in the TD array which together with the integer I above define the impending departure is

ascertained by evaluating the element ACINDICES (I). This array is described in section 6.8. The impending departure has a flight number given by DEPNO(I,J) and is due to leave from gate number GDEP(I,J). NUM is given the value of GDEP(I,J).

(iii) The one attribute of MEMBER is set to AWAY by the statement AIRCRAFT(I,1):= AWAY.

(iv) MEMBER is deleted from the set FLYOUT.

(v) MEMBER is deleted from the set ONGATE.

(vi) MEMBER is added to the set AWAYLHR.

(vii) The element of the array GTD referring to this departure is given the value of the simulation time.

(viii) The attribute of the entity PARK(NUM,0) is set to EMPTY by the statement PARK(NUM,1):=EMPTY.

(ix) The current value of the simulation time is added to the histogram GONE which is described in section 6.10.2.7.

(x) The punctuality of the flight is ascertained by comparing simulation time to TD(I,J). The TA and TD arrays are never updated to include late or early movements, and so always contain the scheduled movement time.

(xi) The punctuality figure, which is negative for an early movement and positive for a delay, is added to the histogram DEPHIS described in section 6.10.2.5.

(xii) Details of simulation time, flight number, departure gate number, punctuality and aircraft type can be printed.

(xiii) If the aircraft does not return to the station on the same day, it is deleted from TIMESET and the following (xiv) to (xvi) are omitted.

(xiv) The entity is added to the set ERESTA.

(xv) An estimate of the time of air debrief is made and the time value of the entity reset to this.

(xvi) The estimated time of arrival of the aircraft is computed and the return arrival flight is identified on the gate timetable. The time of this flight is updated only on the gate plan.

(xvii) The TIMESET is now checked for any further activities, and if it is empty the simulation is ended. Otherwise the clock time is reset and further activities occur dependent on the set to which the newly identified entity belongs.

6.7.8 Significance of Membership in set FLYIN.

The members of this set are aircraft which have completed the air-debrief and whose arrival times have been computed. These times can be used by GATESIM if necessary due to the accuracy with which, in practice, they can be estimated at the time of air-debrief.

When the procedure SCAN identifies the entity with the lowest timevalue, it is identified by the integer MEMBER which, if it is found to belong to the set FLYIN, causes the following procedures to be followed:

(i) The current value of the simulation time is added to the histogram COME which is described in 6.10.2.8.

(ii) The row number in the TA array to which this entity refers, is identified by the procedure MEMNUM and stored in the integer I.

(iii) The column number J, in the TA array which together with the integer I above identifies the arrival as being flight number ARRNO(I,J) to gate GARR(I,J) is evaluated.

(iv) The attribute of the entity is set to ATLHR.

(v) The planned arrival gate, number NUM, is given by GARR(I,J).

(vi) The entity is deleted from the sets FLYIN and AWAYLHR.

(vii) The punctuality of the arrival is evaluated.

(viii) If gate NUM is vacant then activities (ix) to (xvii) are performed, otherwise activities (xviii) to (xxii) are carried out. In each case, (xxiii) and (xxiv) are implemented.

(ix) The punctuality of the arrival is added to the histogram ARRHIS which is described in 6.10.2.4.

(x) The element of the array GTA referring to this arrival is given the value of the simulation time.

(xi) The attribute of the entity PARK(NUM,0) is set to FULL.

(xii) The entity AIRCRAFT(I,0) is added to the set ONGATE.

(xiii) The next movement is ascertained by comparing the value of the element of the array GDEPNO which refers to AIRCRAFT(I,0)'s present occupancy, to the value of the aircrafts next departure as given by the appropriate element in the array DEPNO.

(xiv) If these have the same value, then the aircraft is scheduled to remain on the gate for departure DEPNO(I,J) and the aircraft is added to the set ERESTD.
The ground time available to the aircraft before its next scheduled departure is studied and if this is greater

than the minimum turnround time then the timevalue of the entity is set to TD(I,J)-10. This represents the time when the actual departure time will be computed. In addition, the timevalue of PARK(NUM,0) is set to TD(I,J) which at this stage is the best estimate of the actual departure time. However, if the turnround time is below the minimum required, the timevalue of the aircraft is set to CLOCKTIME+M1-10 and of the gate to CLOCKTIME+M1 where M1 is the minimum turnround time in minutes.

(xv) If DEPNO(I,J) and GDEPNO(NUM,COL+1) have different values, then aircraft(I,0) is scheduled either to remain on the gate and perform no further departure or else to be towed to a parking area to return for a later departure.

(a) In the former case, the aircraft entity is deleted from TIMESET, and added to set NOTALLOC. The timevalue of the gate is set to zero.

(b) If a tow is scheduled, the aircraft entity is added to the set GATEC and its timevalue, together with that of the gate, is set to the value of the simulation time plus the preparation time necessary for a tow.
If the aircraft has no further scheduled departures, it is added to the set NOTALLOC.

(xvi) The value of GTINDEX(NUM) is incremented by one.

(xvii) The time of the impending gate departure as held in the gate entity timevalue is used to update the relevant element of array GTD. The next activity obeyed is (xxii).

Activities (xviii) to (xxi) are performed only if the gate is found to be full on arrival.

(xviii) The estimated delay time before entering this gate is computed by comparing the simulation time to the relevant entry in array GTD.
The maximum acceptable hold time is held in the integer HOLD.

(xix) If the delay time is not acceptable, the procedure GATEALTER is called, and the new gate number stored in NUM. This could well be the same gate if all other changes involved a greater delay than that for the original gate.
The boolean array DIVERT is one dimensional having the total number of gates at its only dimension. By setting DIVERT(NUM) to the value 'true', it is indicated that the aircraft now planned for gate NUM is involved in a delay attributable to gate shortage.

Activity (xx) is omitted if (xix) was executed.

(xx) The time at which the delay commenced is stored in the array element HOLDSTART(NUM).

(xxi) The aircraft entity is added to the set HOLDING and has its time value incremented by 1 minute.

(xxii) If no entries remain in TIMESET the simulation ceases, otherwise TIMESET is scanned to identify the entity with the next lowest time value.

6.7.9 Significance of Membership in set CGATE.
Each member of this set is an aircraft positioned in a non-operational parking area, awaiting tow to a gate for flight departure. The planned time of the tow start is set during the activities carried out in 6.7.11, or else forms part of the initial conditions described in 6.8.
When it is discovered by SCAN that the entity with the lowest timevalue is a member of the set CGATE the following activities are performed:

(i) The row number of the arrays TD,DEPNO and GDEP to which this entity refers is stored in the integer I.

(ii) The column number J of the arrays TD,DEPNO and GDEP, such that the impending departure of aircraft I has the flight number given by DEPNO(I,J), is evaluated.

(iii) The planned departure gate number is stored in NUM.

(iv) A search is made to ascertain if any towing vehicles are available and, if none are, this information can be printed and the aircraft entity has its timevalue set to CLOCKTIME+5.

No alterations are made to the contents of any set and no activities are performed. The activities (v) to (xvii) are omitted and the next instruction is number (xviii) below.

(v) If there is a vehicle available then the activities (vi) to (xvii) are executed.

(vi) The current value of the simulation time is added to the histogram TRACTORS which is described in 6.10.2.10.

(vii) The attribute of the entity TUG(N,0), where N is the vehicle number (ranging between 1 and NMAX), is set to BUSY.

(viii) The simulation time is recorded in the array element TOWSTART(N).

(ix) For use at other activity points in the simulation, it is recorded that the vehicle number N is towing aircraft number I. This is done by using the array TOW(1:AC) and by the statement TOW(I):=N.

(x) The entity AIRCRAFT(I,0) is deleted from the sets CGATE and INCPARK.

(xi) AIRCRAFT(I,0) is added to the set TOGATE.

(xii) The vehicle given by TUG(N,0) is added to the set TOWING.

(xiii) The timevalue of the aircraft is set to the value of (clocktime + a sample taken from the distribution of towing times).

(xiv) A test is now carried out to ascertain if the gate occupancy which this aircraft will form is in fact the one which was planned to be consecutive to the previous movement on the gate. Consider the gate represented by the following bar chart:



A1,A2,A3 represent planned arrivals

D1,D2,D3 represent planned departures

Let A2 be the arrival of the aircraft under tow being considered here.

If D1 was the last departure from the gate, the next occupancy, as far as the arrays GTA,GTD,GARRNO,GDEPNO, ARRG and DEPG are concerned, will commence with the arrival A1. However if flight A1 has a large inbound delay, then A2 could occur before the arrival of A1 in which case the gate timetable arrays must be amended. Hence the above test is carried out and any necessary changes made.

(xv) If the planned departure gate is occupied at the start of the tow, a check is made to ensure that it will be vacant to accept the towed aircraft after a tow time again assumed to have the value of AVTOW. If it will not be free, the procedure GATEALTER is called to perform a gate change.

(xvi) The element in the GTA array which refers to this entity's arrival is set to the value of CLOCKTIME+AVTOW, since in practice the estimates of the time taken for a tow are not accurate. This is because the vehicles are under the Airport Ground Movement Control which is independent of the airline and which has responsibility for all movements within the taxiways. It would therefore be unwise to allow the simulation to use the actual arrival time which it computed previously. (Item (xiii) above).

(xvii) The value of CLOCKTIME, the aircraft number, the planned departure flight number, the planned departure gate and the punctuality of the start of the towing movement can be printed.

(xviii) The set TIMESET is re-scanned to identify the entity with the lowest timevalue.

6.7.10 Significance of Membership in the set GATEC

Each member of this set is an aircraft positioned on an operational gate awaiting a tow to a parking area. Membership of GATEC does not indicate whether the aircraft is scheduled to return later in the day to a gate for a departure. The earliest time at which the tow can start is the summation of the time of arrival of the aircraft at the gate plus the minimum occupancy time.

When it is discovered by SCAN that the entity with the lowest time value is a member of GATEC, the following activities are performed:

(i) The row number of the arrays TA,ARRNO and GARR which refers to the previous inbound flight of this entity, is stored in the integer I.

(ii) The column number J of the same arrays, which defined the immediately prior arrival of aircraft number I as being ARRNO(I,J), is evaluated.

(iii) The gate being occupied by the entity is stored in NUM.

(iv) If there is a further occupancy planned for this gate or if this aircraft is scheduled for a subsequent flight the next activity performed is (viii).

(v) As explained in 6.8.7, the last occupancies on each gate are represented on GDEPNO as all requiring a tow to a parking area. This was done to indicate the possible vacant time after the last arrival on each gate.

(vi) If the aircraft entity is the last planned occupancy of its gate but there are still some flight arrivals outstanding at the station, then the time value of the entity is incremented by 5 minutes and the entity is not deleted from GATEC. Thus the imminent flight arrivals can consider that gate NUM will be available at the new timevalue for an unschedule occupancy.

(vii) If flight arrivals have been completed, the tow is cancelled and the aircraft entity is deleted from the sets GATEC and TIMESET.

(viii) A search is made to ascertain if any towing vehicles are available and if none are, the entity has its timevalue set to CLOCKTIME+5. No alterations are made to the contents of any sets, and the next instruction performed is (xviii) below. If there is a tractor available, the activities continue with (ix) below.

(ix) The allocation of a tractor to the tow is recorded in the histogram TRACTORS.

(x) The element of the GTD array referring to this entity's occupancy is given the value of CLOCKTIME.

(xi) The starting time of the tow is recorded in the array TOWSTART by the statement TOWSTART(N):=CLOCKTIME where N is tractor number being used.

(xii) The tractor number N being used by aircraft number I, is recorded in the array TOW by the statement TOW(I):=N.

(xiii) The attribute of TUG(N,0) is set to BUSY.

(xiv) The aircraft is deleted from the sets GATEC and ONGATE and added to the set TOCP.

(xv) The attribute of the entity PARK(NUM,0) is set to EMPTY.

(xvi) The entity TUG(N,0) is added to the set TOWING.

(xvii) The timevalue of the aircraft is set to the value of CLOCKTIME+ a sample taken from the distribution of towing times.

(xviii) If no members remain in the set TIMESET, the simulation ceases, otherwise a further call to procedure SCAN is made.

6.7.11 Significance of Membership in set TOCP

Each member of this set is an entity representing an aircraft which is in the process of being towed from a gate position to a parking area. The time of arrival at its parking position was determined at the start of the tow by the activity described in 6.7.10.

When it is discovered by SCAN that the entity with the lowest timevalue is a member of TOCP, the following activities are performed:

(i) The row number of the arrays TA,TD, etc., to which this entity refers is stored in the integer I.

(ii) The column number J of the arrays TA,TD, etc., such that the immediately preceding arrival of the aircraft I had the flight number ARRNO(I,J), is evaluated.

(iii) The gate number from which the aircraft departed is stored in the integer NUM.

(iv) The number of the towing vehicle is given by the value of TOW(I) and is stored in N.

(v) The time taken for the tow is evaluated by deducting the value of the element TOWSTART(N) from the current simulation time and is stored in the integer TOWT.

(vi) The value of TOWT is added to the histogram TOWHIS to compile a distribution of the occurrence of tows of which the durations lie within certain ranges. These bands start at 15 minutes and increase in increments of 5 minutes to the last finite range of 60 - 65 minutes.

(vii) The attribute of the entity TUG(N,0) is set to FREE.

(viii) The aircraft is deleted from the set TOCP and the towing vehicle is deleted from the set TOWING.

(ix) The aircraft is added to the set INCPARK.

(x) If the aircraft is not scheduled to perform any further flights that day, it is deleted from the set TIMESET and added to the set NOTALLOC.

(xi) If it has a later flight to perform it is added to the set CGATE and has its timevalue set to the value of TD(I,J)-TOWASK where TD(I,J) is its next scheduled departure time and TOWASK contains a value set by the

input data to be the minimum time between the start of a tow and the scheduled departure time. A check is made to ensure that this timevalue is greater than the current simulation time since, if the tow from the gate took an inordinately long time, the reverse situation could exist. In this case the timevalue is set to the value of CLOCKTIME, i.e. the aircraft has its return tow started immediately.

(xii) The value of CLOCKTIME, the aircraft number, the gate number from which the tow commenced and its arrival in the parking area can be recorded on the line printer.

(xiii) If no members remain in the set TIMESET, the simulation ceases, otherwise a further call to procedure SCAN to identify the entity with the next lowest timevalue is made, and the relevant activities performed.

6.7.12 Significance of Membership in the set TOGATE

Each member of the set TOGATE is an entity representing an aircraft which is in the process of being towed to a gate position from a parking area, and for which the next activity should be its arrival on the gate planned for its next flight departure. The timevalue of each entity in TOGATE is the time at which it will arrive on its gate if it is found to be vacant. This time is set during the activities described in 6.7.9. When the procedure SCAN identifies the entity with the lowest timevalue as belonging to TOGATE, the following activities are performed:

(i) The row number of the arrays TA,TD,etc., to which this entity refers is evaluated by the procedure MEMNUM and stored in the integer I.

(ii) The column number J of the arrays TD,DEPNO and GDEP, such that the impending departure of aircraft I has the flight number DEPNO(I,J), is evaluated.

(iii) The gate number to which the aircraft is being towed is given by the value of GDEP(I,J) and is stored in NUM.

(iv) The tractor number performing the tow is stored in N.

(v) If the attribute of the entity PARK(NUM,0) has a value equal to that of EMPTY, the instructions (vi) to (xvi) are obeyed. Otherwise a jump is made to instruction (xvii) below.

(vi) The value of the element of the GTA which refers to this arrival on gate NUM, is updated by setting it to the current value of the simulation time.

(vii) The time taken to perform the tow is evaluated and added to the distribution TOWHIS.

(viii) The attribute of entity PARK(NUM,0) is set to the value of FULL.

(ix) The aircraft is deleted from the set TOGATE and added to the set ONGATE.

(x) The entity TUG(N,0) is deleted from the set TOWING, and its attribute is given the value of FREE.

(xi) If the aircraft is not scheduled to depart on a flight until after midnight, it is deleted from the set TIMESET. The current value of the simulation time, the aircraft and gate numbers, and the fact that no further departures will be made by this aircraft can be listed on the line printer. The next instruction obeyed is (xviii) below.

(xii) The aircraft is added to the set ERESTD.

(xiii) The aircraft must arrive at least M1+15 minutes before the scheduled departure time, for the first estimate of the actual departure time to be on schedule. For every minute less than M1+15 of available gate time, the estimate of departure time is increased by one minute beyond the scheduled time. For example, if the aircraft arrives 30 minutes before scheduled departure time, and if M1 has the value of 30, the estimate of the actual departure time will be (STD+15).

(xiv) The timevalue of the aircraft is set to the value of the estimate of the time of departure minus 10 minutes.

(xv) The element in the GTD array which refers to this departure is set to the estimated time of departure.

The next activity performed is (xviii) below.

(xvi) Instruction (xvii) is obeyed only when the gate is found to be occupied on arrival.

(xvii) If the estimated time when the gate will be free is found to be less than 45 minutes before the aircraft's STD, the procedure GATEALTER is called to find a new gate

for this occupancy. If this is not possible, the aircraft must wait for the original gate to be vacated and the following are performed; otherwise only instruction (xviii) is followed.

(a) The time when the gate hold commenced is recorded by the assignment HOLDSTART(NUM):=CLOCKTIME.

(b) The fact that the holding aircraft is under tow and is not an inbound operational flight is indicated by setting the element INBOUND(I) to 'false'.

(c) The aircraft is deleted from the set TOGATE and added to the set HOLDING.

(d) The timevalue of the aircraft is increased by 1 minute.

(e) The integer MAXHOLD which records the number of aircraft which hold for a gate throughout the 24 hour period is increased by 1.

(xviii) If there are no members in the set TIMESET, the simulation is ended, otherwise, the procedure SCAN is recalled and further activities performed dependent on the set to which the selected entity belongs.

6.7.13 Significance of Membership in the set ERESTD

Each member of this set is an entity representing an aircraft which is positioned on a gate, and is committed to a flight departure. The timevalue of each entity has been allocated during the activities performed when the aircraft arrived on the gate and corresponds to a time 10 minutes before the first estimate of the actual departure time. It is this estimate which, if required, the simulation has been using when considering other gate or aircraft changes. In practice, the engineering pre-departure check has been completed at this stage and a good estimate of the actual departure time can be made.

When the procedure SCAN identifies the entity with the lowest timevalue as being a member of ERESTD, the simulation time is advanced to the timevalue of the selected entity and the following activities performed:

(i) The row number of the arrays TD,DEPNO and GDEP to which this entity refers is evaluated by the procedure MEMNUM and stored in the integer I.

(ii) The column number J of the arrays TD,DEPNO and GDEP, such that the impending departure of aircraft I is given by DEPNO(I,J), is evaluated.

(iii) The gate on which the aircraft is positioned is given by the value of GDEP(I,J) and is stored in the integer NUM.

(iv) The time of departure is computed by adding the current value of the simulation time to a random sample taken from the distribution FORATD. The formation of this distribution is described in 6.9.3.

(v) The element of the array GTD referring to this departure is set to this computed value.

(vi) The timevalues of the entities AIRCRAFT(I,0) and PARK(NUM,0) are also set to the actual departure time.

(vii) The entity AIRCRAFT(I,0) is deleted from the set ERESTD and added to the set FLYOUT.

(viii) The procedure SCAN is recalled to identify the entity with the lowest timevalue and further activities, dependent upon the set to which the selected entity belongs, are initiated.

6.7.14 Significance of Membership in the set ERESTA

Each member of this set is an entity representing an aircraft which is away from the station and which has its timevalue set to the value of the estimate of its arrival time back at the station, minus twenty minutes. In practice, the estimated arrival time of an inbound flight is made when it has departed from its last stopping point, and, much more accurately, when it is within range of the approach control radar of its destination. This normally occurs about twenty minutes before landing. At this point, some airlines, including BEA, require the flight crew to contact the airline on a private radio frequency to report its latest estimate of arrival. Other airlines, however, monitor the approach control frequency and the estimate of the arrival time is made by ground staff. Irrespective of the method, a good estimate is available about twenty minutes before arrival. This time is called the "air debrief time".

When the timevalue of an entity belonging to ERESTA is reached an attempt is made to simulate the activities which would be performed by the airline ground staff on receipt of the final

estimate of an aircraft's arrival time. It is necessary to test whether the planned gate for the arrival will be vacant and whether the arrival time will allow sufficient ground time for its subsequent departure, if any. Thus, when it is discovered by SCAN that the entity with the lowest timevalue is a member of the set ERESTA, the following activities are performed:

i) The current value of the simulation time is added to the histogram DEBRIEF which is described in 6.10.2.9.

ii) The row number of the arrays TA, ARRNO and GARR to which this entity refers is evaluated by the procedure MEMNUM and stored in the integer I.

iii) The column number J of the arrays TA, ARRNO and GARR such that the impending arrival of aircraft I has the flight number given by ARRNO(I,J), is evaluated.

iv) The planned arrival gate is given by GARR(I,J) and is stored in the integer NUM.

v) The actual time of arrival is computed by adding a random sample of the distribution FORATA to the current value of the simulation time.

vi) The simulation time, the flight number, the fact that it has been air-debriefed, its planned arrival gate and its arrival time can be listed on the line printer.

vii) The aircraft is deleted from the set ERESTA and added to the set FLYIN.

viii) The timevalue of the entity AIRCRAFT(I,0) is set to the computed time of arrival.

ix) As in 6.7.9, instruction (xiv), a test is carried out to ensure that the gate occupancy which this aircraft will form is in fact the one which was planned to be consecutive to the previous movement on the gate. If it is not, then changes are made to the arrays GTA,GTD,GARRNO,GDEPNO,ARRG and DEPG so that, if the last movement on the gate is given by flight number GDEPNO(NUM,N), then the impending arrival has its actual arrival time, its flight number, and its aircraft cycle number stored in column N of the arrays GTA,GARRNO and ARRG respectively. For example, if the impending arrival is planned to remain on its arrival gate for the rest of the day,

then the other arrival, scheduled to precede the one of aircraft I, would find its gate occupied with no prospect of its being vacated. Thus a gate change would be necessary. By altering the arrays at this stage, this situation can be foreseen and a tow planned to allow the gate to be free for the late arriving aircraft. Even though this isolated example were not applicable, the changes are necessary to keep intact the cross references between the gate timetable arrays and the aircraft integrations.

(x) The element of the GTA array referring to the impending arrival is updated to contain the value of the actual arrival time as opposed to the estimate.

(xi) If the planned arrival gate is at this stage occupied and is estimated to remain so until after the arrival time, a gate hold will not be accepted. This was decided because the actual arrival time is known, but the departure time for the aircraft on the gate is only an estimate and an early gate change, even an unnecessary one, causes little inconvenience. On the other hand, a late one, which could possibly be required when the actual departure time becomes apparent, causes considerable disruption.

If the inbound aircraft is scheduled to remain on the arrival gate until a later departure, and if the available ground time is not less than the minimum turnround time, then the procedure GATEALTER is called to perform a gate change for this occupancy. If the available ground time is not sufficient to allow an on-time departure, the procedure ALLCHANGE is called to perform an aircraft change and to make the necessary incurred gate changes.

However, if the aircraft is scheduled to be towed to a parking area, and to be returned later to a gate for a departure, a check is made to ensure that there is sufficient time to perform this towing sequence. If there is, GATEALTER is called to change the gate for the arrival, the departure gate being left alone. If the available time is not sufficient, the arrival is transferred to the planned departure gate and the arrays

GTA, GARRNO and GARR altered accordingly. If this arrival cannot be accommodated on the departure gate because of the previous occupancy, GATEALTER is called to change the gate for the complete ground time.

Finally, if the aircraft is scheduled to be towed to a parking area and is not scheduled to return to a gate during the simulation period, the occupancy formed by the arriving aircraft has its gate changed by the procedure GATEALTER.

After the instruction (xi), the next one obeyed is number (xv) below.

Instructions (xii) to (xiv) apply only when the arrival gate is estimated to be vacant for the inbound aircraft. Only one of these three instructions will be obeyed for any one arrival.

xii) If the aircraft is planned to operate a departure from its arrival gate, a check is made to ensure that the available ground time is not less than the minimum turnround time. If it is, aircraft changes are performed by the procedure ALLCHANGE. Otherwise, no changes are made.

The next instruction obeyed is (xv) below.

xiii) If the aircraft is planned to be towed to a parking area where it is to remain for the remainder of the day, a check is made to ascertain whether the arrival immediately following this tow is confronted with an occupied gate or not. If the gate will still be occupied, and if the later occupancy is terminated with a flight departure, then the occupancy formed by the aircraft being studied in this section has its gate altered by procedure GATEALTER. This is in accordance with the policy of preference being given to departing flights insofaras adherence to the original gate plan is concerned. If the later occupancy is not terminated with a flight departure, any alteration to the gate plan is postponed until the time of air-debrief of the later arriving flight.

The next instruction obeyed is (xv) below.

(xiv) If the aircraft is due to be towed to a parking area before return to a gate for a departure, a check is performed to ascertain if there is sufficient ground time available to perform the towing sequence. If there is, no changes are made to either the gate timetable or the aircraft integrations. If the available time is insufficient the arrival is transferred to the departure gate so that in the arrays GTA and GARRNO, the start of the occupancy which terminates with the departure DEPNO(I,J) represents a flight arrival and not a tow-on as planned. A test is now made to ensure that the arrival can be accommodated on its new gate. If not, the procedure GATEALTER is called to perform a gate change for the complete occupancy.

(xv) The procedure SCAN is called to identify the entity with the lowest timevalue and, dependent on the set to which this entity belongs, further activities are initiated.

6.7.15 SIGNIFICANCE OF MEMBERSHIP IN THE SET HOLDING

Each member of this set is an entity representing an aircraft which is on the ground waiting for its planned gate to become vacant. The aircraft could be under tow in which case its previous activity would have been its departure from a parking area described in 6.7.9. Otherwise, its previous activity would have been a landing, when the activities specified in section 6.7.8.were carried out. In both case the projected holding time for its gate was considered acceptable.

When it is discovered by the procedure SCAN that the entity with the lowest timevalue is a member of the set HOLDING, the following activities are performed:

(i) The row number of the arrays TA,TD,ARRNO,DEPNO,GARR and GDEP, to which the aircraft which is holding for its gate refers, is evaluate by procedure MEMNUM and stored in the integer I.

(ii) The column number J of the above arrays, such that the next departure of the aircraft I is defined by DEPNO(I,J), is evaluated.

iii) If the value of the Boolean array element INBOUND(I) is found to be "true" then the aircraft has just landed on an inbound flight. The gate number NUM is given by the value of the array element GARR(I,J). The current value of the simulation time and the flight number can be printed.

iv) If INBOUND(I) is found to have the value "false", then the aircraft has been towed from a parking area for a departure, so the gate number NUM is given by the value of GDEP(I,J). The current value of the simulation time and the aircraft number I can be printed.

v) If the gate number NUM is still occupied, i.e. PARK(NUM,1) = FULL, then this information can be printed on the line printer and the timevalue of the entity is increased by one minute. In addition, if this aircraft is operating an inbound flight and was diverted from its originally planned gate to this gate, number NUM, on landing, the Boolean array element DIVERT (NUM) would have been set to the value "true" during the activities described in section 6.7.8. In this case, the time at which the hold commenced was not recorded. This is done now with the statement HOLDSTART(NUM) = CLOCKTIME. The value of DIVERT(NUM) is reset to "false", indicating, when the next check for the gate availability is made, that the aircraft waiting entry has had the time when it started the holding period already recorded.

The next activity performed is number (xxv) below.

vi) Only when the attribute of the entity PARK(NUM,0) is found to equal the value of EMPTY are the instructions (vii) onwards obeyed.

vii) The attribute of the entity PARK(NUM,0) is set to the value of FULL.

(viii) The element of the array GTA which refers to the arrival of aircraft I on to gate NUM is set to the current value of the simulation time.

(ix) The entity AIRCRAFT(I,0) is deleted from the set HOLDING and added to the set ONGATE.

(x) If the Boolean array element DIVERT(NUM) has the value 'true' then this aircraft has been diverted to gate NUM immediately on landing and has not held for a gate. The value is altered to 'false' and the next instruction obeyed is number (xii) below.

(xi) The number of minutes for which the aircraft waited is computed, the value added to the histogram GATEQ and also listed on the line printer.

(xii) If the Boolean array element INBOUND(I) has the value 'false' the next instruction obeyed is (xvii) below; otherwise the aircraft is operating an inbound flight and instructions (xiii) to (xvi) are followed.

(xiii) The deviation of the actual arrival time from the scheduled one is computed, and added to the histogram ARRHIS.

(xiv) If the aircraft is planned to remain on the arrival gate until a later flight departure, it is added to the set ERESTD. If the available ground time is greater than the minimum turnround time, timevalues of the entities AIRCRAFT(I,0) and PARK(NUM,0) are set to the values of TD(I,J)-10 and TD(I,J) respectively. Otherwise the timevalues are CLOCKTIME + (M1-10) and CLOCKTIME + M1 respectively.

(xv) If the aircraft is planned to remain on the gate until the end of the simulation, it is added to the set NOTALLOC and deleted from TIMESET. The timevalue of PARK(NUM,0) is set to zero.

(xvi) If the aircraft is due to be towed to a parking area, the entity AIRCRAFT(I,0) is added to the set GATEC and has its timevalue set to the value of CLOCKTIME + M1. The timevalue of the entity PARK(NUM,0) is set to the same value.

The next instruction obeyed is (xxiv) below, the statements (xvii) to (xxiii) applying only to aircraft arriving under tow.

(xvii) The entity AIRCRAFT(I,0) is added to the set ERESTD.

(xviii) The estimate of departure time is computed in an identical way to that in section 6.7.12, item (xiii).

(xix) The timevalue of the aircraft is set to this estimate minus 10 minutes.

(xx) The timevalue of the entity PARK(NUM,0) is set to the departure time estimate.

(xxi) The towing vehicle number N is given by the value of the array element TOW(I).

(xxii) The attribute of the entity TUG(N,0) is given the value of FREE, and the entity itself is deleted from the set TOWING.

(xxiii) The elapsed time between the start of the tow and final positioning on the gate is calculated and added to the histogram TOWHIS.

(xxiv) The element of the GTD array which refers to the departure of this aircraft from the gate is given the value of the timevalue of the entity PARK(NUM,0). If no such departure is planned, the element assumes the value zero because of the instruction (xv) above.

(xxv) If there are no members remaining in TIMESET, the simulation ceases; otherwise the procedure SCAN is called to identify the entity with the lowest timevalue and dependent on the set to which the entity belongs, further activities are initiated.

6.8 Initial Conditions.

6.8.1 Before the start of the simulation, it is necessary to add each time dependent entity to the set TIMESET and to allocate each one a timevalue. By studying the first element of each row of the arrays TA, GARR, GDEP and DEPG, the first activity of each of these entities is ascertained, and the entity is added to the set which will cause the relevant activity to be implemented when the associated timevalue is reached. By referring to the codes described in sections 4.1 to 4.6, the initial conditions can be set up as follows, I being the aircraft number in the range 1 to AC where AC contains the value of the total number of aircraft using, on one day, the station being simulated.

6.8.2 If TA(I,1)> 0, the entity AIRCRAFT(I,0) has a landing on an inbound flight as its first activity. This is reflected by:

i) setting the attribute of the entity to the value of AWAY.

ii) adding the entity to the sets AWAYLHR and ERESTA.

iii) setting the timevalue of the entity to the value TA(I,1)-20.

6.8.3 If GARR(I,1)=GDEP(I,1), the entity AIRCRAFT (I,0) is positioned on a gate from which a scheduled departure is planned to be made. This is reflected by:

i) setting the attribute of the entity to the value of ATLHR.

ii) adding the entity to the sets ONGATE and ERESTD.

iii) setting the timevalue of the entity to the value of TD(I,1)-10.

6.8.4 If neither of the above two conditions apply, the aircraft has a departure as its first flight movement, but has not commenced the gate occupancy which will be terminated by that departure. At the start of the simulated period, it may be positioned on a gate, even its departure gate, or else in a parking area. In either case, the equality GARR(I,1)=2000 indicates that the aircrafts first departure is preceded by a tow on to its gate. It is therefore necessary to ascertain its initial location so that its first tow can be defined as either a tow-off a gate or else a tow from a parking area to its departure gate. This is

6.8.4 done as follows:

Consider gate number NUM. If this gate is not occupied at the start of the simulation, DEPG (NUM,1) will have zero value. Even though the above aircraft (I) has its tow-on and subsequent flight departure as the first occupancy of gate NUM, the value of DEPG(NUM,1) will still be zero. However, if the gate is occupied at time nought, DEPG(NUM,1) will contain the cycle number of the occupying aircraft. Its departure may be formed by a flight or a tow-off.

When the above aircraft (I) is being considered and

TA(I,1)=0 and GARR(I,1) $\neq$ GDEP(I,1),

its location is ascertained by testing the equality DEPG(NUM,1) = I where NUM is varied from 1 to the maximum number of gates.

The aircraft is located on gate NUM if the equality is satisfied, and its initial conditions are set as:

i) The entity AIRCRAFT(I,0) is added to the sets ONGATE and GATEC.

ii) GARR(I,1) is assigned the value of the gate being occupied. This could not be done by the input data because the aircraft may be positioned on its planned first departure gate in which case the equality GARR(I,1) = GDEP(I,1) would have been satisfied and the activities described in section 6.8.3 would have been obeyed.

iii) The timevalue of the entity is set to the value of GTD(NUM,1).

iv) The attribute of the entity is given the value of ATLHR.

If the equality is not satisfied, the aircraft must initially be in the parking area, requiring the following assignments:

i) The entity AIRCRAFT(I,0) is added to the sets INCPARK and CGATE.

ii) The entity's timevalue is set to the value of TD(I,1)-TOWASK.

iii) The attribute of the entity is given the value of ATLHR.

6.8.5 For each value of I, the entity AIRCRAFT(I,0) is added to the set TIMESET. The array elements INBOUND(I) and ACINDICES(I) are set to "true" and 1 respectively. The function of both these arrays are described in 6.8.7.

6.8.6 The entities representing the gate positions must also have their initial states set.

If GTD(NUM,1)=0, the gate is initially empty and the attribute of the entity PARK(NUM,0) is set to the value of EMPTY. Otherwise the attribute is assigned the value of FULL. The array elements GTINDEX(NUM) and DIVERT(NUM) are given the values 1 and 'false' respectively. The significance of both these arrays are described in the following section.

6.8.7 When the procedure SCAN identifies AIRCRAFT(I,0) as having the lowest timevalue, the integer I defines in the integration arrays the row number and hence the flights to which the aircraft is allocated. The specific flight number and time is not identifiable from this. It is not possible to compare the entity's timevalue with the times in the TA and TD arrays to ascertain the relevant movements, since the arrays contain only scheduled flight times. It is necessary to maintain a record, for each aircraft cycle, of the column number, J (say) which will identify the next planned flight movement as being either ARRNO(I,J) or DEPNO(I,J). This record is held in the one dimensional array ACINDICES(1:AC) where AC is the number of aircraft cycles. The value of ACINDICES(I) commences at 1 and is incremented by 1 after each flight departure. A flight arrival causes no change in its value.

Similarly, the identification of a gate number NUM does not specify the next planned movement on the gate. The one dimensional array GTINDEX(1:ST) where ST is the total number of gates, maintains precisely the same record as ACINDICES above. The value of GTINDEX(I) commences at value 1 and is incremented by 1 after each gate arrival. A gate departure does not alter its value.

6.8.7 The Boolean arrays INBOUND and DIVERT both relate to conditions applying when gate holds are encountered.

The array INBOUND is one dimensional with the same number of rows as the TA array. When an aircraft is positioned in the parking area, its next gate is automatically a flight departure one, given by the relevant element in the GDEP array. However, when the aircraft is in the set HOLDING, it may be under tow or forming a flight arrival. In the latter case the arrival gate is held in the GARR array, while in the former, the GDEP array provides the correct value. If the value of INBOUND(I) is 'false', the movement is a tow-on to gate given by GDEP(I,J).

The array DIVERT is one dimensional with the same number of rows as the gate plan arrays. The set HOLDING is primarily intended to list aircraft actually undergoing a gate hold, the duration of which is finally recorded in the histogram GATEQ. However, it is also utilised when a gate arrival, either under tow or on a flight, experiences a late gate change when following the procedures under TOGATE and FLYIN, as described in 6.7.12 and 6.7.8 respectively. If the new gate, NUM, is empty it is essential that a zero length gate hold is not entered into GATEQ. Under such conditions, DIVERT(NUM) is set to 'true' immediately the new gate is identified thus allowing a false entry in GATEQ to be avoided.

6.8.8 The initial positions of aircraft are seen to be derived from the integration and gate plan arrays, according to the conventions outlined in 4.1 to 4.6. The progress throughout the simulation is recorded by the above four arrays. However, the gate plan arrays as represented above, will undoubtedly contain some occupancies which continue into the next operating day. Such gates are regarded by the simulation as unavailable after the last scheduled arrival unless a tow-off can be arranged.

The simplest way of creating one is at the initial condition stage. If GARRNO(I,J) is the last gate arrival and GDEPNO(I,J) is assigned on input as one of the insignificant values, this is altered to the

6.8.8 value 2000, implying a tow. However, when the tow time arrives and no further occupancy has been re-scheduled on to the gate, the tow is cancelled and re-timed to occur five minutes later. The process is continued until all planned movements have occurred. The tow is then cancelled completely.

6.9 Input Data.

The simulation program reads data from two sources:-

i) An allocated disc file called TODISC which contains control data, aircraft integrations and the gate plan.

ii) A pack of data cards containing data on the number of days to be simulated, the starting value for the random number generator, and the delay distributions to be used.

6.9.1 Disc file TODISC.

6.9.1.1 Since the simulation is performed on a daily basis with no link up between days, it is necessary to re-set the initial conditions after each period. This is done by 'rewinding' the file and re-reading the data. In addition, the calculation of the gate timetable reliability requires the initial gate plan to be compared with the achieved one. Since this is done at the completion of a simulated period, it is less wasteful of core store to re-input the initial plan from TODISC into now redundant arrays, say DEPG and ARRG, than to maintain separate reference arrays whose only function is the retention of input data.

6.9.1.2 The disc may be a permanent one or may be named and have data allocated to it by a small program which precedes the main simulation run. The latter was chosen after advice relating to possible unauthorised use of the simulation and its supplied data. The file set up program does not warrant description; suffice to say that it names a scratch disc area, reads data from cards and transfers them to the named area.

6.9.1.3 There are three types of input data cards. viz:

i) A series of nine integer values all of which are mandatory. These are described in 6.9.1.4.

ii) A set of integer values, the number of which is given by one of the values of the type i) card. Type ii) cards are described in 6.9.1.5.

iii) A set of integer variables which represent the aircraft and gate timetables. The number of elements in each plan and their distribution within the integration arrays are determined by reference to values input as type i) and type ii) data above. Type iii) cards are described in 6.9.1.6.

6.9.1.4 The nine mandatory integer values are assigned to global variables when read by the simulation. They are read and must be input in the following order:-

Sequence Number of Integer Value in Card Deck.	Global Variable Name.	Significance.
1	NMAX	Maximum number of towing vehicles available to the simulation.
2	AC	Number of aircraft cycles being input, i.e. first dimension of arrays TA, TD, etc.
3	COL	Second dimension of arrays TA, TD, etc.
4	ACTYPE	Number of different types of aircraft.
5	ST	Number of gates on gate plan, i.e. first dimension of arrays GTD, GTA, etc.
6	STCOL	Second dimension of arrays GTD, GTA, etc.
7	GTTYPE	Number of different types of gates.
8	SSS	Size of a one dimensional array used by SIMON procedures only.
9	NSNO	Number of maintenance restricted aircraft.

6.9.1.5 Type ii) data cards are read into three arrays called COLUMN, GATES and NSAC with dimensions (1:ACTYPE, 1:2), (1:GTTYPE, 1:2) and (1:AC) respectively. The variable array bounds refer to the global identifiers described in 6.9.1.4.

The array NSAC is used to identify the cycle numbers of the aircraft schedule which are maintenance restricted. This is done by setting NSAC(I) to zero for non restricted cycles and to 1 for restricted ones. Every element of the array is set to zero before any data is read. The number of restricted cycles having been input and stored in the identifier NSNO. The row numbers in the integration arrays corresponding to these restricted cycles are read into J say, permitting the assignment NSAC(J) :=1 to be made. The row numbers need not be in ascending order.

The remaining arrays COLUMN and GATES are two dimensional and are assigned values by varying the row index more slowly than the column one, i.e. the data can be regarded as being in pairs each of which is assigned to two array elements in the same row of COLUMN or GATES. These arrays have precisely the same function with the former referring to the aircraft integration arrays and the latter to the gate timetable arrays. In the following section the function of the array COLUMN is described.

The integer ACTYPE contains the value of the number of aircraft types which form the schedule, but cannot identify the range of cycles planned for each one. This is the function of the first column of each row of array COLUMN. For example,

i) let ACTYPE have the value 4,

ii) one aircraft type is planned to operate cycles 1 to COLUMN (1,1) inclusive.

iii) second aircraft type is allocated cycle numbers COLUMN(1,1) + 1 to COLUMN (2,1) inclusive,

iv) third aircraft type is allocated cycle numbers COLUMN(2,1)+1 to COLUMN(3,1) inclusive,

v) last aircraft type is allocated cycle numbers COLUMN(3,1)+1 to COLUMN(4,1) inclusive.

6.9.1.5 While this information is used by the simulation to ascertain the range of aircraft cycles which may be included in a search for an aircraft change, the values held in column two of arrays COLUMN and GATES, are used only to control the input of the aircraft and gate schedules. The value held in COLUMN(1,2), say, gives the number of column elements in the integration arrays for which data will be input provided the cycle number does not exceed COLUMN(1,1). Similarly, the value of COLUMN(I,2) is the number of values to be read into one row of the integration arrays provided the cycle number lies between the values of COLUMN (I-1,1)+1 and COLUMN(I,1) inclusive.

It is seen that within an aircraft type, the same number of column values must be provided per cycle, even though in some cases this may result in the non-significant values 0 and 3000 being required on input. Between types the number of values can be varied. This was adopted after noting that long range aircraft such as the Douglas DC8H operated by United rarely perform more than one turnround at any one station within twenty four hours. The Boeing 737 on the other hand was planned to perform up to 5 turnrounds per day at O'Hare. Since all aircraft cycles are contained in the arrays TA, TD, ARRNO, DEPNO, GARR and GDEP it follows that there are more non significant elements in the array rows referring to DC8H aircraft than to those of the Boeing 737. The inclusion of the second column in the arrays COLUMN permits a reduction in the number of non significant data values for the DC8H.

However, it must be ensured that every element of the integration arrays has an assigned value. This is done before data input by allocating the value zero to all elements in TA, ARRNO and GARR, and the value 3000 to those in TD, DEPNO and GDEP.

6.9.1.6 Type iii) data cards consist of values to be assigned to the aircraft integration and gate plan arrays, and are provided in 6 sets of records in the following order:

Set Number	Read into Arrays	Order of Reading for Row I.
1	TA and TD	TA(I,J), TD(I,J), J=1 to J_{MAX}
2	ARRNO and DEPNO	ARRNO(I,J), DEPNO(I,J), " "
3	GARR and GDEP	GARR(I,J), GDEP(I,J), " "

The value of J_{MAX} for row I is ascertained by referring to the values held in array COLUMN.

4	GTD and GTA	GTD(I,J), GTA(I,J), J=1 to J_{MAX}
5	GDEPNO and GARRNO	GDEPNO(I,J),GARRNO(I,J), " "
6	DEPG and ARRG	DEPG(I,J), ARRG(I,J), " "

The value of J_{MAX} for gate number I is ascertained by referring to array GATES.

6.9.2 Data cards read directly by the simulation program.

There are three types of data cards required.

i) The first card contains one integer field giving the number of days to be simulated using one set of delay distributions.

ii) The second card contains one integer field containing the starting value for the random number generator.

iii) The third set of cards contains data representing cumulative probability distributions from which random samples are extracted during the simulation. Three types of distributions are required each being defined by 21 values. The first identifies the data, and is in the range 0-10. This is followed by ten pairs of numbers T and P, say, where P is the probability that an event will occur before time T has elapsed. The distributions are read into arrays called TOWTIME, FORATA and FORATD. The formation of these distributions is discussed in section 6.9.3

6.9.3 Formation of distributions TOWTIME, FORATA and FORATD.

The Simon sampling procedure SAMPLE requires that all input distributions are held in cumulative form. This enables empirical distributions to be used, but has the disadvantage that theoretical ones must be converted into actual values and probabilities. It is not possible using SAMPLE, to input the parameters only of a normal distribution, say. If however, this presented any great problem in terms of data preparation time, a small procedure could be written to convert the parameters into the cumulative values required by SAMPLE. This was not found to be necessary in GATESIM.

6.9.3.1 Distribution TOWTIME.

This distribution represents the elapsed time between the start and finish of an aircraft towing movement between a gate area and a non-operational parking one. The data was obtained from records maintained by station staff of BEA at London Heathrow. The mean time of 141 tows was found to be 26.4 minutes which compares well with the 30 minutes assumed by station staff.

The same distribution was used when simulating United at O'Hare, for three main reasons.

i) The absolute value of the mean tow time is of little relevance provided it is close to that used by the ramp planner when allocating the tugs. It is the distribution about this mean which is significant. In the main, the tow time is dependant on taxiway and ramp congestion which is considered comparable at Heathrow and O'Hare.

ii) When the results of the simulation of two airlines with totally different schedules are compared, it is advisable to reduce the number of variables by as much as possible.

iii) The times recorded at O'Hare were not those of tow start and tow finish. The times when tugs were allocated to a tow and after it, when they were available for further duties, were recorded. This introduced other factors such as meal breaks

6.9.3.1 iii) and non-towing activities which were undertaken when no immediate tows were required. Using the raw data there was no way to eliminate their distorting effect.

The cumulative distribution TOWTIME is shown in Figure 1 of Appendix 6.

6.9.3.2 Distribution FORATA.

This distribution is used to ascertain the actual flight arrival time after allowance has been made for the previous departure delay from the same station, if applicable. It represents the change in delay between departure and subsequent arrival. It was derived from basic flight punctuality data of over 600 departure and arrival pairs.

It would be expected that difference in delay is dependant on the size of departure delay, the sector lengths, and on outstation turn round time. However, for the sake of simplicity, it is desirable that one distribution be sampled to obtain all arrival times.

Histograms of the change in delay were available for 3 different departure delay sizes, viz, no delay or early, one to nine minutes delay, and 10 minutes or more delay. An attempt was made to identify a theoretical distribution from which these 3 could have been derived. This was unsuccessful at the 5% significance level. Bearing in mind the design aims of the simulation which require that the delay generation procedures are simplified as much as realistically possible, it was considered that if necessary, a maximum of two distributions representing the change in delay data could be accepted. This would permit a simple "either or" condition to apply and would not seriously affect the run time. Any larger number of distributions require more complex subroutines to identify their applicability, and would affect programme execution time.

An attempt was therefore made to define two such distributions. When the departure delay was 10 minutes or more, the change in delay was found to be acceptably described by a normal distribution with a mean of -2

6.9.3.2 and a standard deviation of 14.4 minutes. Unfortunately, when the departure delay was less than 10 minutes, an equally suitable distribution could not be identified, again at the 5% significance level.

It was decided therefore in the interest of simplicity, to ignore the departure delay size and form one empirical distribution representing the delay change. This is shown in cumulative form in figure 2 of appendix 6.

No similar data was available for United's operation so the same distribution was used when simulating UAL. This again reduces the number of variables when comparing the results from GATESIM of two different airlines and schedules.

6.9.3.3 Distribution FORATD.

This distribution represents the turnround delays at the station being simulated. For each gate plan simulated 12 such distributions were used to compare the gate performance under differing punctuality conditions. The comparison is more easily performed when there is some formal relationship between the distributions. This is best provided by theoretical ones.

The normal distribution was chosen and the 12 distributions formed by varying the mean three times and the variance four. The variance was chosen such that the ratio mean: variance was constant for the different means.

FORATD is sampled in GATESIM at time ETD-10 minutes where ETD is either the scheduled departure time or the earliest departure time based on arrival delay plus minimum turnround time. Hence a 100% punctual station performance requires that FORATD has a mean of 10 minutes, and zero variance.

It was decided therefore that the first four FORATD distributions should have a mean of 10 and standard deviations of 2, 5, 10 and 15 minutes. The mean was increased to 12 and to 14 to obtain the remaining eight distributions.

Each distribution was converted into cumulative form as required by the Simon procedures.

6.10 Output of Results.

This includes:

i) Histogram of deviation between actual and scheduled flight arrival times.

ii) Histogram of deviation between actual and scheduled flight departure times.

iii) Histogram showing the size and number of gate holds.

iv) Histogram showing the time taken to tow aircraft between gate and parking areas.

v) The peak number of towing vehicles required.

vi) The gate timetable reliability as a percentage.

vii) The turnround reliability as a percentage.

The procedure ANALYSE described in section 5.19 studies the gate timetable planned occupancies and separation times, resulting in the evaluation of parameters which can be used to compare different plans. In addition to this it is advisable to know the daily profile of specified events. e.g. The planned frequency of occurrence throughout the day of flight arrivals, departures, allocation of rowing vehicles etc. This was ascertained during "Clean runs" by amending certain histogram handling SIMON procedures as described in section 6.10.2.

It would appear that considerable emphasis would be placed on the difference between the planned profiles and the achieved ones. This is not the case as small actual variations from schedule can result in large scale frequency alterations and vice-versa due to the choice of size and location of the bandwidths within a day. It is very difficult to quantify the cause of such shifts especially when comparing schedules of different airlines. Equally, their effect on the allocation of resources is not readily measurable. The airlines rely on their punctuality as a quantitative yardstick of performance. Certainly the thought of amending resource levels on the basis of a crude estimate of demand movement is inconceivable when the prime object of the operation is to achieve on time performance. It is the schedule feasibility rather than the resources, which require study, provided that the available airport resources are sufficient to satisfy the plan. The use of such histogram outputs was considered to be questionable if not misleading and was therefore not produced during the simulation of delay fraught operations.

6.10.1 The initial intention was to print these results on completion of each simulation run which was planned to represent thirty passes of one day's operation. However, as described more fully in chapter 11 , the limitation imposed by computer time availability demanded the maximum results from each job submission. This was achieved by simulating as many days as possible commensurate with the time limit set by the job category, and by printing the results on a daily basis. This of course required further manual collation but significantly reduced the number of job submissions required. The maximum number of passes under one set of delay distributions forms part of the input data cards and when this was achieved during a run, the next sequence of passes using a new set of delay distributions was commenced. Full use of the maximum job time was obtained.

6.10.2 Output Histograms.

Eight histograms are compiled during the program execution. For each one, a one-dimensional integer array is declared globally and the histogram is referred to by using the array name without use of subscripts. All histogram handling is done by procedures provided in the SIMON package, though small modifications have been performed on them.

6.10.2.1 Originally the procedure HISTOGRAM(A,B,C) where A was the globally declared array with indices 0 to 16, B and C being integer values, set up a histogram with ten band widths, all of equal size, plus one undefined band beyond each of the upper and lower defined band limits. The value of B gave the lower limit and that of C the band width.

The element A(0) referred to the band below the lower limit
A(1) " " " first defined band width
A(2) " " " second defined band width
.
.
.
A(10) referred to the highest defined band width
A(11) " " " band above the upper limit
A(15) was given the value of C
A(16) " " " " " B
A(12), A(13) and A(14) were used to record values necessary for the calculation of the histogram mean and variance.

6.10.2.1 The procedure call ADDTO(A,D) resulted in the element A(I) being increased by 1, where A(I) referred to the band width within the range of which the value of D lay. Therefore, in this form, the procedures HISTOGRAM and ADDTO can be used to summarise the frequency of a quantity falling within certain limits. The departure delays for example can be so classified.

6.10.2.2 However, only 10 discrete and 2 undefined band widths exist and it was required in the simulation to produce, in addition, a summary of the occurrence of certain movements throughout the day. This could be done by adding the value of the simulation time at which the activity occurred to a histogram with a band width of 60 minutes extending from 0 to 1440, i.e. 24x60. This resulted in changing the original SIMON procedures HISTOGRAM and WRITEDOWN which print out the histogram. Instead of declaring the integer array to be of size 0 : 16, the upper limit was changed to the value of a new formal parameter MAX introduced into HISTOGRAM. The band width is now stored in A(MAX-1) and the lower limit in A(MAX). Then A(MAX-2), A(MAX-3) and A(MAX-4) are used to record the same information as did A(14), A(13) and A(12) respectively. WRITEDOWN was modified to permit the printing of the extra values. Both ADDTO and WRITEDOWN required the addition of the new parameter MAX.

6.10.2.3 Histogram TOWHIS.
TOWHIS is an integer array of size 0 : 16 and it compiles a histogram giving the distribution of actual times in minutes required to perform tows from the gate area to a parking area. The lower limit is 15 minutes and the band width is 5 minutes.

6.10.2.4 Histogram ARRHIS.

ARRHIS is an integer array of size 0 : 16 and it represents a histogram giving the distribution of the deviation of the actual flight arrival times from the scheduled ones. It does not provide separate information regarding the time of day at which the deviations occurred; only one distribution for the complete day is provided. The lower limit is -5 minutes, i.e. 5 minutes early, and the band width is 10 minutes.

6.10.2.5 Histogram DEPHIS.

DEPHIS is similar to ARRHIS in that it is used to represent punctuality figures, this time for departing flights. The lower limit is 10, i.e. 10 minutes late and the band width is again 10 minutes.

6.10.2.6 Histogram GATEQ.

GATEQ is similarly an integer array of size 0 : 16 and it represents a histogram giving the distribution of the length of time for which individual aircraft are required to wait for the planned gate to become vacant. There need not be any entries in this histogram. The lower limit is 5 minutes and the band width is 5 minutes.

6.10.2.7 Histogram GONE.

GONE is an integer array of size 0 : 28 and it represents a histogram giving the frequency of occurrence of actual flight departures for each hour of the day.

6.10.2.8 Histogram COME.

COME is an integer array of size 0 : 28 representing a histogram which gives the frequency of occurrence of actual flight arrivals for each hour of the day.

6.10.2.9 Histogram DEBRIEF.

DEBRIEF is an integer array of size 0:28 representing a histogram giving the frequency of occurrence of the contact made between the aircrew and ground staff prior to a flight arrival. The time of this "air-debrief" is set at twenty minutes before the estimated arrival time, but since the actual arrival time is determined

6.10.2.9 by the simulation during the "air-debrief" activities, and need not equal the estimate, the addition of a debrief occurrence to DEBRIEF, need not be followed in exactly 20 minutes time by an addition to COME.

6.10.2.10 Histogram TRACTORS.
TRACTORS is an integer array of size 0:28 representing a histogram giving the frequency of occurrence of the commencement of towing activities between gates and a parking area, irrespective of direction.

6.10.2.11 The lower limit and band-width for GONE, COME, DEBRIEF and TRACTORS are both 60 minutes.

6.10.3 The maximum number of towing vehicles available to the simulation forms part of the input, and can become a limiting factor in gate changes and gate timetable reliability. However, since the main exercise of the program as it was used in this work, was to estimate the reliability of a given plan, this restriction was not in fact evoked. A large number of vehicles were specified as being available and the number in use at any one moment was monitored. The maximum number was printed and used as one of the comparison parameters between gate plans.

Gate timetable reliability was defined in section 3.6. as being the percentage of flight departures which were operated from their planned movement gate. On completion of one pass of a day's operation, the arrays GDEPNO and GARRNO contain the gate movements as they were performed. The file TODISC contains the operation as it was envisaged. This file is rewound and the initial gate timetable flight numbers are read into the now redundant arrays GDEP and GARR. If no gate changes have been made, the arrays GDEPNO and DEPG would be identical. By comparing the two arrays the number of flight departures which operated from gates not designated to them can be ascertained.

6.10.4 The turnround reliability is calculated in a similar manner by reading the planned aircraft integrations flight numbers from the file TODISC into the redundant arrays TA and TD. The achieved performance is recorded in the arrays ARRNO and DEPNO. An unscheduled turnround exists if TA(I,J) = ARRNO(A,B) and TD(I,J) $\neq$ DEPNO(A,B). By considering all significant elements of the arrays and hence all turnrounds, the number of unscheduled ones is computed.

6.10.5 It is emphasised that the above two reliabilities reflect the end result of one day's operation. They do not imply that the turnrounds or gate departures ascertained as having adhered to the plan, remained in that state throughout the pass. They may well have been altered before reverting back to their original state. For this reason a running total of aircraft and gate changes is not made during the simulation passes. The more laborious methods described above were preferred even though they may not reflect the true number of flights requiring decisions by operations staff. This was not the design aim of the program.

6.11 Additional global identifiers have their values assigned within the program and are not altered during execution. These are:

ATLHR, AWAY, BUSY, FREE, FULL, EMPTY,
TUGMAX, HOLD, TOWASK, AVTOW, M1.

6.11.1 ATLHR and AWAY represent attributes of the entity AIRCRAFT(I,0). They are assigned the values 1 and 2 respectively.

6.11.2 BUSY and FREE represent attributes of the entity TUG(N,0) and are given values 1 and 2 respectively.

6.11.3 FULL and EMPTY represent attributes of the entity PARK(NUM,0) and are given the values 1 and 2 respectively.

6.11.4 TUGMAX is given the initial value zero. It is updated during the simulation and, on exit, contains the value of the maximum number of towing vehicles in use at any one time.

6.11.5 The integer HOLD represents the minimum planned separation time in minutes between gate occupancies. It is used during the simulation when testing if any action is necessary to avoid a possible gate hold. It is not normally used as a parameter for procedure GATEALTER.

6.11.6 TOWASK is an integer identifier and represents the number of minutes between a flight departure and the first request for a towing vehicle if the operating aircraft is positioned on a non-operational parking area.

6.11.7 AVTOW is an integer identifier and contains the value of the mean time in minutes required to complete a tow between a gate area and a parking area.

M1 contains the value of the minimum time in minutes required to perform a flight turnround.

APPENDIX 6

FIGURE 1 Cumulative frequency distribution of towing times. TOWTIME.

FIGURE 2 Difference in delay between departure and return arrival.

References 1. University of London Computer Centre Manuals:-

i) Algol on the CDC 6600.
ii) A guide to UPDATE.
iii) Introducing UPDATE 1.2.

2. International Computers Limited Manuals:-

i) Algol.
ii) The Simon Package.

Cumulative Frequency Distributions

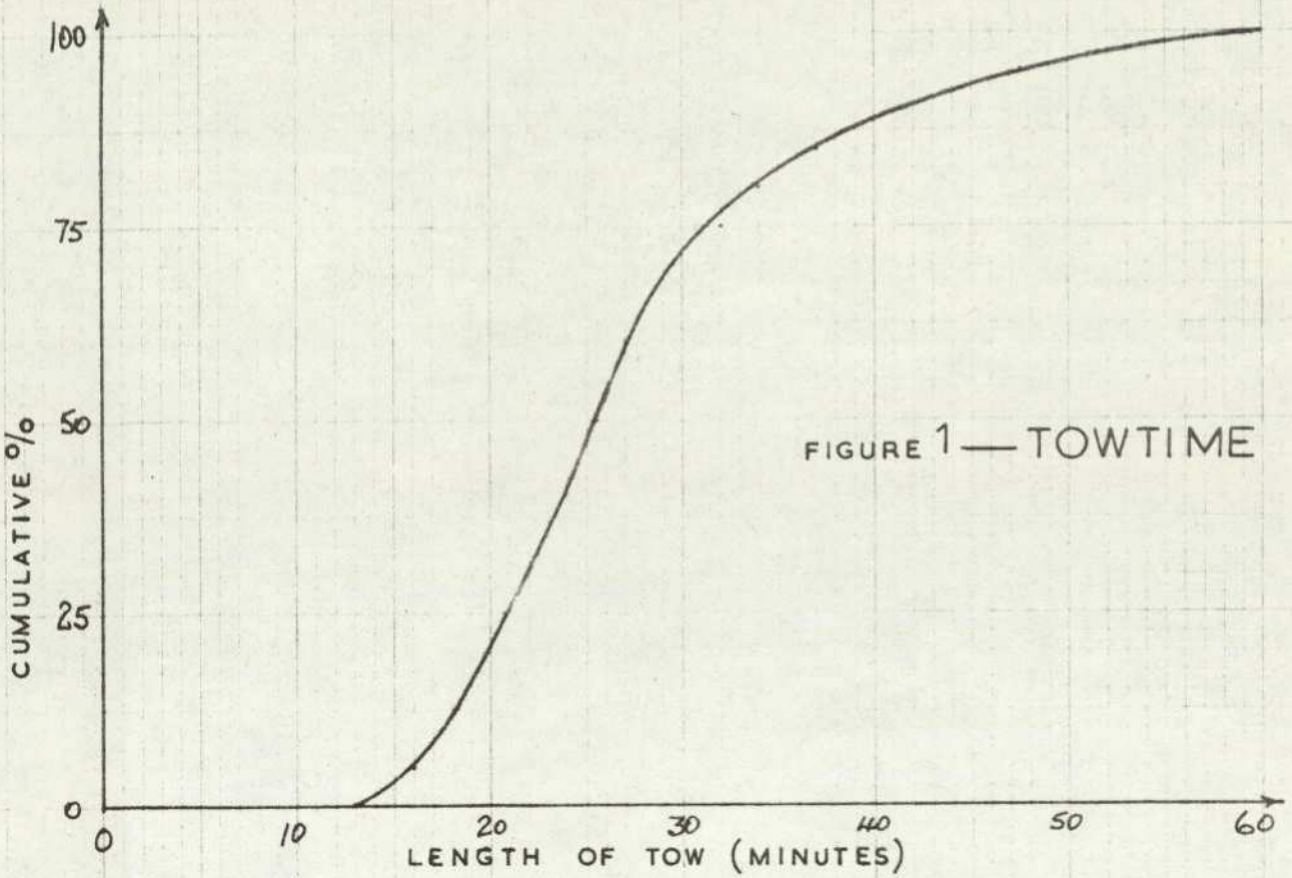


FIGURE 1 — TOWTIME

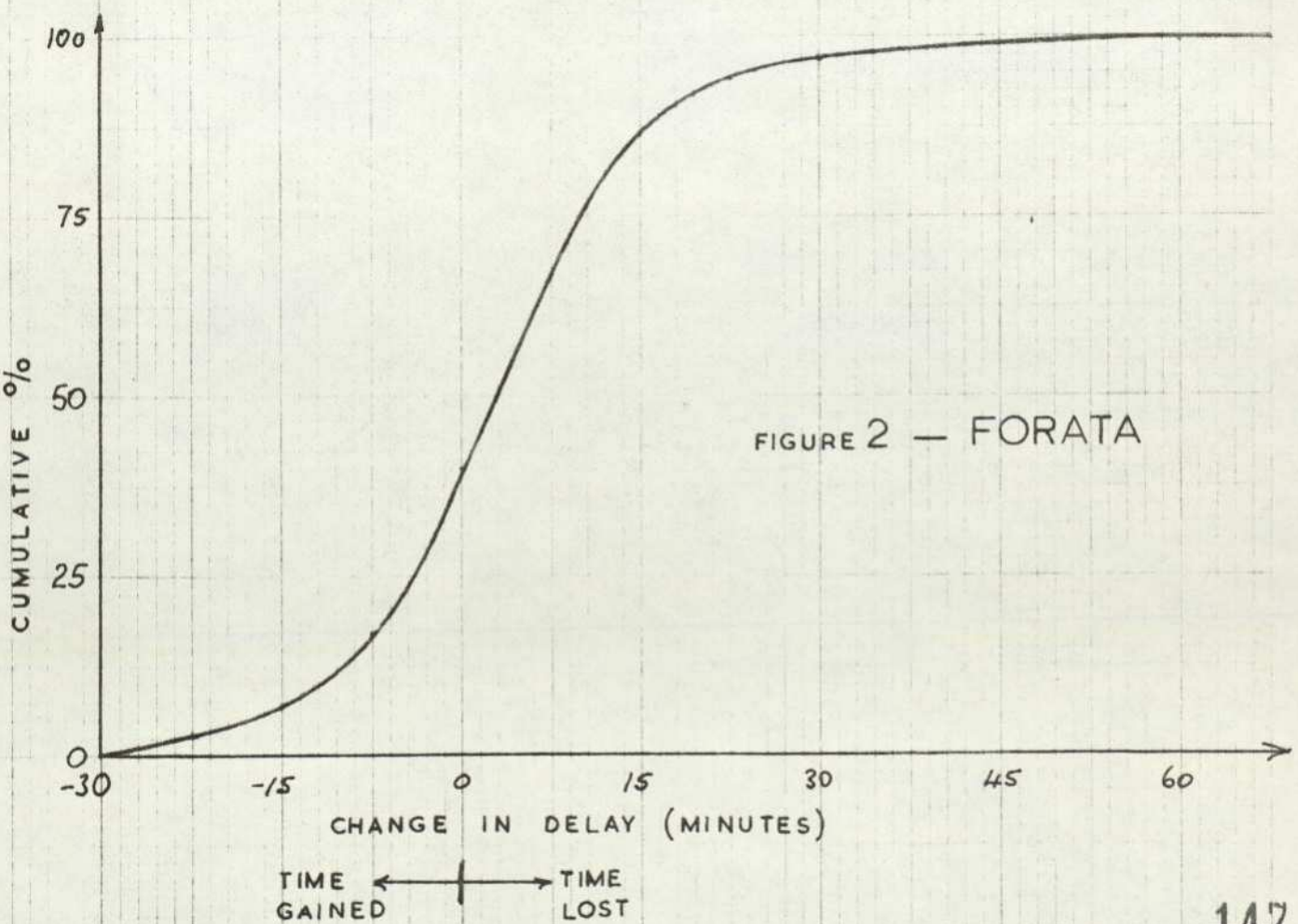


FIGURE 2 — FORATA

CHAPTER 7.

The Design Logic and Assumptions.

7.1 Introduction.

7.2 How complex?

7.3 Definition of GATESIM's aims.

7.4 The gate timetable.

7.5 Measurement of gate timetable performance.

7.6 Measurement of gate utilisation.

7.7 Simulation control points.

7 THE DESIGN LOGIC AND ASSUMPTIONS

7.1 Many simulations have been devised to study specific aspects of airline operations, some of which are discussed in chapter 17. In the design stage, it is essential that the aspect of particular interest be constantly referred to so that unnecessary complications may be avoided. It is important that the simulation concerns itself with the main problem area and does not become bogged down in peripheral details which have little or no effect on the end result. On the other hand, care must be taken to ensure that the design does not reflect the pre-conceived ideas of the designer to such an extent that their validity cannot be disproved by the model. A balance must be achieved between creating a monolithic simulation and a simple but unrealistic one. In the former case it becomes increasingly difficult to isolate the cause from the effect while in the latter, the logic may be such that the results must coincide with the beliefs and expectations of the designer.

7.2 In the arena of airline operations, so many conditions must exist before a flight departure can be performed that it would appear necessary to generate all of them in a simulation. A departure would be registered only when all such activities were complete. Included in these are:-

i) Aircraft must be allocated to flight.
ii) Fuelling operation must be complete.
iii) Full complement of flying and cabin staff are required.
iv) Engineer must satisfactorily complete pre-departure check.
v) Passengers and baggage must be aboard.
vi) Doors must be closed.
vii) Permission to commence taxying must be received from Ground Traffic Control.

Even this limited list illustrates how the generation of an aircraft departure time can escalate into a major simulation exercise. Under certain design aims this may be necessary and the relationship among the above activities may be important. The study may be concerned with the number of timesthe engineer declares the aircraft to be unserviceable after all passengers and baggage are aboard. Alternatively, the frequency of refuelling delays resulting in an additional delay due to Ground Traffic Control problems may be required. However, if the study were intended to investigate the effect of a late departure on runway queuing time, a simpler approach is justified. It would be acceptable to create a delay from an empirical or theoretical

distribution of delays and to concentrate the bulk of the simulation on the progress of the aircraft after it has left the gate.

7.3 It is fitting to redefine the aims of the simulation program GATESIM and to consider the areas requiring least attention and those requiring considerable effort. The design aim can be stated as follows:

i) To estimate the disruption to a gate timetable which should be expected from operating a given flight programme into which delays can be injected.

ii) For a given flight programme to estimate the expected change in gate timetable disruptions and flight delays due to different methods of formulating the gate plan.

iii) To identify, if possible, the type of philosophy to be used in constructing a gate plan when the intention is to achieve maximum gate reliability with limited gate resources.

This immediately provides certain requirements from the program:

i) A gate timetable must form part of the input data.

ii) The definition for a "disruption to a gate timetable" is necessary.

iii) Parameters which may be used to measure the method of gate timetable construction must be defined.

iv) The ability to inject flight delays must be available.

v) The allocation of gates must be permitted to affect, if necessary, the flight punctuality performance.

These are individually considered in sections 7.4 to 7.8.

7.4 The representation of gate timetables in array form was described in section 4. It is emphasised that every flight movement must have a corresponding gate movement, whereas the reverse need not apply. The latter condition may occur in two ways:

i) a gate movement may be a tow off or on.

ii) a gate may be regarded as an overflow one and not scheduled to accommodate any occupancies. It is still represented in the gate arrays but its occupancy activity times are given insignificant values (0 or 3000). It is not necessary that these hypothetical zero occupancies have corresponding zero flight movements.

7.5 A gate timetable can suffer disruption in several ways, each of which affect its validity to some extent. Some of these deviations are independent of the gate plan while others may be the direct result of attempting to use it. Consider the following examples:

i) A flight arrival is late and its scheduled gate is available

ii) A flight arrival is early and its scheduled gate is available

iii) A flight departure is late from its planned gate, but the gate will be free for the next scheduled occupancy.

iv) As (i) except arrival is by means of a tow-on.

v) As (ii) except arrival is by means of a tow-on.

vi) As (iii) except departure is by means of a tow-off.

In all of these cases, the timetable has been disturbed only insofar as the activity times are concerned. This may result in operational problems for the airlines but cannot in any way be the result of poor gate timetable planning. Thus the analysis of these unscheduled movements should be related to the flight schedule, station delays and en-route performance. However, an arrival delay may result in an aircraft substitution in which case the planned gate occupancies must be altered to accommodate the unscheduled turnrounds. Aircraft and gate changes are discussed in section 4.9.

This type of disturbance can negate some of the advantages of using a gate plan as listed in 3.3 and the availability of gates can have an effect on the degree to which the airline successfully absorbs the aircraft changes. In this type of situation it is desirable to be able to differentiate between a gate timetable which can react to such amendments with the minimum of change to itself in the manner consistent with the operator's gate change policy and one which must suffer a large rescheduling due to its inherent rigidity and may result in gate occupancies inconsistent with the airline's policy.

7.5.1 It was seen in section 3.3 that one of the advantages of using a gate plan lay in the ability to allocate resources to gate areas each of which has a pre-determined activity level. The gate area activity is governed in the main by scheduled departure times modified by the length of the turnround. It would appear therefore that the alteration of a departure would have a measurable effect upon the allocation of resources within a gate area and that an unscheduled arrival coupled to a planned gate departure would have a smaller effect. The one exception to this is when the unscheduled turnround is of such short duration that extra resources are required. The policy of United, American and Delta reflects practical agreement with this, in that each airline directs its ramp controllers to adhere as closely as possible to the departure gate allocations.

7.5.2 The ability of a gate timetable to absorb unscheduled arrivals so that the integrity of the departure plan is unaffected, seems to be a measure of the operational efficiency of the plan. However, even this is not independent of the aircraft integrations. An aircraft change may involve an aircraft already on its planned arrival gate and not provided with sufficient ground time to permit a tow to its new departure's planned gate. This is not a shortcoming of the gate plan but will be regarded as one if the gate reliability is defined as the percentage of departures which leave from their planned gate. This disadvantage however will be present with the same probability of occurence provided that the comparison of gate timetables is limited to when they have been compiled from the same flight integrations. The examples (i) to (vi) above will not adversely affect the gate reliability when defined in this manner. Having adopted this principle, the simulation must be designed to retain the departure schedule wherever possible without jeopardising punctuality which is, of course, the final assessment of station performance.

7.6 Having adopted a criterion of performance, it is necessary to measure the quantity and utilisation of the resources required to achieve it. The quantity is simply the number of gates which are available, but the utilisation is much more difficult to define. It was not quantified by any of the airlines studied by the author. A brief description of operating policies and facilities of these airlines is necessary at this stage together with an outline of two methods of constructing a gate timetable, each of which is used by the described airlines.

7.6.1 GATE POLICY "LAST OUT - FIRST IN" (LOFI)

This policy states that the gate which is to be allocated to an arriving aircraft is that one which was most recently vacated. It results in some gates being very highly utilised while others exhibit low use. LOFI has the merit of highlighting spare gate capacity by concentrating it in a limited number of gates and is used to a considerable extent by long term planners when considering total station gate capacity.

7.6.1.1 Provided maximum use is made of towing vehicles, the minimum quantity of gates needed for a given schedule is ascertained by applying this policy. It is apparent also that a LOFI timetable is unique for one flight schedule and one set of gate restrictions. It is, however, not normally used operationally.

7.6.2 Gate Policy "First Out - First In" (FOFI).

This is the corollary to LOFI in that the gate allocated to an arriving aircraft is that one which had been vacant for the longest period. This results in the gates having similar occupancy profiles. Unlike LOFI, the gate timetable constructed under FOFI is dependent on the number of gates available for use, as well as the flight schedule and gate restrictions. Consequently, any schedule for which a LOFI plan has ascertained a minimum of N gates, can be contained in X gates (where $X \geq N$) under the FOFI policy. The problem remains of comparing the utilisations when using N or X gates, both under FOFI conditions. This is discussed in 7.6.8 to 7.6.12.

7.6.3 American Airlines at La Guardia Airport, New York.

La Guardia is owned by the New York Port Authority from whom the airlines lease terminal areas. The concourses, holding lounges, gate areas etc., are the responsibility of the airlines who have complete operational control over them. The American facility consists of one main concourse with 10 gates, and an eleventh gate leased from United Airlines at the base of the neighbouring concourse. A more detailed account of the American carriers' operations is given in chapter 13.

Before a schedule is approved, it is studied by the schedules department, independent of La Guardia personnel, to ensure that it can be accommodated within the station capacity and the gate restrictions. A gate timetable is constructed using the LOFI principle (see 7.2.) and the additional constraint, that where possible, the minimum separation time between arriving and departing aircraft on the same gate is 15 minutes. This results in the minimum gate requirement for the schedule. However, there appeared to be little quantitative analysis as to whether it would be feasible operationally and no parameters were defined whose evaluation could aid the planners in making this decision. The concept of gate reliability was certainly not entertained at this stage.

La Guardia ramp personnel have the responsibility of creating the operational gate timetable for a given schedule and they apply much more detailed guidelines which are discussed in 13.1.3.

7.6.3 The gate timetable for summer 1969 had a station average time of 35.3 minutes which compares well with a gate minimum average separation time of 25.2 minutes and a maximum of 43.0 minutes. This excludes gate 4 which is intentionally under-utilised, and achieves a mean gate separation time of 66.0 minutes. The above figures are based on analysis using the variable time span method as described in 5.19.3.2 under procedure ANALYSE.

7.6.4 United Airlines at Chicago O'Hare Airport.

As at New York, the airlines using O'Hare Airport lease terminal areas from the airport authority and have complete control over their own concourses and gates. This is of special significance at O'Hare where United, in 1969, operated equipment ranging from Caravelles to Super DC8's and were able to design jetways and parking positions capable of handling such diverse aircraft types. This advantage is underlined with the advent of Boeing 747's, TriStars and DC10's.

As with American airlines, before a new schedule is approved, it is checked to ensure that O'Hare (together with all other stations) has sufficient gate areas. United employ an interesting ruse in that their scheduling department assume that only 18 gates are available to accommodate the schedule. This number was apparently arrived at by trial and error, and is obviously dependent on the flight movement profile of the airline. United have demonstrated by their successful operation at O'Hare that this method is satisfactory for them. However, it should not be applied carte blanche to other airlines with a different type of operation. It is interesting to note that the formulation of a gate timetable using a LOFI policy (see 7.2.) applied to UAL's operation results in 18 gates being required. This may be coincidental since no conscious effort is made by UAL to apply the philosophy. Whereas American used a 'Pseudo' LOFI policy to ascertain if their operation could be contained within the total number of gates available, UAL use a similar policy in an attempt to accommodate their operation in less than the maximum number. An unanswered question was whether United in fact 'padded out' their operational gate plan into unnecessary extra gates when in fact a FOFI policy on the reduced number of gates may have been able to produce a departure reliability similar to that achieved with 21 gates.

7.6.4 The gate timetable for summer 1969 had a station mean separation time of 45.0 minutes distributed in the range 22.8 to 105.5 minutes over the gates. This implies that the gate occupancies are less evenly distributed than with American.

7.6.5 Delta Airlines at Atlanta Airport.

Delta leases two concourses, each with twelve gates from the airport authority and again has complete operational control over its gates. This is imperative for Delta not because of the diversity of fleet as with UAL (though this problem does exist) but because of the highly peaked nature of the flight movement profile. During 1969, approximately 63% of Delta's passengers at Atlanta made on-line connections, so a high degree of bunching of feeder flights from a trunk route arrival or departure is desirable. Naturally, this results in very poor gate utilisation. Mean separation time is 93.6 minutes while the gate means vary from 58.6 to 171.9 minutes.

As with UAL and AA, Delta tests each projected schedule for compatability with the Atlanta gate resources, but due to the nature of their operation and the large amount of connecting passengers, the effect of the gate timetable on flight punctuality, though still quantitatively not measured, is reasonably assumed to be less than with a more even flight movement distribution. This is based on the assumption that the traffic peaks are separated sufficiently so that the reactionary effect of a disruption on the gate timetable is considerably reduced. The main consideration in compiling the timetable is simply to ascertain if the gates can accommodate the largest ground activity period or not. If the gates are sufficient in number, the flights are arranged so that from historical data, connecting passengers have the shortest distance to travel between aircraft. No attempt to increase gate utilisation or even to measure it, is considered.

7.6.6 Western Airlines at Los Angeles.

As described in section 13.4, Western do not operate one formalised gate timetable for a given daily schedule. The ramp personnel create a new timetable every day after aircraft have been allocated to the schedule. However, a representative gate plan for summer 1969 had a station mean separation time of 85.7 minutes, with the gate means varying from 56.7 to 119.6 minutes, excluding gate 57.

7.6.7 United Airlines at Los Angeles Airport.

United's operation at Los Angeles is planned in a similar manner to that at O'Hare. There are 13 operational gates but the author was not able to ascertain the number of gates which the schedule planners assumed were available when testing the viability of a new schedule. However, the summer 1969 schedule had a LOFI requirement of 12 gates so it seems reasonable to draw a comparison with O'Hare and assume that this is the figure which is used.

The operational timetable for summer 1969 had a mean station separation time of 37.4 minutes and is distributed among the gates in the range 21.4 to 65.1 minutes.

7.6.8 It is seen that none of the airlines operated or planned under true FOFI or LOFI policies respectively, but some indications were noticed of a tendancy towards them. This is to be expected since both are extreme examples. Nevertheless, it is generally agreed within the airlines that a FOFI policy amended, where necessary, to conform with the operating procedures and facility restrictions of a given carrier and airport, will produce a more practical operating plan than will a LOFI policy. This is based on their experience and on man's apparent love of symmetry. It is a claim which begs quantitative justification and is further discussed in section 9.3.

7.6.9 It would appear reasonable to base a description of a gate timetable on its proximity to either of these two extremes. This should prove useful when comparing planned gate timetables of different airlines or different stations since the flight profile differences are manifested in the LOFI (say) timetables and the planned ones. Theoretically, they should be self cancelling, so that the individual performance indices should reflect the variation in gate utilisation caused by facility restrictions and operating policy without the normally ever present excuse of incomparable arrival and departure patterns.

7.6.10 While this is acceptable in theory, provided such an index can be evaluated, its practical value is in considerable doubt. There is little evidence of airlines comparing different stations when their real purpose is to attain the best performance from each one. Consequently, any comparison tends to be limited to the estimated effects of different timetables at the same airport. In this situation, there is scant reason to introduce a parameter designed to eliminate the differences between flight profiles when the

7.6.10 profile itself remains constant. On the other hand, it may be argued that having evaluated the optimum range of the gate measurement index once, it can be applied to all stations with equal confidence, thus simplifying the timetable design for each of them.

7.6.11 It is suggested that the effort required to design and evaluate this index, if in fact it is mathematically describable, would far outweigh its usefulness, for the following reasons:-

i) The construction (or demolition) rate of gates together with their cost precludes the possibility of facilities being tailored to suit short term changes in flying programmes. This implies that maximum utilisation cannot be maintained over a number of schedule changes. The assumption that commercial demand takes preference over gate usage has naturally been made.

ii) Only at selected airports is high gate utilisation a necessity.

iii) The likely performance of a gate timetable cannot be readily estimated due to the necessity to relate it to the estimate for the base LOFI plan (say). It is unlikely that this would be done by station staff.

iv) Similarly headquarter staff in general are not concerned with the details of a station's gate plan reliability; they are more interested in a "go or no-go" situation. For this purpose, a much simpler and broader parameter is necessary. This is provided by gate and station mean separation and occupancy times. In addition the variance of the distribution of the individual separation times provides a rough guide as to how evenly occupancies are spread amongst the gates. A plan constructed under a LOFI based policy is expected to have a higher separation time variance than that constructed using a FOFI policy, provided the distribution relates to the complete gate area and not to individual gates. When gates are treated separately, a large variance of gate means and of gate variances will normally be exhibited by a LOFI plan, when compared to the FOFI one.

7.6.12 It appears therefore that these statistics provide a basic, relatively simple method of analysing a gate plan. It remains to be seen whether timetable reliabilities can be related to them. This is one of the main functions of the simulation. The statistics are dependent on the compilation method of the plan, but unlike the above "performance index", are also dependent on the flight profile. It is necessary therefore to establish any relationship between them and the reliability of gate departures by using one set of flight movements and several gate plans, before proceeding to investigate the effect of different flight profiles. This is further discussed in chapter 10.

The procedure ANALYSE, described in section 5.19 provides an analysis of the gate timetable, while the simulation itself, at the end of each day's operation, calculates the achieved gate timetable reliability.

7.7 Having stated that the analysis of a gate timetable and the estimation of its reliability when subjected to operational delays are among the prime objectives of the simulation, it is necessary to design a realistic method of injecting the flight disruptions. The conditions under which a gate change will be requested must be listed together with the timing of the request. In practice, reviewing the feasibility of both the gate plan and the flight integrations is a continuous process but the incidence of an aircraft's actual movement or the receipt of a new estimate of one, causes the review to be intensified. It is these triggering activities which must be isolated. This is best discussed by considering two broad divisions of gate plan disruptions, viz i) no aircraft integration changes are involved, ii) aircraft changes are required.

7.7.1 No Aircraft Changes.

The events which normally result in a gate change being contemplated are as follows:

i) An inbound flight provides an accurate estimate of its landing time and is found to precede the latest departure estimate of the aircraft occupying the planned arrival gate.

ii) A flight departure is delayed so that it will affect an incoming aircraft which has already provided an accurate estimate of its arrival time.

iii) Similar to i) except the aircraft is to be towed on to its gate, the event time being the scheduled towing vehicle allocation time.

7.7.1 iv) Similar to iii) except that the following occupancy is formed by an aircraft tow-on prior to its flight departure. The towing operation will have commenced.

v) An inbound aircraft provides an accurate estimated arrival time before the preceding occupancy on its planned gate has commenced. If the estimate indicates that the arriving aircraft will require the gate before its planned predecessor, this occupancy replaces the original one and vice versa. This will result in the separation time, if any, between the two occupancies being checked, with a view to changing the gate of the second occupancy. If the arrival estimate was such that the occupancies should occur in the planned order, but interference between the two is inevitable, condition i) above applies.

vi) An inbound aircraft provides its arrival estimate and is found to provide insufficient time for its planned double occupancy (i.e. tow off then tow on for next departure). This requires the tow to be cancelled and a gate, preferably the planned departure one to be allocated to the new occupancy. The arrival estimate, when viewed in the context of forming part of a single occupancy, may now result in condition i) or v) above applying.

vii) The arrival estimate of a flight may indicate that though its planned gate will be vacant at its arrival time, the following occupancy will be affected. If the inbound aircraft is planned to operate a subsequent departure, the decision regarding the later occupancy is normally deferred until the final estimate of its arrival time is available. However, if the original flight is the aircraft's last sector of the day, consideration should be given to changing its gate providing the later occupancy terminates with a flight departure. This is consistent with maintaining the integrity of the gate departure plan.

viii) On arrival, the planned gate is found to be occupied caused by the arrival being earlier than estimated or the departure later. Based on the most recent departure estimate, it must be decided whether a new gate is to be allocated or a gate hold accepted.

It can be seen that gate decisions are primarily made at four definable points in time:-

a) On receipt of accurate arrival estimate, i.e. when aircraft is in airport control area and in contact with airport control tower.

b) Actual arrival time.

c) Time of allocation of a towing vehicle before positioning an aircraft on to a gate from a parking area.

d) On receipt of estimate of actual flight departure time.

7.7.2 GATE CHANGES CAUSED BY AIRCRAFT RE-ALLOCATIONS.

The adoption of a gate timetable as a practical tool requires that all unscheduled turnrounds be absorbed into an updated version of the timetable immediately the new occupancies are known. As stated in section 3.3 , one of the advantages of operating a gate plan is achieved when staff are allocated to particular gate areas having had regard to the number and distribution of flight movements planned for that area. Consequently any deviation from this profile, if not broadcast in advance, would cause more disruption than that experienced if no gate plan existed. In the latter case, resources (manpower and facilities) would have been supplied from one large source whose size was dependent on total airline movements and not on those from small groups of gates. In addition, no detail preparation for specific turnrounds would be commenced until the gates were firmly allocated. Since, by using a gate plan, this preparation continues on the assumption that flights will operate from their normal positions, it is essential to inform everyone concerned of even the smallest change irrespective of its proximity in time. This assumes greater importance as the number of aircraft and occupancies involved in an aircraft change sequence increases, since unscheduled turnrounds may be incurred several hours after the causal late arrival (say) has completed its new turnround. Hence if a gate timetable is to be regarded as a practical method of allocating resources, it must be demonstrated that a rapid amendment is possible immediately following the creation of unplanned occupancies.

This can be done and is discussed in more detail with respect to American and United Airlines in sections 13.1 and 13.2. As in section 7.7.1. it is necessary to identify the events which would normally result in an aircraft change being requested. These include:-

i) On arrival, possibly after an in-flight interrogation of the aircrew, the aircraft is found to be unserviceable and unable to operate its next flight.

ii) During the pre-departure check the aircraft is found to be unserviceable and must be withdrawn from the service for which it is being prepared.

iii) At any of the following activities it may be apparent that the estimated arrival time of the aircraft will cause a delay to its next departure, even assuming that the minimum turnround time can be achieved.

a) Departure from same station on the departure prior to the one in which there is an inevitable delay.

b) On receipt of departure time from station en route to station under study.

c) On receipt of estimated arrival time at station under study, direct from the aircraft en route to the station.

Naturally the decision to request an aircraft change will depend on the credibility of the arrival estimate. It would be taken at activity time a) only if the departure delay was considerable and the elapsed time until the aircraft's return was small. Conversely, a small projected arrival delay received under condition c) may result in a change being sought immediately.

7.7.3 A summary of the preceding two sections is given in the table below. If possible it would be desirable for any simulation of a gate timetable to be capable of making the stated decisions at the event time's shown.

	Event Time	Decisions or Activities Required.
1	A/C Departure from home station	a) Estimate arrival time of return flight if applicable. b) Estimate arrival time at outstation. c) Consider an integration change for aircraft if it is scheduled to return to home station with an excessive estimated arrival delay
2	Departure from Outstation	a) As above, except estimate of arrival time at home station can be made more accurately.
3	Receipt of Arrival Estimate from A/C inbound to home station.	a) Consider an aircraft change if estimated arrival delay would incur a departure delay to next flight. b) Consider a gate change if planned arrival gate is forecast to be occupied at ETA. c) If on arrival A/C is scheduled to be towed to a parking area before its next departure, consider the cancelling of tow if ETA causes sufficient reduction of ground time. d) Consider an aircraft change if the aircraft captain, having stated his ETA, indicates a malfunction which will render aircraft U/S on arrival.
4	Aircraft Arrival at home station.	a) Consider a gate change if planned gate has not been vacated. b) Consider cancellation of tow to parking area if arrival delay is sufficiently large.

	Event Time	Decisions or Activities Required
5	Aircraft arrived at home station + 10 minutes.	a) Consider possibility of an aircraft change if engineer declares aircraft U/S after discussion with captain. b) Estimate departure time (ETD).
6	ETD - 10 minutes.	a) Ascertain if aircraft is serviceable on completion of pre-departure inspection. b) Estimate departure time more accurately.
7.	Time of planned start of tow from gate to parking area.	a) If towing vehicle is available, estimate time of arrival of aircraft in the parking area. b) If towing vehicle is not available, estimate time when tow can commence. Consider possibility of gate or aircraft change due to this delay.
8	Time of start of planned tow from parking area to gate.	a) If tow can commence, estimate time of arrival on the gate. b) If tow can commence, consider a gate change if the planned gate is forecast as being full at estimated gate arrival time. c) If tow cannot start consider aircraft change if delay will affect departure.
9	Arrival of aircraft in gate vicinity when under tow.	a) If gate is occupied, consider a late gate change. b) If gate hold or change incurs a delay consider aircraft change to reduce possible departure delay. c) Estimate departure time.
10	Outstation events.	As for home station as far as estimating departure time, aircraft serviceability state an arrival time at next station. Details of gate availability are unnecessary.

7.7.4 The necessity and indeed the feasibility of incorporating the above event times and decisions into a simulation are discussed in the following sections. The paragraph numbers refer to event numbers above.

1 Aircraft departure from home station.

a) This is an essential activity since the return arrival estimate can be made by home station staff independently of the aircraft crew and outstation personnel. At such an early stage in the flight plan of the aircraft there is no merit in making a sophisticated computation in an attempt to forecast the arrival time accurately. In practice, the estimate is obtained by adding the departure delay to the scheduled arrival time, thus assuming scheduled flight durations and outstation ground times. This has been adopted for the simulation.

b) The provision of the estimated arrival time at the aircraft's destination, while of interest to the outstation, has no direct effect on the home station's gate timetable reliability. The activities at the outstations are important only in so far as they contribute to a delay or early arrival back at the home station. This return arrival time can be obtained in the simulation by sampling from a theoretical or empirical distribution which is compiled to reflect the total of the flight and outstation delays. Any refinement of this involving the outstation ground times requires the complete aircraft integrations for all stations to form part of the input data. It is considered that the additional data preparation, together with the increased core store and run time requirements of the simulation, could not be justifiable within the scope of this project.

c) At departure time, an aircraft change can be considered for the aircraft's next home station turnround but the usual practice is limited to identifying the turnround as being unlikely to remain as planned. The change sequence is not implemented at this stage because of the uncertainty with which the availability of other

c) substitute aircraft can be ascertained. It was decided that the simulation would not be permitted to perform a re-allocation and that the identification of future arrivals as probable sources of disruption was unnecessary. The latter restriction was based on an analysis of why the arrivals were earmarked in practice. It was purely to provide extra time in which the estimates of aircraft movements could be collated and matched with the operational requirements when the time for a decision regarding a change became imminent. The simulation, of course, stores this data as it proceeds and can reference all of it at the appropriate time. It does not need reminding once the parameters have been set.

2 Aircraft departure from line station.

a) Since the simulation has no knowledge of outstation movements (see 1(b) above), no estimate of arrival times can be made based on the aircraft's departure time from an outstation. Event 2(a) is therefore superfluous.

3 Receipt of arrival estimate from aircraft inbound to home station.

Every airline studied provided the means whereby accurate estimates of arrival times were available between 10 and 30 minutes before arrival. The methods varied between airlines - some have company radio frequencies which permit the air crew to provide their own estimates, while others monitored air traffic control frequencies. This is more fully discussed in chapters 13 to 15 where individual airline procedures are described. In the simulation there is plainly a need for this facility. The difficulty comes in deciding the point in time when the estimate should be made. This is important since from this time onwards, the simulation will be permitted to reference the estimate, which in practice, is sufficiently accurate to be regarded as the actual arrival time.

3 However, if the simulation, having created the estimate, is permitted to base decisions on it, knowing that the actual arrival time is identical, care must be taken to ensure that the estimate is not made earlier than the point when such an accurate one could be made in practice. Having stated in 1(a) above that the first estimate of arrival is obtained by carrying forward a home station departure delay to its next arrival, it appears reasonable to decide on the actual arrival time at ETA - mean debrief interval. The latter is defined as the mean time between receipt of final arrival estimate and the actual arrival. This is satisfactory provided that large scale arrival delays are not generated at the debrief time. It implies that large scale outstation and in-flight delays are not simulated. The program will accept these delays if presented with them, will perform gate changes and produce an estimate of the achievable gate reliability. However, the simulation, under these circumstances, would have factual arrival times available to it when in practice only estimates would apply. Gates and aircraft changes would be affected.

The restriction on the size of delay to be injected at ETA - debrief interval is acceptable and within the design aims of this simulation for the following reasons:

i) Stations which warrant a study of this magnitude are predominantly main base ones, where stacking of incoming aircraft is common. In this situation, even a large stacking delay can be accurately forecast at its commencement and it is acceptable that after the aircraft debrief time, the simulation can regard the latest estimate of arrival time as being the actual. The debrief time will always precede or coincide with the joining of a landing queue.

ii) It is the 'home' station which is under study and it is unreasonable to expect that all outstations and aircraft serviceability will improve or worsen this performance to a marked extent within the time span of one schedule change. It is more reasonable to assume that they will maintain their current level.

ii) The factor which may exhibit considerable variation is the terminal delay (stacking) which was shown to be simulated adequately under the ETA - debrief interval method.

iii) A high percentage (81% for BEA, 47 % for UAL at O'Hare) of the aircraft forming turnrounds at the main base visit the station at least twice in the same day. Reactionary arrival and departure delays thus contribute substantially to the overall punctuality and emphasise the practicality of "delay out - delay in" philosophy as an original estimate.

3 a) It is essential that an aircraft change be considered at the time of receipt of final arrival estimate. If the scheduled departure time minus the estimated arrival time is less than the minimum turnround time, an aircraft change is requested by calling procedure ALLCHANGE.

3 b) A gate change is considered at the same time having established that one of the following applies:

i) Gate is full and is forecast to remain so until after the arrival time of the incoming aircraft. No allowance is made for a possible gate hold period because the gate vacation time is only an estimate and cannot be relied upon to be correct. This is discussed under paragraph 6(b) below.

ii) If incoming aircraft was planned for a double occupancy, but the available ground time does not permit the towing sequence, the arrival occupancy is cancelled and the departure one altered to include both flight movements. A further gate change for the complete occupancy may be necessary if interference with the previous one is apparent.

iii) Arrival gate is empty but incoming occupancy will interfere with following one. A gate change for the first occupancy is considered only when it is planned to terminate with a tow off, while the subsequent one terminates with a flight departure. This maintains the policy of retaining departure gate integrity whenever possible.

3 c) The cancellation of a tow due to the reduction in available ground times is partially covered by 3(b)ii) above. If the arrival delay is sufficiently large, it may be necessary in addition, to request an aircraft change.

3 d) Some airlines, including BEA, carry out a technical debrief of the aircrew immediately after the final arrival estimate has been made. The purpose of this is to give ground engineers extra time in which to assemble spares, equipment etc., which may be required following the captain's technical description of a snag. If the snag is serious enough, the debriefing engineer may request an aircraft change, but in many cases, it is not possible to obtain a sufficiently detailed description of the symptoms to allow positive identification of the required rectification action. In this case, the engineer will warn the aircraft integration controllers that a change may be sought when more information is obtained after the aircrafts arrival. The controller thus has more time in which to plan a possible change sequence, but under no circumstances would he broadcast them until the request had been confirmed. Ramp activities would continue unaffected. In a simulation there is obviously no need to create this extra "think" time but a requirement may still exist for the ability to create a serious snag which in reality, would undoubtedly render the aircraft unserviceable. Although the frequency of occurrence is not available it could easily have been compiled, at least for BEA. Realistic data about the length of time for which the aircraft remained unserviceable is virtually impossible to obtain from any of the airlines studied. To be of any value, a distribution of aircraft unserviceability time must be available.

Surprisingly, it is not. Figures are quoted by the airlines but further study proves them not suitable for the purpose of this simulation. Nor can they be corrected with any degree of accuracy. This is further discussed in 7.7.5 under the heading

d) "Aircraft Unserviceability". It was decided that at air debrief time the simulation would not be at liberty to declare an aircraft unworthy to perform a departure because of in-flight defects rendering the aircraft unserviceable.

4 Aircraft arrival at home station.

a) If the planned arrival gate is found to be occupied, the simulation will allow the aircraft to wait provided the gate will be available within a prescribed maximum period. This varies between airlines but 10 minutes is an acceptable figure. Otherwise a gate change will be requested. There may of course be no alternative in which case a longer hold is inevitable. As will be seen in 6(b) below, the actual departure time of a flight is ascertained at either STD - 10 minutes or ATA + 20 minutes whichever is the later. Up to this time, the simulation may reference only the estimated departure time which is STD or ATA + 30 minutes. Thus if the incoming aircraft is debriefed during this period, its gate may be left unchanged on the basis of the departing aircraft adhering to its estimate. On arrival however, and finding the gate still occupied, the simulation is permitted to reference the actual departure time when calculating the hold time. This is acceptable, since in practice, although the actual departure time may not be exactly known, an accurate estimate is known.

b) The cancellation of a planned towing movement is not considered by the simulation at flight arrival time. Section 3(c) described how the tow could be cancelled on receipt of the final arrival estimate. Since this estimate coincides with the actual arrival time, a second check on the feasability of a tow is unnecessary.

5 Flight arrival time at home station + 10 minutes.

This event time was considered because it allows the ground engineers time to assess any defects experienced by the flight crew on the preceding sectors (and possibly reported on the air debrief). This does not imply that the engineer can

5 identify a defect within 10 minutes, but merely allows him some time to decide if he requires longer than the planned turnround time for further investigation.

a) The engineer can and does withdraw an aircraft from service because of the nature of a defect discussed with the flight crew. As in 3(d) above where the same problem arose, but at air-debrief time, it was feasible to collect data which would allow a probability of "aircraft withdrawal" to be input to the simulation. The difficulty of deciding the length of time for which the aircraft is to remain unserviceable is again encountered. Suffice it to state here that because of the observations made in 7.7.5, it was decided not to include aircraft unserviceability data in the simulation.

b) Any estimate of departure time made at ATA + 10 minutes is in practice merely an estimate of when the aircraft will technically be in a fit state to fly. There has not been sufficient time since arrival to provide an intelligent estimate of how the fuelling, loading, passenger handling, etc., are proceeding. The removal of the possibility of aircraft unserviceability allows the simulation to proceed further with the turnround until the time when a more realistic estimate of operational delays can be made. However, before that time is reached, the simulation may require to reference the aircraft's departure time, so a crude estimate must be previously available. This can easily be provided at the actual arrival time. If the available ground time is greater than the minimum required, then ETD is made to coincide with STD. If the turnround time is below the minimum, then ETD = ATA + minimum turnround time. This coincides with observed practices.

6 Activities at ETD - 10 minutes.

a) The exclusion of aircraft serviceability data precludes the possibility of an aircraft delay due to technical failure during the pre-departure check.

b) The departure time can be estimated with a good degree of accuracy at this stage. The distribution of time periods between ETD and ATD can be formed empirically and sampled by the simulation to obtain the final estimate. It would appear that the available accurate data on departure delays could be corrected to allow for minimum turnround times. This would summarise the actual effect of aircraft unserviceability and operational station delays, but would present problems of analysis when simulating different airlines and/or several stations. A much neater method is to use theoretical distributions to generate the delay. These can be accurately defined and cannot be regarded as a product of one airline's or station's method of working. The results of the simulation in terms of punctuality and gate reliability can then claim to be the estimated effect of operating under a defined distribution of station delays. It is easier to show the effect of varying the mean station delay at a constant value of mean/variance, or the effect of increasing the variance at constant mean. This method is adopted for creating departure delays.

7 Time of planned start of tow from gate to parking area. It is possible for a gate timetable to be limited by the number of towing vehicles available to move the aircraft between gates and non-operational parking areas. This need not be caused simply by a shortage of tugs, but where the two areas are divided by "live" taxiways or runways, the number of tows being performed at one time may be restricted by the airport authority. The facility has been provided in the simulation whereby such a maximum number may be input.

a) If a towing vehicle is available, at the planned start time, the tow commences immediately. The actual arrival time in the parking area is calculated by sampling from a distribution of the time taken to perform the tow. This may be either emperical or

7 a) theoretical. Since in this study the effect of altering the tow time distribution was not being undertaken, an empirical distribution was used. During the towing period, it is possible that an aircraft change may be originated by a different aircraft and the simulation selects the aircraft under tow as being a necessary participant. The estimated time of arrival in the parking area need not be referenced since it is possible to halt the tow and return the aircraft to a new or the original gate. This is done by airlines via radio contact and can be reproduced in the simulation. Thus at the departure from the gate, the actual tow finish time can be allocated to the aircraft, knowing that no advantage in possessing this data is given to the simulation.

b) In theory, if no towing vehicle is available at the planned start time of a tow, a survey should be made to ascertain the earliest start time and whether this provides a sufficient period in which to remove and return the aircraft for an on-time departure. In reality however, the ground times of aircraft with double occupancies are not so critical that they cannot withstand a delay to their tow. This is necessary because of the uncertainty with which some airlines can state the towing time, due possibly to tows having to cross taxiways and runways. The simulation would unnecessarily be made more complicated by allowing the cancellation not only because the gate timetable would require amendment, but because estimates of when each active tow is due to end must be made. It would not be permissible to reference the computed actual finish time as described in 7(a) purely because of the scatter of towing times which can be experienced. It was decided to accept a delay to the tow and to have the simulation check every 5 minutes if a tug has become available. If the aim of running the simulation had been to ascertain the effect of limiting the number of towing vehicles it might well be better to permit tow

7 b) cancellation under these circumstances, and to measure the effect of tug shortages by the difference in gate timetable reliability.

8 Time of planned start of tow from parking area to gate.

a) Ground Traffic Control at most airports co-ordinate the movement of towed aircraft as well as taxying ones and normally give preference to the latter. Consequently, it is difficult for a tug driver to provide his company with an accurate estimate of the tow duration time. The normal procedure is to accept this restriction and make a crude estimate by assuming a mean journey time, without even consulting the driver. Whereas in 7(a), the simulation did not need to reference the finish time of the tow, it may be required to do so in this case, since the aircraft is approaching and not leaving the gate. The actual arrival time is computed by sampling from the distribution of tow times, but an estimate is also made assuming the mean duration. The simulation is permitted to refer only to the estimate until the actual time occurs.

b) Since the towing vehicle can be contacted by radio, its gate destination can be altered between time of vehicle dispatch and start of the tow. In the extreme, the gate could be changed during the journey, but this is rarely resorted to. The facility to request a gate change before the tow commences, must be included in the simulation. The gate departure time which is referred to may only be an estimate, if the start time of the tow is more than 10 minutes before the first estimate of the aircraft's departure time. It is therefore possible for the simulation not to request a gate change, only to experience a departure delay from the gate and be forced to request a late gate change (see 9(a)).

8 c) If the tow cannot be started because of a shortage or limitation on towing vehicles, it is conceivable that an aircraft change would be considered. It was never experienced during observation and is considered unlikely to occur for the following reason. The imminence of a shortage would most probably manifest itself before any acute embarrassment such as this were encountered. As a result care would be taken on positioning the aircraft initially, so that it would be possible to taxy it to its gate. Alternatively, although a shortage of towing vehicles may exist, it is likely that a push-out tug, not equipped with radio, would be capable of re-positioning the aircraft within the parking area to facilitate engine start and taxying. It was decided therefore, as in 7(b) that it was not necessary to over complicate the simulation by allowing a request for an aircraft change at this stage. As above, a check is made every 5 minutes to ascertain the availability of vehicles.

9 Arrival of aircraft in vicinity of gate when under tow.

a) During the tow, if the planned gate is seen to be experiencing unexpected delayed departure, the tow can be re-directed to a new gate, if available, with little increase in the journey time. It was considered unnecessary to force the simulation to recheck the gate availability on a regular basis. Instead, if the gate is full on arrival and the maximum holding time would be exceeded without a gate change, then the procedure GATE ALTER can be called and if successful the aircraft is positioned on the new gate one minute later than it would have been on the old. This does not exactly simulate real conditions, but bearing in mind the infrequency of the event, and the ability of the controllers to change the gate whenever the delay is apparent, it is considered to be acceptable.

9 b) If a gate hold is accepted, and combined with a long tow time, the possibility of an aircraft change would seem to be reasonable. However, for this condition to exist, there must remain less than the minimum gate time before departure. An aircraft change requested at this time would undoubtedly incur its own delay because of the time to arrange the change and to prepare the substitute aircraft. Since the simulation is not designed to generate these delays, a false on-time departure may occur if it were allowed to call ALL CHANGE. The initial delay is accepted.

c) If the gate is vacant, an estimate of the flight departure time must be made after positioning the aircraft. This can be regarded as an identical situation to that described for activities 4 and 5 above where the arrival was formed by a flight movement and not a tow. The simulation estimates the departure as occurring at STD or ATA + minimum ground time whichever is later.

10 Outstation Events.

It is unnecessary to simulate any of these activities provided that the actual flight arrival time at the home station is obtained from data which includes the effect of delays and aircraft unserviceability at the outstation. A distribution has been compiled which shows the deviation between the planned sum of flight times and outstation ground times and that actually achieved. This is sampled at the air debrief time to obtain the actual arrival time.

7.7.5. Aircraft Unserviceability.

In the previous section, reference was made to events at which it would be desirable to allow the simulation to declare an aircraft to be unserviceable for technical reasons. It was stated that probability distributions could be formed which would enable a "go" or "no go" decision to be made. Two fundamental difficulties are encountered when it is necessary to quantify the time during which the aircraft remains unserviceable. One concerns the collection of data while the other involves the design of the simulation and the manner in which departure times are calculated.

7.7.5.1. Collection of Data.

All the airlines studied make an attempt to record the distribution of aircraft unserviceability durations and use it as a measure of aircraft reliability and of maintenance performance. The method of compiling the data does not, and probably cannot, take into account the desireability of making the aircraft serviceable, or the reduction in down time which could be achieved by extra engineering resources. If a spare serviceable aircraft is available and can be substituted for the U/S one, several factors may prevail which result in rectification work being delayed. Engineering facilities may be committed to existing turnrounds each of which receive a higher priority than that accorded to what has become an unserviceable but spare aircraft. A routine maintenance check may be imminent, in which case the defect will be rectified when sufficient labour is available to commence the check. Maintenance controllers may take the opportunity to have cleared other non safety defects at the same time thus apparently increasing the gravity of the original fault. It may be possible to clear a certain defect in a short time if more than one mechanic was allocated to the task. However, when the aircraft may not be required for some time, a conscious decision to lengthen the elapsed maintenance time may be taken to conserve manpower.

7.7.5.1. The above situations usually apply when the aircraft has been withdrawn from service, but other anomalies appear when it remains allocated to its departure with other ground handling activities proceeding as normal. A departure delay may be incurred by cargo loading (say) and is larger than that which would have been caused by maintenance demands. The delay is attributed in this case to cargo handling and the aircraft unserviceability may go unrecorded. If the engineer knows that he can complete his rectification within the cargo delay, he would probably not report the aircraft as being unserviceable, and would class his action as part of the pre-departure check. Naturally this does not imply any contravention of legal requirements of Certificates of Compliance etc., all of which are scrupulously adhered to.

It can be seen that operational priorities affect the recording of unserviceability purely because the data can only reflect the time between the aircraft being declared unserviceable and being certified as fit for further service. The small periods tend to be overlooked because of masking effects of other delays and long turnrounds, while the more serious cases may be magnified because of other defect rectification or the lack of pressure on maintenance for a serviceable aircraft as soon as possible.

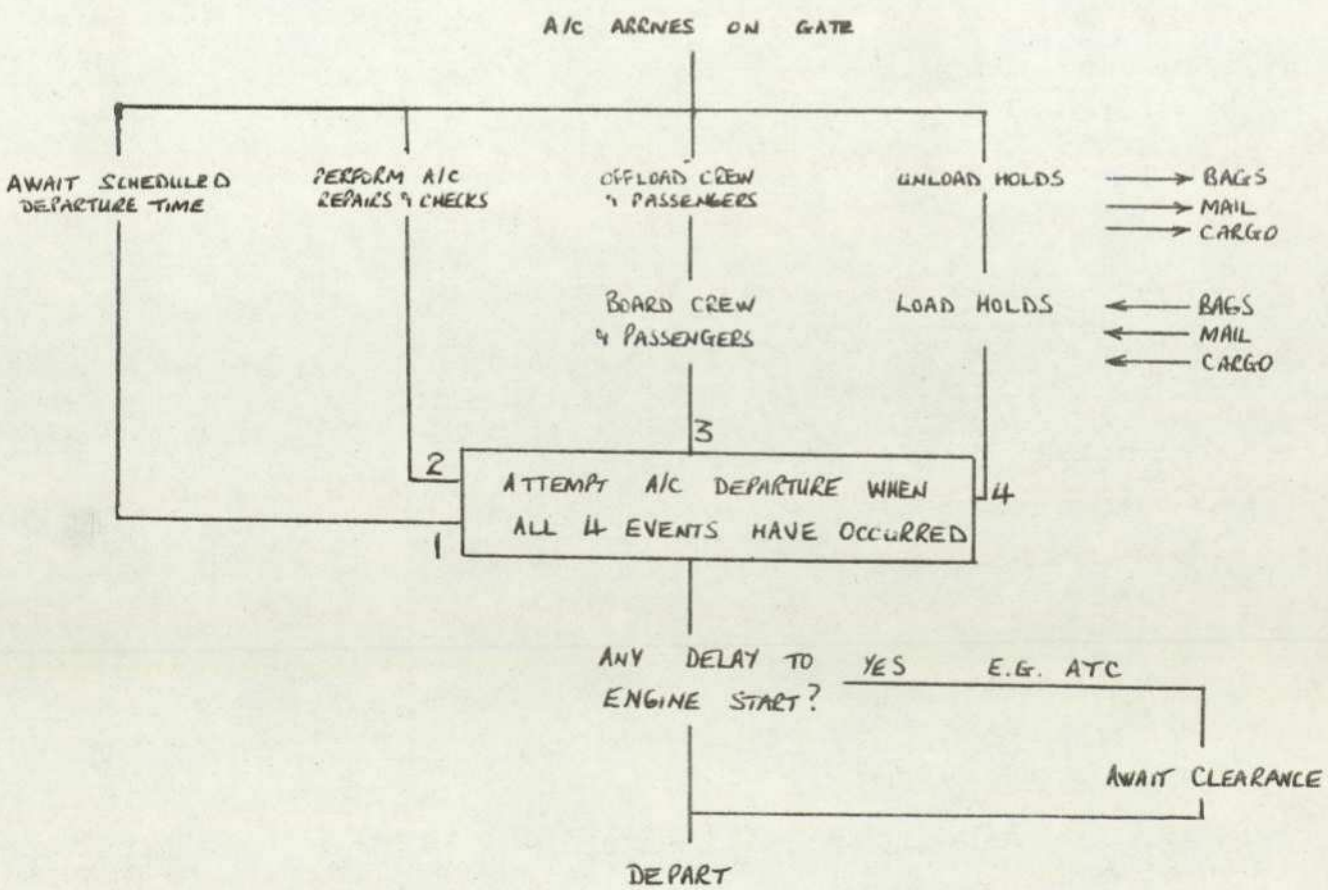
7.7.5.2. Effect on Simulation Design.

The philosophy used throughout GATESIM has been to introduce complex subroutines only when the design aim requires them, and to simplify as much as possible those facets of airline operations whose detailed effects are of no direct interest to this study or lend themselves to analysis, if necessary, outside the simulation. This is best illustrated by comparing the complex subroutines which were designed to perform aircraft and gate changes, with the methods adopted for delay generation. The end result of the latter, i.e. the actual departure or arrival time, is of prime importance to the simulation, but it is not of any

7.7.5.2. interest in this project to ascertain the departmental allocation of blame for the delay. Unserviceability however does affect the gate timetable in that a U/S aircraft may occupy an operational gate area during rectification. The difficulty of obtaining realistic data was described in the preceding section, but assuming its availability, it would be necessary to alter the method of departure time generation if it were to be included as a parameter.

It has been shown that a departure can occur only after the occurrence of certain activities. One of these is the successful completion of the aircraft repairs or checks. The diagram below shows six other activities:

i) scheduled departure time has been reached.
ii) freight holds have been unloaded as necessary
iii) freight holds have been loaded as necessary
iv) passengers and crew have disembarked as necessary
v) passengers and crew have embarked as necessary
vi) permission from ground control to commence push back.



7.7.5.2. It is apparent from the above network that not only is serviceability data required, but also probability distributions concerning the activity times for unloading and loading the payload and its overheads and for obtaining permission to commence the departure when ready. This requires that either individual theoretical distributions are used or else the airlines delay data is capable of being broken down into component causal distributions. The interactive effects of the different causes render the latter approach unrealistic. The use of theoretical distributions is possible but suffers from two drawbacks:-

i) Each departure activity would involve at least four calls to a sampling procedure and regular checks (every minute after the scheduled departure time has been reached) to ascertain if all pre-departure activities had been completed. Only then would the flight movement be permitted. This in itself implies that each aircraft has at best four more attributes each of which must be altered once during a simulated turnround. When simulating an operation such as United's at O'Hare where the 200 or so departures may have a mean delay per departure of 10 minutes, the above task could result in 3000 extra activities per simulated day.

ii) Considerable testing would be required to ensure that the theoretical distributions were such that realistic delay rates were obtained. This is doubly difficult when simulating an airline which has not in practice operated the gate timetable being simulated. While the simulation can easily identify any delayed departure whose earlier arrival on the gate experienced a gate hold, it would require considerably more programming to trace any later reactionary delays. Probably the simplest and best way of ensuring realism of the distributions would be to simulate the operation using a hypothetical gate timetable in which each gate has only one

7.7.5.2. ii) occupancy. In this way no delays could be attributed to the gate plan. The original objection of extra proving runs remain.

7.7.6. Effect of Excluding Aircraft Serviceability from the Simulation.

7.7.6.1. Aircraft changes are the result of the non availability of the planned aircraft at time of departure and normally are caused by one of two factors:-

i) planned aircraft was late in arriving on the preceding flight

ii) on arrival aircraft was declared to be unserviceable.

Obviously the exclusion of serviceability data precludes the simulation from requesting aircraft changes by reason of ii) above. This implies that the schedule reliability will be higher than that actually achieved. It is difficult to estimate with a given degree of confidence the increase which would be expected but the following paragraph provides a very crude method.

Assume that during the operating day of 12 hours the mean recorded (!) unserviceability time be one hour and that one standby aircraft was available. The maximum number of departures which could avail themselves of the standby is 12. If 100 flights were planned, a first estimate of the increase in schedule reliability as reported from the simulation would be 12%. The two most obvious assumptions in this are that the flights are distributed evenly throughout the day and that the spare aircraft requires no further preparation for departure after it has been declared serviceable.

7.7.6.2. The effect of the apparent increase in the schedule reliability on a gate timetable is even more obscure since it depends also on the maintenance policies employed by each airline. American and United regard their gate plans as of prime importance because of the shortage of gates at some airports and do virtually no rectification work to standby aircraft while still positioned on the gate. BEA however, prefer to remove the aircraft from the gate only when specialised equipment or men are required or when the estimated rectification time will prevent the aircraft from fulfilling its intended standby role for the remainder of the operating day.

7.7.6.2. A comparison of the operating methods of the five major airlines studied is given in Chapter 15. Suffice it to state here that of the carriers who successfully operate gate timetables, none permit rectification action to interfere with planned occupancies unless of course the aircraft is immobilised. No attempt is made in this project to financially justify the removal of a defective aircraft to enable the achievement of a higher gate timetable reliability. It is considered that each airline has adopted turnround maintenance practices most suited to their operation and organisation and that it would be naive to suggest these be altered overnight to ensure a more successful gate timetable. Any such alteration will be achieved after long and careful study of individual operations which is outside the scope of this project. It is simply the gate timetable which is being researched here and the factors in its construction which affect its reliability. Consequently, although absolute measures of simulated performance are of value, they must only be estimates, and much more importance is placed on their relative values. It is these trends which will be analysed to isolate the significant parameters of a gate plan.

The inclusion of unserviceability data would not only lead to an even more complex simulation, but would result in it becoming a one airline, one airport study. It is seen that although the adopted design neither analyses nor generates unserviceability as an aircraft attribute, it does not ignore it entirely. Departure delays were shown to be incurred by combining an arrival delay with a station delay which was defined at ETD-10 minutes. This last minute delay has unserviceability as one of its

7.7.6.2. constituents. In reality, it is possible that the aircraft operating the gate occupancy departure may differ from that operating the arrival activity and that this was caused by an engineering originated aircraft change. The simulation will not record this, but will nevertheless experience the associated delay. In this way the effect of operational disruptions can be estimated and are not blurred by individual maintenance practices.

In summary, the simulation assumes that standby aircraft may be used to minimise delays, that the generated delays include the alleviating effect of spare aircraft, and that any substituted spare departs from the planned gate without being recorded as an unscheduled turnround.

APPENDIX 7.

References 1. A practical approach to Computer Simulation in Business
Carter and Huzan.

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Tocher.

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Naylor, Balintfy, Burdick, Chu.

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CHAPTER 8

Limitations imposed by the design of the simulation.

8.1 Outstation delays.

8.2 Departure delays and flight cancellations.

8.3 Delays to first arrivals at simulated station.

8.4 Station resources.

8.5 Gate holds.

8.6 Interchangeability of different aircraft types.

8.7 Interchangeability of different gate types.

8.8 GATESIM as a general planning tool.

8.9 Measure of schedule performance.

8. LIMITATIONS IMPOSED BY THE DESIGN OF THE SIMULATION.

This chapter is intended to record the factors of an airline operation which this simulation was neither designed nor intended to study and therefore not capable of analysing. It is important to realise the limitations of any planning tool and to define its method of working. The latter has been done in previous chapters in which some of the limitations also are inferred. These are set out below.

8.1 Outstation movements are not simulated, so the effect on main base punctuality of performance improvements at individual outstations cannot be estimated. The first estimate of arrival time back at the main base is based on the scheduled "absence" time together with the actual departure time and does not take into account the length of turnround at intervening points. In addition, the actual arrival time is obtained at ETA - 20 minutes by sampling from a single distribution which is of course independent both of the original departure delay and the outstation turnround times. It is therefore unwise to simulate large scale outstation delays because the simulation will ascertain the actual arrival time at ETA-20 minutes which could in fact be ATA - one or two hours. It is clearly unrealistic to permit actual knowledge of the arrival time so far in advance. The limit of credibility has not been established since in this study only one distribution was used for this purpose.

8.2 Departure delays are generated by combining any arrival delay with a minimum ground time and a sample from a probability distribution at time ETD-10 minutes. No aircraft changes are requested after the actual departure time has been fixed so it is not possible to estimate the number of aircraft changes which resulted in passengers and cargo being offloaded. This of course is one of the results of including delays caused by unserviceability in the single departure data distribution.

As with the in-flight delays, it is unwise to simulate large scale departure delays because the simulation is not capable of creating flight cancellations which would be one probable alleviating course of action in reality.

8.2 While cancellations would be of undoubted interest to a simulation studying the reliability of aircraft integrations, they are of less significance when the objective is the evaluation of a gate timetable. They normally occur in a high delay rate situation in which the gate timetable has little credibility irrespective of its initial design. Since this simulation will adhere to the original gate plan as closely as possible, always ensuring that each turnround is allocated to a gate, it is wasteful to use it in an attempt to study an operation which in practice will degenerate into a "first come, first parked" situation. The maximum delay rate has not been ascertained since the maximum recorded in this study was approximately 5 minutes per departure. Even this figure represents a poor performance for an average day.

8.3 Although as many days as required can be simulated in one run of the program, each day is independent and assumes that aircraft are positioned on the correct loading gate each morning. This results in no reactionary delays being experienced by aircraft whose first movements of the day at the main station are arrivals. With an airline like BEA whose operation is so concentrated at London Heathrow, with the majority of the fleet night stopping there, the effect is minimal. This is aided by the fact that most aircraft away from London overnight have sufficient ground time to recoup earlier delays. It is therefore acceptable to regard these aircraft as having no reactionary delays and to generate their actual arrival time by sampling from the in-flight and outstation delay distribution.

BOAC's operation exhibits different characteristics because of the length of time for which aircraft may be away from London. Reactionary arrival delays in this context have little meaning since the original departure delay from London has no bearing on the eventual return punctuality. However, in its present form the simulation would ascertain the actual arrival time at STA-20 minutes since in most cases there will be no earlier departure time in the same day by which an ETA may be calculated. This means that the distribution to be sampled must generate the complete arrival delay. Clearly this must in the case of long haul operations, contain some large delays when the problems referred to in 8.1 are experienced. It would be necessary in this case to have two distributions, a sample from one providing a first estimate of ETA-20 minutes, while the second one which would be of limited mean and dispersion, could provide the actual arrival time.

8.3 It would therefore be inadvisable to simulate an operation which has a preponderance of long haul incoming flights, without modifying the method of creating arrival delays.

8.4 The only facilities which the simulation permits to affect the operation are towing vehicles and gates. The availability of loaders, engineers, cleaners and even passengers are not considered in their own right. As with serviceability, the effects of these latter resources are included in the departure punctuality distributions. This is not completely satisfactory since random samples from this distribution may result in departure times being set which involve more minimum length turnrounds with a given time period than the resources can accept in practice. The simulation however will not generate a further delay while awaiting capacity. It can be argued that this type of delay is in fact included in the distribution and that it will be experienced by a different departure. While this is true, the simulation will tend to reduce the significance of departure bunching since it does not recognise it as such. However, it is considered unwise to impose limits on, for example, minimum turnround frequencies since apart from gates and towing vehicles, the resources required to perform a turnround are independent of the type of gate timetable, if any, being used. Conversely, the number of free gates and towing vehicles at any one time is directly related to the gate timetable and this is reflected by the ability of the simulation to create gate and aircraft changes, together with gate holds when a shortage of either resource is experienced.

8.5 Airlines vary considerably in their attitudes to gate holds and to the latest time at which a gate change should be initiated. It is assumed here that the aircraft is told of its planned gate ten to twenty minutes before arrival. Some airlines ensure that the planned gate is either empty or within a few minutes of being so, before allocating it to the incoming flight. If any dubiety exists about the actual time of vacancy of the gate, an alternative is given to the arrival. This can result in poor gate timetable reliability but has the merit of almost completely eliminating late gate changes. At the other extreme, some airlines will accept at gate allocation time, a planned hold of up to 10 minutes, but retain the authority to alter the gate after the aircraft arrives.

8.5 In this simulation a more moderate approach has been used. At the time of air debrief, the actual arrival time is available and if this precedes the most recent estimate of the gate availability time a gate change is initiated. Otherwise the planned gate remains. When the departing aircraft belongs to set FLYOUT i.e. its actual departure time is available for reference, gate holds will not be experienced by the arriving aircraft. Alternatively, if the departing aircraft belongs to set ERESTD, its departure time has not been computed and the gate availability time is the first and crude estimate of it. Consequently, gate changes which are unnecessary may be originated at air debrief time, while an apparently acceptable arrival time may require a late change. This is realistic in most situations except where a large a station departure delay is experienced. Normally this is maintenance oriented and its incipience is known before ETD-10 minutes. The simulation has no such prior knowledge and bases its decision on the ETD. This will tend to increase the number of simulated gate holds and late gate changes. It is felt that this is compensated by the fact that GATESIM has great confidence in its own information and decisions, and when both departure and arrival times are known, it will not create a gate change even though the separation time is exactly zero. Under these actual conditions, the tendancy would be for a gate change to be requested.

It is necessary to emphasise that late gate changes and holds both require the airline to have the facility to contact the aircraft after it has landed.

8.6 As described in section 6.9.1.4., the input data are arranged such that integrated cycles fall into N sections where N is the number of aircraft types. This was done to ensure that type changes could not occur. This is more limiting than in reality where such changes are permitted under controlled conditions to alleviate the effect of a temporary shortage of one aircraft type. These controlled conditions include information on aircraft performance, facilities at destination, passengers and freight on the relevant flights, etc. None of this is available to the simulation and without these limiting factors the simulation could if permitted, create a large number of type substitutions using its rules of minimising delays and timetable disruptions. This is considered more serious than the policy adopted. It is apparent that the frequency of type substitution cannot be measured by GATESIM.

8.7 Since gate changes are represented in exactly the same way as aircraft changes, both being processed by the procedure ACCHANGE, it is apparent that gate type changes are permissable. It is possible to identify in the input data, those gates which are identical. As with aircraft changes, ACCHANGE may be presented with locally declared arrays which represent those gates identical to that for which a change is being sought. In this case, no gate type changes would be possible. Conversely, the global arrays representing all gates may be presented to the procedure in which event, a gate change will be chosen according to the logic of ACCHANGE and irrespective of the gate type. It is possible that a Viscount may be repositioned to a Boeing 747 gate and vice versa. Obviously, the most realistic approach would be to input a link of "aircraft type to acceptable gate types" thus limiting the number of feasible gate changes. This requires considerable programming effort.

It is necessary to recall the design aim which stated that the methods of gate timetable construction should be studied. The relevant parameters included separation times, occupancy times, number of departures per gate, etc. If no gate type changes are permitted, then each set of identical gates may be regarded as having individual timetables each with their own set of descriptive parameters. The timetable reliability is however, a summary over all the gate types and it would be impossible to isolate which set(s) of gates most affected its value. The approach suggested above as being the nearest to reality, in which aircraft and gate types are linked suffers from similar criticism, though less intense.

Both approaches enforce limiting factors on the simulation and tend to reduce its applicability as a policy tool and transform it into a poor example of a "one airline one airport" simulation. This was not its purpose and is one which could be much better satisfied by a simple simulation in which gates are allocated to flights as they arrive, with limited attention being paid to a gate timetable.

As implied above, it was decided to regard all gates as being identical and capable of accommodating every aircraft type. This is the broadest possible approach and one which allows the results to be applied to more limiting conditions. An operational timetable can be broken down into several independent and non-interchangeable units and have the optimum gate construction policies applied separately to each. Difficulty can arise where some gates are partially interchangeable, e.g. a B707 gate cannot accommodate a B747 but the reverse is not

8.7 possible. While the theoretical solution may be complex, the practical answer is that no airline would permit a small aircraft to jeopordise the unloading/loading of a "jumbo". In effect, the smaller aircraft would either cause a series of gate changes within its own gate area or else accept a hold in the normal manner.

It is seen that gate type changes are even more circumstantial than aircraft type changes and that by regarding all gates as identical, the operational effect of non interchangeability can be estimated. Partially interchangeable gates must be regarded as an unplanned alleviating factor, which while easing a specific parking problem, will reduce the gate timetable reliability.

8.8 The simulation involves many complex procedures as described in Chapter 5, and is consequently expensive to run, requiring large core store and high run times. These are shown in more detail in Chapter 11. It is the aircraft and gate change procedures which are the cause of this, resulting in run times being more dependent on the number of such alterations rather than on the number of departures as such. It is therefore unwise to regard this simulation as a general multi-purpose planning tool which can be amended and expanded to permit the study of other aspects of an airline's operation. While it is possible that the actual simulation part of the program could provide the basis for a more general approach, it is doubtful if the gate and aircraft change procedures would be required in such depth as this project demanded.

8.9 The input to the program was shown to include a formulated gate plan. It is important to realise that the simulation merely alters this plan as dictated by the operational conditions, and monitors such modifications. It does not attempt to forecast the number of gates required to provide a given level of departure reliability. The flight schedule will be operated from the stated number of gates and the success will be measured in terms of punctuality, gate timetable reliability and gate holds and not by the number of times extra gates had to be used.

CHAPTER 9.

SIMULATION OF THE OPERATION OF UNITED AIRLINES AT O'HARE AIRPORT, CHICAGO.

9.1 Reason for simulating UAL.

9.2 Construction of operation gate plan.

9.3 Details of five gate plans simulated.

9.4 Simulation of gate plans UAL1, 3 and 5.

9.5 Conclusions drawn from simulation of UAL1, 3 and 5.

9.6 Simulation of UAL2 and 4.

9.7 Summary of results.

9 SIMULATION OF THE OPERATION OF UNITED AIRLINES AT O'HARE AIRPORT, CHICAGO.

9.1 It was decided to use UAL's flight schedule for summer 1969 as the first input to the simulation for several reasons which included the following:

i) During a six week resident study at O'Hare, it was apparent that UAL attached considerable importance to the operation of a pre-planned gate timetable.

ii) Data was available to enable the gate timetable reliability to be obtained for a period of one month.

iii) Over 200 departures were operated from 21 gates which were under the exclusive control of the airline.

iv) The use of standby aircraft was kept to a minimum and aircraft integration changes were almost exclusively of type DIRECT or INDIRECT. This resulted in the secondary aircraft reallocations and the associated reactionary gate changes being kept to a minimum. The gate changes which did occur were therefore a good reflection on the gate timetable parameters and the flight schedule and were less affected by the aircraft maintenance cycles. This provides a good basis on which to test the simulation and compare the results of different gate plans.

9.2 Although the schedule was operated from 21 gate areas, two adjacent small areas were normally combined and used as one parking point, giving an operational total of 20 gates. UAL's schedule planning staff assumed that only 18 gates were available, and regarded the two extra gates as providing an operation buffer. There was no statistical basis for this, nor was there any attempt to forecast the effect on punctuality etc., if the 18 gate plan had been implemented. The simulation provides an opportunity to investigate this and to quantify the advantages, if any, which the two extra gates provide.

9.2.1 The operational gate timetable was constructed by the same staff as would implement it, so the emphasis in the planning stage relied more on practical experience than on theoretical plans such as LOFI or FOFI. This is offered an ideal opportunity for further comparison.

9.2.2 At the time of the study, UAL operated DC8s, Boeing 720s, 727s, 737s and Caravelles, and parking limitations did exist for the four engine aircraft on some gates. With these exceptions the gates were considered to be completely interchangeable and no

9.2.2 attempt was made to park the aircraft according to type. However, airlines with a more diverse range of aircraft each requiring different ground equipment, may elect to design individual gates for each type. Less radical is to create sets of "one type" gates separated by multi-type gates which act as overflow areas for the adjacent gates.

9.3 UAL's operation was simulated under five different gate plans, one of which was the operational one (called UAL1). The other four were:

UAL2 - It was attempted to create four types of non interchangeable gates which would be planned to accommodate only the following aircraft

gate type 1 all small 4 engined aircraft, i.e. B720, DC8
gate type 2 all large 4 engined aircraft, i.e. DC8 series 61 and 62
gate type 3 all variants of the B727
gate type 4 B737 and Caravelle.

It was found that the operation could not be contained in 20 gates, but required 26. This incurs a large capital expenditure penalty, but also exhibits much less congestion on at least some of the gates. The object of simulating this programme was to ascertain the effect of the extra six gates.

UAL3 - This is a compromise between fully interchangeable gates and non interchangeable ones as described in 9.2.2. Six types of gates were defined, four of which were as in UAL2. The other two were not fully interchangeable but had the following flexibility:

gate type 5 B737, Caravelles, B727
gate type 6 DC8, B720, B727.

This gate plan was accommodated on 20 gates but the distribution of occupancies on each gate differed from the operational plan UAL1.

Although in UAL2 and 3, sets of non interchangeable gates have been created, reference is made to section 8.7 where the advisability of maintaining such a usage policy during the simulation was discussed. After initial set up of the plan, the gates are considered to be fully interchangeable with the gate departure reliability and punctuality performance being measured against timetable parameters such as separation times, occupancies per gate etc and not against the number of gate types.

9.3 UAL4 - This plan was formulated by adopting the LOFI method of occupancy scheduling. It is interesting to note that the number of gates required was 18 - the same number as the UAL planners assumed were available during the schedule evaluation stage. All gates were taken to be fully interchangeable.

UAL5 - This plan was formulated by adopting the FOFI method over 20 gates. The occupancies are evenly distributed throughout the gates which are again taken to be fully interchangeable.

9.3.1 The above five plans have been constructed under differing policies, each of which can be applied to any other airport operation. While the parameters which describe each plan cannot identify the policy under which each was generated, they may be used to compare the plans, provided each were based on the same aircraft integrations. They reflect the result of applying one policy as opposed to another.

The following table illustrated how the mean and standard deviation of the gate separation times vary.

Plan	Policy	Gates	Separation Time Data. (Mean mins)	St. Dev.	Rel. Dispersion
UAL 1	Operational	20	45.0	40.7	0.90
UAL 2	Non interchangeable	26	70.3	74.7	1.06
UAL 3	Partially interchangeable	20	43.1	43.0	1.00
UAL 4	Interchangeable, LOFI	18	36.7	42.8	1.17
UAL 5	Interchangeable, FOFI	20	46.7	32.1	0.69

Table 1.

The separation time data were calculated using the gate variable time span method as described in sections 3.2 and 6.19.

9.3.2 In appendix 9, the gate timetables are shown in bar chart form in figures 1 to 5, while tables 1 to 5 provide analysis summaries of each gate within timetables as output by procedure ANALYSE. Table 6 shows the distribution of gate occupancy and separation times in band widths of ten minutes, while table 7 gives the same separation time data in steps of one minute. These results are summarised in figures 6 to 9 and 35, 36.

9.3.3 Primary attention should be paid to plans UAL1, UAL3 and UAL5 since these require the same resource levels. It is seen from figures 6 and 8 that the distribution of their separation times

9.3.3 varies considerably and that the operational timetable UAL1 tends towards a compromise between the other two. As expected UAL5, which is constructed under the FOFI principle, exhibits few short separation times with only 1.4% of the total being less than 20 minutes. The operational timetable however has 17.2% of its separation times less than 20 minutes. The figure for UAL3 increases to 21.3% indicating the higher number of occupancies which are required on some stands due to the preclusion of certain aircraft types on others. At the other end of the scale, UAL5 demonstrates that only 11.1% of separation times have the luxury of being over 70 minutes in length whereas UAL1 has 15.2% and UAL3 has 16.8%. This is considered to be less significant than the distribution properties up to this point since in this case all three plans have approximately the same numbers of separation times up to 1 hour in length. This value is considered to be more than sufficient to cater for normal operational disturbances, and separation times in excess of it are expected to be relevant only when related to a LOFI policy.

This is because, under LOFI, the apparent excessive separation times are not in fact realised and are hence necessary in the plan because of the need to accommodate occupancies displaced from their planned gate after a small disturbance occurs in conjunction with a very small separation time.

From figures 6 and 8 it would appear reasonable to expect the least gate change requests under UAL5, but to be uncertain of the relative merits of UAL1 and UAL3. If the operation exhibited small numbers of large delays (in excess of 40 minutes), it is probable that UAL1 would be disrupted less frequently. The occurrence of larger delays would reduce the confidence of this claim and possibly even reverse it.

In section 7.5 it was stated that the effectiveness of a gate timetable would be measured by computing the percentage of departures which left from their planned gates. This can be totally different from the number of times a gate change is requested. It is feasible that a timetable which has a high minimum separation time of 20 minutes (say) and has occupancies evenly distributed throughout the gates (i.e. FOFI), may require most gate changes to be of type INDIRECT SWOP, i.e. several gates

9.3.3 are involved. Conversely, a LOFI type plan with its inherent large scatter of separation times, may be more capable of providing an alternative gate without disruption to other occupancies. However, because under LOFI, a significantly larger number of short separation times exists, the frequency of the demands for a gate change may well be so much higher that the product of number of requests and departures disrupted per request may negate the advantage of having simple individual gate changes.

Hence, by comparing the distributions of separation times, obtained from different gate plans relating to the same flight schedule, the plan most likely to provide the least number of gate change requests may be estimated, but it is not possible to assume that this plan will also exhibit the best timetable departure reliability.

9.3.4 The adoption of a LOFI schedule as in UAL4 results in a reduction in the number of required gate areas even though other gates may be less well utilised than under FOFI. As seen from figures 4 and 5, the LOFI plan has 11 gates with at least 12 occupancies, whereas the FOFI plan has only four. Both plans have only one gate on which less than 9 turnrounds are planned and it is the one from the LOFI plan which has the poorer utilisation (55.2 to 49.6 minutes mean separation). This is a somewhat unfair comparison and could be improved by comparing a FOFI 18 gate plan with UAL4, or else UAL5 (FOFI 20 gates) with UAL4 in which two apparently spare gates are planned.

This was considered but rejected for the following reasons:-

i) The spare gates would in reality be used as on-line servicing positions and would not be available for flight turnrounds as intended.

ii) In the U.K., gate areas are controlled by the airport authorities who would be reluctant to accept overflow gates as an operational necessity when operating under LOFI. Pressure would probably be brought to bear on the airline either to utilise the gates or relinquish them. This situation does not apply to the same extent in U.S.A.

9.3.4 iii) It has been assumed in i) and ii) above that the high frequency of small separation times requires the extra two spare gates to accommodate displaced occupancies. While this may be true to maintain a certain level of gate departure reliability, the effect on the following of withdrawing the two spare gates cannot be estimated:

a) amount by which GTR will be reduced
b) effect on number and length of gate holds
c) effect on punctuality.

9.3.5 In a mixed fleet operation which includes the new generation aircraft (e.g. B747, DC10), it is probable that the large aircraft will be limited to a few specially modified gate areas. It would be totally unrealistic to modify all gates purely to achieve full interchangeability of occupancies. "Type parking" has been accepted for these aircraft purely on account of their size. However, there exists other factors which suggest that this method may be beneficially extended so that aircraft of different types which have similar external dimensions may be segregated. These resolve around the term "aircraft availability" as used in the maintenance concept of "Reliability and Maintainability". This is outlined in the following paragraph.

9,3.6 Aircraft Availability can be defined as the probability that the aircraft will be serviceable at any time due to the combined effects of its own reliability and of the maintenance actions which are possible within a specified time period. The reliability component is a function of design, maintenance philosophy, etc and does not relate directly to the position of the aircraft on the ramp. Maintainability, on the other hand, which is the second component of availability, can be affected by the aircraft's location. Maintainability is the probability that when maintenance action is initiated under certain conditions, a faulty item will be restored to service within a specified time. As an example of this, a typical operating goal for the new "airbus" type aircraft is that 98% of defects should be rectified within 45 minutes after two year's experience of the aircraft type. For this

9.3.6 figure to be achieved a fast reaction time by station maintenance staff must be achieved. This can be further broken down into:

i) engineers must be specialists on particular type of aircraft and/or systems and not merely very competent on several types.

ii) information such as aircraft manuals, aircraft defect history etc, must be readily available.

iii) spares must be readily available.

iv) tools and ground equipment must be to hand.

Although these conditions are best achieved by type parking, no airline operating several types is known to have fully implemented it because of the large number of gates required. Compromises have been reached and in BEA for example, type control has been set up as far as their maintenance personnel are concerned. Four technical control areas each provide specialists cover for one aircraft type, namely Trident 1, Trident 2, Trident 3 and Vanguards.

Because of the relatively smaller number of turnrounds of Viscount and BAC 1-11 aircraft, one control accepts responsibility for them and has the associated skilled mechanics. This arrangement satisfies condition i) above and goes some way towards ii), but makes no attempt to satisfy iii) and iv).

It is claimed that conditions ii), iii) and iv) above would be achieved by implementing type parking and that the engineering content of station delays would be reduced. The simulation GATESIM is not capable of verifying this because technical delays are not isolated from the total departure delay. However, the reliability of the gate timetable can be investigated and the hypothesis that extra gates increases the flexibility of the gate plan may be tested. It is necessary to use the same delay distributions as were applied to the other timetables for the following reasons:

a) alteration to the distributions would prejudge the effect of the conditions i) to iv) above on engineering delays

b) any increase (or decrease) in the gate departure

9.3.6 b) reliability can be positively attributed to the plan itself only if other variables remain constant

c) punctuality and gate holds can also be used as a measure of comparison between gate plans provided the method of injecting the delays and the input delay data is unchanged.

As a result of the above, UAL2 was constructed and was found to require 26 gates as described in 9.3 under UAL2. It is seen that each gate is not limited to only one type of aircraft since it was felt that with six basic types, some with very small activity levels, such a restriction is over-severe. Each type of gate is permitted to accommodate two aircraft types. The mean station separation time rises to 70.3 minutes while the relative dispersion of individual separation times is comparable with that of UAL1, 3 and 4.

It is expected therefore that UAL2 will achieve the highest gate departure reliability and exhibit the lowest number of gate holds. The effect of the latter on departure punctuality should be beneficial but will be manifested only if gate holds were found to be a contributary factor towards delays in the other plans.

9.4 Simulation of gate plans UAL1, 3 and 5.

The results of simulating the above plans are summarised in tables 8 to 12. Each plan was tested under 12 different main station delay distributions. The distribution which was used to generate arrival delays was kept constant, as was that of the gate to parking area towing times. The departure delay distributions were normal ones with mean and standard deviations as shown in tables 8-12.

It was intended that each plan and delay distribution combination would be simulated over a period of thirty-one delays. This was achieved initially, but a reduction in computer time allocation by the University of London Computer Centre to all external Universities, resulted in this being reduced accordingly. The number of days simulated is also shown. Basic sampling theory has been applied to the estimates of the gate reliability to obtain the upper and lower limit values. These are shown in table 12.

9.4.1 Variation of Gate Timetable Reliability (GTR) with Mean Station Separation Time (MSST).

Figures 10 to 12 illustrate how the GTR is related to MSST when the latter ranges from 43 to 47 minutes. This is too small a range to permit extrapolation to any extent, but the general trend of increasing GTR with increasing MSST is to be expected. The actual values of MSST are not significant, but it should be noted that an increase of just under 4 minutes in MSST can result in a decrease of up to 8% in GTR. For United at O'Hare this results in 17 extra departures leaving from the wrong gate per day.

The apparently small MSST range of only 3.6 minutes represents about 800 gate minutes separation time for the station or 40 for each gate, and is achieved only by considerable alterations to the distribution of separation times as evidenced by figures 8 and 9.

The highest MSST of 46.7 minutes (UAL5) is achieved by allowing 44.9% of the separations to be in the range 30-59 minutes, whereas the lowest of 43.1 minutes has only 24.1% in the same range. The difference in MSST would be greater but for the fact that although UAL5 exhibits a large reduction in the number of short separation (20 minutes), a reduction in the number of long ones (60 minutes) has a counteracting effect.

In summary, although the range of MSST appears to be very limited, the difference between a value of 43.1 and 46.7 minutes can be significant in terms of achievable GTR. It is impossible to ascertain the effect on GTR of a similar difference in MSST when the absolute values of MSST are significantly different from 43-47, but it is reasonable to assert that as the absolute values increase, the effect of a four minute difference will decrease. Similarly, a decrease in the absolute values should result in a 4 minute change having a greater effect.

9.4.2 Variation of GTR with the Relative Dispersion of Separation Times.

Figures 13 to 15 show how the departure reliability increases when the relative dispersion of the separation times decreases.

9.4.2 Although only three points are used on each graph, it is considered important that the correlation between GTR and the relative dispersion is consistently better than between GTR and mean separation time. It appears that United's operation at O'Hare is such that the highest gate plan reliability is achieved by maximising the mean separation time within the constraint of maintaining the minimum relative dispersion of separation times.

As implied in 9.3.3, the small number of long separation times in UAL5 has not reduced its flexibility but probably enhanced it.

This does not imply that long separation times are detrimental to timetable reliability, but clearly indicates that they do not ensure gate flexibility when they are achieved at the expenses of increasing the number of short separations. The ability of a long gate vacancy to absorb an additional occupancy, with the minimum of disruption, apparently does not compensate for the increased number of requests for gate changes occasioned by the higher number of closely packed turnrounds. This is to be expected since it is necessary for the long vacancies to occur in the same time band as the small ones for any alleviating effect to be possible. With UAL5, none of the three short separation times (20 minutes) lie within the span of any of the twenty long ones (70 minutes). In the case of UAL3, the short and long separation times are distributed such that of 31 short ones which occur in 7 one-hour bands, only 14 can be accommodated on substitute gates with no other gate disruptions. This results in 17 turnrounds which have the highest probability of incurring gate changes, not having an available alternative gate.

9.4.3 Effect of gate timetables on departure punctuality.

This is of prime importance since many of the advantages accruing from the use of a gate plan are rendered void if its adoption is accompanied by worsening punctuality. It must be remembered that this simulation does not forecast the effect of introducing any gate plan where none existed before, but it can be used to compare punctuality performances under different timetables provided they are the only parameters which have been altered. Table 9 shows the following for

9.4.3 plans UAL1, 3 and 5, each operated under 12 input delay distributions:

i) mean delay per departure
ii) standard deviation of distribution of delay per departure
iii) percentage of departures with a delay in excess of 9 minutes.

The table, together with figures 16, 17 and 18 illustrate how little the mean delay per departure varies between the plans. The relative dispersion of the delay distribution alters slightly more but the maximum variation from 4.90 to 4.34 occuring as it does when the mean delay is only 0.6 minutes per departure, is not considered to be significant. The percentage of departures delayed in excess of 9 minutes is used only as an illustration of the effect of these delay distributions.

It appears that little or no change in punctuality performance should accompany the introduction of a new gate plan even though its characteristics vary widely from the previous one. This is again qualified by stating that although the distribution of separation times may differ significantly, the mean station separation times should not be widely apart. This may be over restrictive but is a necessary qualification with the results available from UAL1, 3 and 5.

9.4.4 Effect of gate timetables on duration and frequency of gate holds.

The occurrence of a gate hold has a threefold effect, namely:

i) It is irksome to passengers who are forced to wait disembarking while probably within sight of the terminal building where, in many cases, a vacant gate will be visible. The last impression of the flight is therefore one of delay and may reduce the degree of satisfaction built up over the period from check-in to touch-down.

ii) The airport authority is unlikely to welcome the extra congestion caused by the waiting aircraft.

9.4.4 iii) The available ground time of the aircraft is reduced and to ensure an on time subsequent departure, the airline may be forced to provide extra staff during the reduced occupancy.

It is clear that gate holds are undesirable even though the departure punctuality and schedule reliability is unaffected. This was seen to be the case with UAL1, 3 and 5 above, although the availability of extra staff was not restricted, as described in section 8.4. However, table 10 illustrates that both the frequency and duration of gate holds vary considerably between the plans.

Figures 19 to 21 illustrate how the frequency of gate holds decreases with increasing MSST. Similarly, figures 22 to 24 show how the total ground time lost due to gate holds decreases in the same way. It is interesting to consider these results in conjunction with figures 10 to 12 where GTR is plotted against MSST. The low frequency of gate holds achieved by UAL5 coincides with the highest GTR. Although it is false to assume from this that a decrease in gate holds will result in better gate departure reliability, it is reasonable to claim that of two plans being studied, it is likely that the one which exhibits the lowest GTR also has the highest incidence of gate holds, provided of course that the same conditions apply in each case. It must be emphasised that a high number of gate holds is not the cause of low GTR, but is another manifestation of the inflexibility of that particular plan.

9.4.5 Effect of altering gate-hold policy within a given gate timetable.

In the simulation, a gate hold is permitted only if the estimated holding time is less than a pre-set maximum, unless of course there are no other gates available. The number of holds can thus be altered by varying this value. Since the only alternative to a hold is a gate change, the achieved GTR must decrease with a decreasing frequency of holds. The corollary to this is not necessarily true because the increased number of holds is obtained by permitting longer holds. Although figures 16 to 18 showed that departure punctuality was unaffected by a change in gate plan and the associated

9.4.5 change in the holding characteristics, this only applied when the intended maximum hold was 10 minutes. An increase in this value will inevitably affect punctuality and eventually schedule reliability. The gate hold will force an arriving aircraft to occupy its planned gate and if no late aircraft changes are permitted, will ensure that the departure also will be from the correct gate. The larger the gate hold, the more probable becomes a late departure which not only may interfere with the next occupancy but could create aircraft changes on return to the station. The hypothesis that an increase in the number of holds will permit a higher gate departure reliability is thus considered to be invalid.

The relationship which the frequency and duration of gate holds has with the achieved departure punctuality performance is shown in figures 25 to 30. The departure punctuality is expressed as mean delay length per departure. For plans UAL1, 3 and 5, the number of holds and the minutes held per 100 departures are linearly related to the mean delay. The slope of the line, together with the Y axis intercept, reflects the ability of the plan to absorb disruptions which are not sufficiently severe to create a gate change. For a given departure delay rate, UAL5 requires the least number of gate holds within the range of delays shown though the growth rate of holds is higher than for UAL3.

9.4.6 Effect of departure punctuality on GTR within a given gate timetable.

Figures 31 to 34 show GTR plotted against departure punctuality expressed as the percentage of flights departing less than 10 minutes late. The relationship is seen to be linear with correlation coefficients of 0.92, 0.965 and 0.92 for gate plans UAL1, 3 and 5 respectively. In each graph 12 points are plotted representing the 12 separate delay generation distributions input to the simulation.

From the graphs alone it is not possible to compare the three timetables ability to withstand off scheduled movements. It is possible that an operation which caused 30% (say) of departures to be delayed 10 or more minutes under UAL1 would result in 40% being delayed a similar time under UAL5. Were this true, a gate timetable reliability of 86% or so would be achieved under UAL1 while 88% could be expected

9.4.6 under UAL5, but at the penalty of poorer punctuality. Fortunately, in section 9.4.3, it was shown that for a constant level of originating disruptions, the achieved punctuality is not altered from plan to plan within the stated limits of UAL1, 3 and 5. Consequently it is possible to claim that in the above example, UAL5 should achieve 91% GTR with no increase in departure delays.

However it is the author's view that such a precise application of figures 31 to 34 is a misuse of the intentions of the graphs. Their main purpose is to indicate the vulnerability of a given gate plan to changes in punctuality performance. It is the gradient of the line, rather than the Y axis intercept, which is important. These indicate that UAL5 is least responsive to increases in small delays, while UAL1 is the most vulnerable to them, though this differs only slightly from UAL3.

9.5 The results of the simulation of UAL1, 3 and 5 can be summarised as follows:

i) GTR increases with mean station separation time, but appears to be more closely related to the relative dispersion of the separation times. The highest value of GTR should be achieved when the relative dispersion is at its lowest value consistent with as high a value of MSST as possible.

ii) Within the stated ranges of generated delays and of gate plans, the departure punctuality is unaffected by the type of gate plan in use.

iii) Gate holds tend to decrease with increasing MSST and with decreasing relative dispension of separation times.

iv) An increase in the departure delay rate is accompanied by an increase in frequency and duration of gate holds irrespective of the gate plan being used.

v) Gate holds do not appear to have significant effect on punctuality.

vi) The expected value of GTR under a defined plan can be related directly to departure punctuality expressed as the percentage of flights departing within 10 minutes.

9.6 Simulation of plans UAL2 and UAL4.

The main object in running the simulation under plans UAL2 and UAL4 was to ascertain whether the general trends and relationships illustrated in the previous two sections could be applied to an operation where the level of gate resources was considerably altered. In UAL2, 26 gate areas are required and a very high value of 70.3 minutes for MSST is obtained. UAL4 on the other hand requires only 18 gates which are naturally more congested than in UAL2, this being reflected in the MSST having a value of 36.7 minutes.

9.6.1 Parameters of UAL2 and UAL4.

The distribution of occupancy times of the two plans differ only very slightly from each other and from plans UAL1, 3 and 5, as evidenced by figures 7 and 35. That of the separation times however, vary considerably as shown by figures 6, 8 and 36. UAL4 has a massive 44.9% of its occupancies separated by less than 20 minutes while only 16.8% have one hour or more between the preceding one. The former is by far the largest and the latter the smallest of all the five plans.

The LOFI policy, under which UAL4 is constructed, is designed to achieve this high figure of small separation times, but the theory is meant to provide also a maximum number of long separation times. This appears to be contradicted by UAL4 until it is remembered that only 18 gates are being used. The policy has in fact been so successful that two infinitely long separation times exist! By excluding these two gates, some long separation times, which under LOFI are intended to support the highly congested gates have been eliminated. The timetable reliability is expected to be considerably lower than the other plans, but may in fact be higher than that achievable under the 20 gate LOFI plan. The latter possibility exists because UAL4 may be so tightly packed that gate holds and not gate changes predominate. If this is so, a decrease in departure punctuality should be observed when compared with other plans which had the same components of initial disturbance.

9.6.1 Despite the elimination of two gates, the low MSST value of 36.7 minutes is coupled with the highest relative dispersion figure of 1.17. The results from UAL1, 3 and 5 suggest that these figures above will cause a decrease in GTR if item i) in section 9.5 can be applied to the reduced resource facility unless item v) in the same section is found to be invalid.

The distribution of separation times of UAL2 as shown in figures 6 and 36 is vastly different from the other plans, having a mean of 70.3 minutes and a standard deviation of 74.7. In general, UAL2 exhibits a smaller number of separation times in each bandwidth up to the range 60-69 minutes, with the biggest decrease occurring in the range 20-29 minutes. From 70 minutes upwards, the pattern is reversed, culminating in UAL2 having 21.4% of its separations more than 100 minutes. This should result in a large increase in the achievable GTR together with a decrease in the number of gate holds.

9.6.2 Variation of GTR with MSST and relative dispersion of separation times.

In section 9.5, item i) claimed that although a linear relationship was established for UAL1, 3 and 5 between GTR and MSST, it was more probable that the relative dispersion had a greater degree of control over the achievable value of GTR. For a constant resource level, and for a given flight schedule, there are distinct limits between which both these gate variables may alter. However, when the number of available gates is changes, and the flight schedule is kept constant, these limits may be exceeded.

This occurs in both UAL2 and UAL4, being much more pronounced in the former case. UAL2 was based on an arbitrary allocation of aircraft types to specific gate types and viewed as one complete timetable, bears no resemblance to LOFI, FOFI or a quantitative combination of the two. The creation of aircraft type gates could easily have extended to permit only one aircraft type on each gate, in which case more than 26 gates would have been required and the value of MSST would be further increased.

9.6.2 It is considered that a set of relationships developed under a limited resource condition cannot be expected to apply when the resource can be increased by an indefinite amount.

Consequently, although the broad principle of increasing GTR with increasing MSST is still thought to apply, extrapolation of figures 10 to 12 are not expected to give a reasonable estimate of UAL2's GTR. The relative dispersion of separation time exhibited by UAL4 does not appear to be greatly different from that of the other plans, but again, because of the great increase in MSST, the standard deviation is sufficiently high to expect even the GTR - relative dispersion dependancy to break down. In summary UAL2, is expected to achieve the highest GTR value of all the plans, but to attain it in a manner inconsistent with extrapolation of figures 10 to 12 or 13 to 15.

UAL4 on the other hand differs by only two gates from plans UAL1, 3 and 5, and has an MSST value of only 6.4 minutes below UAL3. Although this is achieved by large scale alterations to the distribution of separation times, the difference in MSST value is sufficiently small to expect that UAL4's reliability will approximate more closely than UAL2 to the pattern defined by plans UAL 1, 3 and 5.

In the following table, the simulated GTR values for UAL2 and 4 are compared with the values obtained by extrapolation of graphs 10-12 and 13-15.

Input Distrib.		UAL2 - 26 Gates			UAL4- 18 Gates LOM		
		MSST f'cast	R.D. f'cast	simul	MSST f'cast	R.D. f'cast	simul
Mean	Std.Dev.	GTR %	GTR %	GTR %	GTR %	GTR %	GTR %
10	2	100	94.5	97.1	87.9	93.2	97.6
10	5	100	93.6	96.7	85.9	91.9	96.3
10	10	100	87.7	93.9	75.0	85.0	88.5
10	15	100	83.1	91.4	71.2	80.1	83.2
12	2.2	100	92.6	96.3	83.8	90.7	96.1
12	5.5	100	91.3	95.8	80.4	89.0	93.6
12	11.0	100	85.7	92.7	76.1	83.4	86.7
12	16.4	100	80.9	89.3	70.5	78.4	79.9
14	2.4	100	91.7	95.2	81.0	89.5	96.0
14	5.9	100	90.6	94.5	81.9	88.6	91.3
14	11.8	100	83.4	91.3	72.9	80.8	81.5
14	17.6	100	78.2	88.2	68.6	76.1	76.2

9.6.2 The reliability of UAL2 as forecast, using MSST as the sole criterion, bears no resemblance to that actually obtained in the simulation. In fact, the achieved GTR is lower than that obtained under UAL5 for all input delay distributions with the exception of the most severe (mean = 14, s.d. = 17.6).

This implies that either a linear dependancy is not applicable in the higher values of MSST, or else that MSST is the wrong parameter from which GTR should be estimated. The relative dispersion plot provides a better estimate of the reliability but is seen to be consistantly below the achieved figure. This is again considered to be because of the large differences in MSST and standard deviation.

It is concluded that it is totally unrealistic to permit extrapolation of figures 10 to 12 or 13 to 15. It would appear that at the high levels of GTR achieved by UAL2 and 5, the percentage of occupancies below 20 minutes in length could best explain the reduction in GTR from UAL5 to 2. There is always going to be a residual level of gate change requests whenever these short separations exist and independent of their distribution above 20 minutes.

The result of UAL4 corroborates the evidence supplied by UAL2 that MSST should not be the sole basis for estimating GTR. The MSST estimates for GTR are seen to be consistantly below the actual values. However, in this case, if the two eliminated gates are regarded as two separation times of 24 hours each in length, the value of MSST for the plan increases to 49.7 minutes. This is unrealistic but if the gates are regarded as having separation times which coincide with the main operating period of the day, namely 0700 to 2100 hrs, the MSST is found to have a corrected value of 44.1 minutes. With this correction, the MSST based estimate is considerably higher than that achieved, which is just as unacceptable as the reverse.

The estimate of UAL4, based on relative dispersion, is much more realistic and although slightly below the achieved value, an explanation can be offered. It hinges on the frequency and duration of gate holds showing an increase over other plans as discussed in section 9.6.4. Because of the shortage of gates, holds are forced to be accepted when a gate change would be prepared.

9.6.3 Effect of gate timetable on departure punctuality.

Table 9 shows how the departure punctuality expressed as mean delay per departure, is constant at the levels shown in figures 16-18. This indicates that despite an increase in gate numbers in UAL2, an improvement should not be expected in punctuality and that justification of capital expenditure for such expansion should be sought in other areas, such as GTR and gate hold improvements.

9.6.4 Effect of gate timetables on frequency and duration of gate holds.

From figures 19 to 24, it is expected that both the duration and frequency of gate holds should have low values under UAL2 and high ones for UAL4. From table 10 it is seen that UAL4 does incur more disruptions due to gate holds, but neither the frequency nor the total time lost is as high as figures 19 to 24 would indicate. It should be noted that the mean hold has not altered to any extent which supports the claim that departure punctuality is unaffected. UAL2 does not behave as expected, exhibiting a poorer performance than both UAL1 and 5. This emphasises the view that MSST is the wrong basis on which to base any quantitative estimate of gate performance.

9.6.5 Relationship between departure punctuality and gate hold frequency and duration.

The variation of gate hold frequency is shown in figures 37 and 39, while the total number of minutes held per 100 departures is shown in figures 38 and 40.

The frequency of holds in UAL2 achieve a linear correlation coefficient of 0.75 with the departure punctuality and a gradient of only 0.028. Since the frequency at zero delay rate reflects the inherent ability of the plan to absorb small arrival disruptions, the value of 0.64 for UAL2 compares very favourably with 1.75 for UAL4 and 1.01 for UAL3, but poorly with UAL1 and 5 which have intercepts of 0.21 and zero respectively. With the exception of UAL4, these intercepts appear to be directly dependent on the number of separation times less than 10 minutes in length. The exception of UAL4 can be explained by the high percentage (44.4) of separations in the range 10 - 19 minutes.

9.6.5 Figure 39 (UAL4) is seen to exhibit considerable scatter with a correlation coefficient of only 0.46. This must be considered in conjunction with the absolute values of the gate hold frequencies and the high degree of congestion on some gates.

Despite the above comments comparing gate performance as measured by gate holds, the maximum is only 2.2 per 100 departures, or around five holds per day for United at O'Hare. In other words, five arrivals and five departures deviate from the schedule sufficiently to have a calculated overlap of less than ten minutes, estimated at the commencement of the hold. Since the creation of an arrival delay is independent of the size of the preceding separation time on its planned gate, and a departure delay is similarly independent of the following one, the occurrence of a gate hold is dependent on a random combination of two unscheduled movements coinciding with a specific range of planned separation times.

In UAL4, 44.9% of separation times are less than twenty minutes, and if by chance the movements forming these separations have been allocated large departure delays, coupled possibly with early arrivals, gate holds become highly probable. If, however, these movements are allocated very small schedule deviations, few gate holds should occur. Thus it is expected that a large scatter in frequency of gate holds should be apparent from day to day of the simulation. The achievement of the steady state condition obviously requires more passes when such a preponderance of small separation times exist. Unfortunately, this was not possible due to the limited computer time available. It is considered therefore that the large scatter of results obtained for UAL4 is explained by the particular vulnerability of certain gates to off-schedule movements and by the failure to counter this effect by increasing the number of days simulated. It is felt that the same reasons can be applied to the scatter apparent in figure 40.

9.6.6 Effect of departure punctuality on GTR within a given gate timetable.

Figures 41 and 42 plot the variation of % GTR with departure punctuality expressed as the percentage of flights which depart less than ten minutes late. Linear correlation coefficients of 0.95 and 0.99 are obtained for UAL2 and UAL4 respectively. As stated in 9.4.6, it is the gradient of the correlation lines which is important, and the values are found to be 0.21 and 0.51 for UAL2 and 4 respectively. These indicate that one of the advantages gained from increasing the number of gates to 26 is that the timetable reliability will be considerably less affected by changes in the number of small departure delays.

The value assigned to this attribute is of course dependent on the operational cost which a gate change involves, and the degree to which the departure punctuality varies from day to day. It is probable that if a given operation is basically unpunctual, extensive facilities and procedures will exist for easy implementation of gate and aircraft changes. In this case, it is less important to have a gate plan with a low dependancy on changes in levels of departure punctuality than to operate one whose dependancy is higher, but whose GTR at the mean delay rate is inherently better.

Conversely, if an operation has proved to be consistantly punctual, an occasional bad day will create sufficient unusual problems without having the additional one of a gate plan whose GTR is seriously effected by this change in punctuality. Thus in this case, it would be prudent to operate a plan with a low vulnerability to delay rate changes.

9.7 From the preceding three sections it is apparent that the relationships developed from the results of simulating UAL1, 3 and 5 are restricted in their sphere of applicability. Clearly the value of MSST and the relative dispersion of separation times have an effect on the achievable value of GTR, but a linear relationship certainly cannot apply unless within a very small range of MSST or R.D.

This is not the severe limitation which it appears at first sight, when the conditions under which an airline will apply the dependancy are considered. It has been emphasised throughout this project that

9.7 the simulation should not be regarded as capable of estimating the absolute value of achievable GTR, but does provide an acceptable method for comparing gate plans. Only in exceptional circumstances will airlines alter the number of gates which are available to them, and these will usually occur as part of a general development plan linked to long term expansion rather than to the short term schedule change requirements. It is suggested therefore that constant resource level conditions will apply in the majority of occasions when the adoption of a new gate plan is contemplated. In addition, if the concept of GTR is to be used as a selection parameter for the new plan, the airline will, in most cases, have monitored the actual values and should be able to create a datum point, suitable to their operation, from which by the relative performance of other timetables as estimated by the simulation, can be plotted. In this context it is worth repeating that large differences in gate plans and associated separation time distributions do not appear to create large differences in either MSST or relative dispersion of separation times.

As a result of this, it is suggested that in most applications of this research work, the range of MSST and R.D. of separation times, will probably be of the same magnitude as that exhibited by UAL1, 3 and 5, in which case it can be accepted that:-

i) GTR tends to increase with increasing MSST.

ii) GTR tends to increase with a reduction in the amount of scatter of separation times.

iii) The relative dispersion has a greater effect on GTR than does the MSST value.

iv) The highest intrinsic reliability will be achieved by a gate timetable which is constructed as closely as operationally possible to the FOFI policy.

Although the duration and frequency of gate holds vary according to the gate plan in use, the achieved departure punctuality does not seem to be affected by a change in them. As stated previously, this is based on the simulation's assumption that extra resources will be available, if required, to ensure that a minimum duration turnround can be performed.

9.7 Under a FOFI policy, the shortest separation times occur during the most congested gate periods and since gate holds have an increasing probability of occurrence as the separation time is reduced, gate holds are more likely to occur during these busy periods. There is unlikely to be a group of staff consistantly under-employed during these periods, so the occurrence of a gate hold will incur a penalty in terms of either additional staff, as assumed by the simulation, or else by incurring a departure delay. This may cause a further disruption to the gate and even the aircraft integrations. It is therefore desirable that a low level of gate holds accompany an inherently high value of GTR.

Figures 43-45 show how the frequency of gate holds varies with the MSST, figures 46-48 shows its relationship with the relative dispersion of separation times, while figures 49-51 illustrates the dependancy on the percentage of occupancies which have separation times of less than ten minutes. Each of these graphs exhibit discontinuities which can be attributed in the main to UAL2 in figures 43-48, and to UAL4 in figures 49-51. In the latter case, frequency of gate holds gained from the simulation is considerably higher than that suggested by the trends of results from UAL1, 2, 3 and 5. This can be partly explained by the large difference in the number of separation times in the range 10-19 minutes.

There is nothing magical about the choice of the value ten in the statement "% of separation times less than ten minutes in duration". It is used simply because ten minutes was the selected bandwidth of the output distribution. If in fact the frequency of holds can be related to such a percentage, the value of the separation time from which it is calculated is expected to vary with the punctuality distributions. For example, if the mean delay length is only two minutes as opposed to twenty two, it is reasonable to postulate that in the former case, the frequency of holds would be independent of the number of separations in the range 20-25 minutes, but that the latter delay condition would show some degree of dependency.

Table 7 shows a detailed analysis of the separation times in plans UAL1-5. Discontinuities are apparent at ten, twenty and twenty-five minutes, this being especially noticeable in UAL4. Against each separation time is shown the percentage of separations less than

9.7 or equal to the stated value. For each integer value from zero to twenty nine minutes, the frequency of gate holds was plotted against the respective percentage for each gate plan in an attempt to ascertain:-

i) Is the frequency of gate holds dependent on the percentage of total separation times below a certain value?

ii) If this dependancy is ascertained, does the critical value change with an alteration in flight punctuality?

No correlation could be justified for any value up to nine minutes, but the discontinuity at ten minutes allowed a good correlation at that value. In all cases this continued up to the maximum shown of twenty nine, but since cumulative percentages were used, this is considered to be the result of the high correlation at the ten minutes value.

Table 11 in appendix 9 shows the results of the attempted linear correlations over the complete range of separation times. Figures 52 to 54 show gate hold frequency plotted against the percentage of separation times less than eleven minutes and the respective correlation coefficients.

The conclusion to question i) above is therefore most emphatically affirmative with the critical value of separation time being eleven minutes. It would appear from the results that this value is independent of the punctuality performances since the same critical value applies when the mean delay ranges from one to fifteen minutes per delayed departure. Only in the two most severely delayed cases did the critical value show signs of increasing. While this is to be expected, the most significant increase in correlation was still obtained by changing the limit from ten to eleven minutes, so it is considered that this value contributes most to the dependancy.

It is seen from figures 52 to 54 that the intercept on the Y-axis increases with increasing mean departure delay, indicating that even when all occupancies are separated from each other by more than the critical value, a residual level of gate holds will occur, and that this level is dependent on the flight punctuality. Probably more surprising is the relative gradients of the lines.

It appears from figure 54 that by increasing the size of the mean departure delay a significant reduction can be made in the frequency of gate holds provided the percentage of separation times below the critical value is in the range 15-20%. This apparent anomally has

9.7 two contributory causes to which are attached different degrees of importance dependent on the type of operation being considered. If it is predominantly hub and spoke, like BEA's an increase in departure delays will cause an increased probability of an arrival delay and of an aircraft change.

If the operation is not so heavily "hub and spoke" orientated, arrivals will be affected to a lesser extent than above, and aircraft changes will not be so frequent, but the estimated length of gate holds will be increased sufficiently to warrant a gate change. Thus it would appear that in both cases a decrease in gate holds may be obtained at the expense of a lower value for GTR. This is not inconsistent with section 9.4.4 where it was stated that of two timetables, the one with the lower GTR is likely to have the higher frequency of holds, since in this context it is not timetables which are being compared, but the performance within one timetable.

APPENDIX 9

TABLE 1	Analysis of Gate Plan UAL 1
2	" " " " UAL 2
3	" " " " UAL 3
4	" " " " UAL 4
5	" " " " UAL 5
6	Gate Plan Occupancy and Separation Time Summaries.
7	Distribution of Separation Times.
8	Gate Timetable Reliabilities.
9	Departure Punctualities.
10	Gate Holds.
11	Linear Correlation of Gate Holds with separation time parameters.
12	Limits of GTR.

FIGURE 1	Gate Plan UAL 1
2	" " UAL 2
3	" " UAL 3
4	" " UAL 4
5	" " UAL 5
6	Cumulative Distribution of Separation Times UAL 1-5.
7	Cumulative Distribution of Occupancy Times UAL 1-5.
8	Histogram of Separation Times UAL 1, 3 and 5.
9	Histogram of Occupancy Times UAL 1, 3 and 5.
10,11,12	Variation of GTR with Mean Station Separation Time UAL 1, 3 and 5.
13,14,15	Variation of GTR with Relative Dispersion of Separation Times UAL 1, 3 and 5.
16,17,18	Mean Delay Rate variation against MSST, UAL 1, 3 and 5.
19,20,21	Frequency of gate holds against MSST, UAL 1, 3 and 5.
22,23,24	Total Time Held against MSST, UAL 1, 3 and 5.
25,27,29	Gate hold frequency against mean departure delay, UAL 1, 3 and 5.
26,28,30	Total Time Held against mean departure delay UAL 1, 3 and 5.
31,32,33,34	GTR against departure delay rate.
35	Histogram of Occupancy Times UAL 2, 4.
36	Histogram of Separation Times UAL 2, 4.
37,39	Gate hold frequency against mean departure delay UAL 2, 4.
38,40	Total Time Held against mean departure delay UAL 2, 4.
41,42	GTR against departure delay rate UAL 2, 4.
43,44,45	Frequency of gate holds against MSST, UAL 1-5.
46,47,48	Frequency of gate holds against Relative Dispersion of Separation Times UAL 1-5.
49,50,51	Frequency of gate holds against % of Separation Times less than 10 minutes.
52,53,54	Frequency of gate holds against % of Separation Times less than 11 minutes.

TABLE 1 GATE PLAN UAL 1.

GATE	TIME SPAN	NO OF OCCUPANCIES	SEPARATION TIMES		OCCUPANCY TIMES	
			MEAN	STAND.DEV.	MEAN	STAND.DEV.
1	0750-2212	11	31.3	16.6	47.1	5.6
2	0001-2246	13	49.4	51.5	55.6	13.8
3	0118-2318	12	57.5	56.4	52.5	14.0
4	0110-2315	13	48.6	52.5	53.3	9.5
5	0615-2334	15	22.8	22.6	46.5	8.7
6	0715-2206	9	34.9	17.5	64.1	46.8
7	0600-2104	8	53.3	39.8	59.8	18.4
8	1119-2355	7	36.3	20.9	71.7	75.4
9	0803-2219	10	42.4	23.8	43.2	5.6
10	0720-2154	11	37.2	25.5	42.3	8.9
11	0740-2214	12	26.6	8.0	46.3	9.4
12	0715-2239	9	53.0	18.3	49.7	19.0
13	0117-2335	8	105.5	82.3	61.8	40.3
14	1208-2335	5	79.4	65.0	58.0	15.4
15	0715-2234	12	30.2	14.6	46.4	10.5
16	0558-2338	11	51.4	41.1	45.0	11.3
17	0008-2000	10	50.4	27.5	68.8	54.6
18	0804-2100	9	33.7	17.4	52.6	23.1
19	0620-2328	12	39.8	24.5	45.9	11.6
20	0905-2350	6	69.7	30.4	77.8	24.2
Total:		203	45.04	40.72	52.87	27.04

TABLE 2 GATE PLAN UAL 2.

GATE	TIME SPAN	NO OF OCCUPANCIES	SEPARATION TIMES		OCCUPANCY TIMES	
			MEAN	STAND.DEV.	MEAN.	STAND.DEV.
1	0017-2315	14	50.6	54.6	47.8	10.3
2	0115-2055	10	61.0	59.4	57.0	15.0
3	0605-2100	7	70.6	40.2	57.3	11.4
4	0001-2135	8	57.6	58.8	104.1	103.5
5	0600-2318	5	151.6	105.8	56.0	7.3
6	0008-2334	8	101.4	122.0	74.4	68.8
7	0615-2128	15	16.5	10.3	44.4	8.7
8	1153-2355	5	74.8	35.3	69.6	46.6
9	0558-2234	9	64.3	32.8	46.3	11.9
10	0805-2350	8	63.0	31.3	55.1	21.2
11	0715-2328	10	45.7	34.5	51.6	23.8
12	0620-2135	9	49.8	16.9	51.9	13.9
13	0715-2246	9	45.0	34.6	58.4	16.3
14	0801-1947	9	38.0	21.9	40.4	10.0
15	0912-2105	5	98.8	63.1	43.8	5.2
16	0804-2202	6	84.2	48.2	55.5	23.3
17	0610-1918	6	86.3	32.8	45.0	7.7
18	0715-2104	6	77.5	43.1	60.7	17.4
19	0117-2335	3	387.0	256.0	59.0	7.8
20	0740-2219	8	57.1	30.7	52.8	7.3
21	0620-2154	9	59.8	24.8	44.0	9.6
22	0715-2239	7	84.3	34.7	47.7	8.1
23	0813-2335	8	71.9	28.9	43.4	9.7
24	0715-2338	7	85.1	50.2	55.3	29.9
25	0907-2206	6	91.3	33.7	38.5	4.8
26	0720-2214	4	119.7	87.4	103.8	111.2
Total:		201	70.27	74.66	54.67	36.24

TABLE 3 GATE PLAN UAL 3.

GATE	TIME SPAN	NO OF OCCUPANCIES	SEPARATION TIMES		OCCUPANCY TIMES	
			MEAN	STAND.DEV.	MEAN	STAND.DEV.
1	0715-2104	8	77.5	43.1	60.7	17.4
2	0017-2335	8	122.6	104.9	52.1	12.7
3	0110-2315	12	58.8	52.1	51.6	12.2
4	0605-2318	12	33.0	18.7	53.1	12.6
5	0001-2100	11	46.7	60.5	67.7	42.2
6	0803-2100	9	40.7	23.4	45.7	8.0
7	0615-2334	13	17.1	12.3	62.8	56.0
8	0757-2355	12	32.8	23.1	47.0	10.3
9	0558-2234	12	33.5	14.0	49.5	12.8
10	0008-2328	15	42.8	59.0	50.5	16.7
11	0805-2350	10	48.2	32.0	46.3	6.8
12	0610-2128	12	24.9	22.2	51.6	22.0
13	1100-2246	8	41.9	21.1	46.4	22.9
14	0921-2335	11	32.2	20.5	45.5	12.2
15	0525-2338	12	40.5	21.1	50.6	22.0
16	0740-2219	9	45.3	25.9	52.3	11.8
17	0806-2154	7	38.0	22.1	80.3	88.6
18	0715-2206	10	49.6	25.7	39.5	7.6
19	0720-2239	10	39.0	29.5	52.9	23.9
20	1021-2214	8	39.4	24.0	49.7	8.2
Totals:		207	43.09	43.01	52.37	28.64

TABLE 4 GATE PLAN UAL 4.

GATE	TIME SPAN	NO. OF OCCUPANCIES	SEPARATION TIMES		OCCUPANCY TIMES	
			MEAN	STAND.DEV.	MEAN	STAND.DEV.
1	0715-2334	10	50.4	34.1	47.5	15.1
2	0017-2335	16	38.1	53.5	49.3	12.0
3	0615-2338	11	45.8	33.3	49.0	17.2
4	0605-2205	12	30.0	19.2	50.0	14.7
5	0001-2036	13	27.8	22.2	67.2	80.9
6	0110-2315	13	39.6	53.9	62.3	22.0
7	0630-2318	13	33.1	23.9	44.5	10.0
8	0758-2234	12	30.0	15.0	43.0	5.6
9	0008-2110	13	38.1	54.5	59.0	29.2
10	0118-2212	13	46.9	56.7	49.5	22.2
11	0525-2328	14	26.8	34.9	50.6	21.1
12	0610-2214	12	30.8	26.5	49.6	10.5
13	0715-2154	11	33.3	24.7	46.6	7.2
14	0715-2335	9	57.1	88.7	51.8	21.6
15	0740-2355	11	37.0	26.5	51.6	11.4
16	0755-2350	12	31.6	17.9	48.0	8.8
17	0806-2219	8	55.2	77.8	51.4	14.4
18	0921-2206	11	23.1	14.7	46.5	12.0
Total:		214	36.71	42.77	51.11	26.21

TABLE 5 GATE PLAN UAL 5.

GATE	TIME SPAN	NO. OF OCCUPANCIES	SEPARATION TIMES		OCCUPANCY TIMES	
			MEAN	STAND.DEV.	MEAN	STAND.DEV.
1	0715-2338	9	54.3	27.9	54.9	10.8
2	0001-2239	15	45.7	49.5	44.8	10.8
3	0008-2100	12	54.9	52.5	49.4	23.1
4	0615-2315	13	34.1	12.4	44.4	11.0
5	0905-2334	9	47.6	20.7	49.0	9.0
6	0906-2335	9	44.7	23.7	51.9	13.4
7	0600-2128	11	36.2	16.2	48.2	10.4
8	0720-2318	11	42.8	21.8	44.3	11.4
9	0525-2234	9	60.4	23.0	53.9	14.1
10	0555-2205	11	32.5	9.6	55.6	22.0
11	0757-2135	9	36.0	12.8	54.9	36.8
12	0805-2246	9	43.2	15.5	54.7	20.9
13	0110-2328	13	55.1	50.8	47.8	11.4
14	0115-2206	11	59.5	57.4	54.2	17.4
15	0620-2214	10	42.2	15.4	53.2	18.1
16	0801-2154	8	49.6	21.3	54.5	21.6
17	0801-2335	10	44.7	17.5	48.7	12.6
18	0806-2355	9	58.3	26.3	47.1	7.5
19	0813-2350	10	47.8	18.1	45.9	12.7
20	0803-2219	9	49.2	22.9	45.9	13.1
Total:		207	46.73	32.05	49.82	16.96

TABLE 6 GATE PLAN OCCUPANCY AND SEPARATION TIME SUMMARY.

GATE PLAN	UAL 1				UAL 2				UAL3				UAL 4				UAL 5				BEA1				BEA2			
	SEP'S		OCC'S		SEP'S		OCC'S		SEP'S		OCC'S		SEP'S		OCC'S		SEP'S		OCC'S		SEP'S		OCC'S		SEP'S		OCC'S	
TIME SPANS	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%
0-9 Minutes	8	3.9	-	-	9	4.5	-	-	12	5.8	-	-	1	0.5	-	-	-	-	-	-	-	-	-	-	1	0.7	-	-
10-19 "	27	13.3	-	-	12	6.0	-	-	32	15.5	-	-	95	44.4	-	-	3	1.4	-	-	10	6.9	-	-	63	42.6	-	-
20-29 "	56	27.6	-	-	41	20.4	-	-	67	32.4	-	-	40	18.7	-	-	62	30.0	-	-	10	6.9	-	-	23	15.5	-	-
30-39 "	27	13.3	41	20.2	21	10.4	42	20.9	20	9.7	44	21.3	17	7.9	47	22.0	42	20.3	46	22.2	20	13.8	23	15.9	9	6.1	21	14.2
40-49 "	21	10.3	74	36.5	17	8.5	74	36.8	15	7.2	78	37.7	17	7.9	80	37.4	27	13.0	77	37.2	24	16.6	59	40.1	10	6.8	59	39.9
50-59 "	13	6.4	43	21.2	11	5.5	42	20.9	15	7.2	43	20.8	8	3.7	43	20.1	24	11.6	43	20.8	16	11.0	19	13.1	9	6.1	19	12.8
60-69 "	20	9.9	24	11.8	13	6.5	21	10.4	11	5.3	21	10.1	6	2.8	24	11.2	26	12.6	22	10.6	19	13.1	9	6.2	7	4.7	10	6.8
70-79 "	10	4.9	10	4.9	16	8.0	9	4.5	7	3.4	10	4.8	11	5.1	10	4.7	7	3.4	10	4.8	11	7.6	5	3.4	4	2.7	5	3.4
80-89 "	7	3.4	2	1.0	11	5.5	2	1.0	9	4.3	2	1.0	6	2.8	2	0.9	3	1.4	2	1.0	10	6.9	7	4.8	4	2.7	7	4.7
90-99 "	1	0.5	1	0.5	7	3.5	1	0.5	4	1.9	1	0.5	3	1.4	1	0.5	5	2.4	1	0.5	12	8.3	3	2.1	-	-	2	1.4
100 "	13	6.4	8	3.9	43	21.4	10	5.0	15	7.2	8	3.9	10	4.7	7	3.3	8	3.9	6	2.9	13	9.0	20	13.8	18	12.2	25	16.9
TOTALS:	203		203		201		201		207		207		214		214		207		207		145		145		148		148	

SEP'S - Separation Times. Actual Numbers and % of Total.

OCC'S - Occupation Times. " " " " "

TABLE 7 DISTRIBUTION OF SEPARATION TIMES IN BANDWIDTHS OF ONE MINUTE

SEP. TIME MINUTES	UAL 1			UAL 2			UAL 3			UAL 4			UAL 5		
	N	C	C%	N	C	C%	N	C	C%	N	C	C%	N	C	C%
0	1	1	0.5	4	4	2.0	3	3	1.5	-	-	-	-	-	-
1	0	1	0.5	0	4	2.0	1	4	1.9	-	-	-	-	-	-
2	0	1	0.5	0	4	2.0	0	4	1.9	-	-	-	-	-	-
3	0	1	0.5	0	4	2.0	1	5	2.4	-	-	-	-	-	-
4	1	2	1.0	0	4	2.0	1	6	2.9	-	-	-	-	-	-
5	1	3	1.5	2	6	3.0	2	8	3.9	-	-	-	-	-	-
6	1	4	2.0	1	7	3.5	1	9	4.3	-	-	-	-	-	-
7	1	5	2.5	1	8	4.0	1	10	4.8	-	-	-	-	-	-
8	2	7	3.5	1	9	4.5	2	12	5.8	-	-	-	-	-	-
9	1	8	3.9	0	9	4.5	0	12	5.8	1	1	0.5	-	-	-
10	4	12	5.9	1	10	5.0	6	18	8.7	39	40	18.7	-	-	-
11	2	14	6.9	0	10	5.0	2	20	9.7	9	49	22.9	-	-	-
12	0	14	6.9	0	10	5.0	0	20	9.7	7	56	26.2	-	-	-
13	1	15	7.4	0	10	5.0	2	22	10.6	6	62	29.0	-	-	-
14	1	16	7,9	1	11	5.5	2	24	11.6	5	67	31.3	-	-	-
15	11	27	13.3	8	19	9.4	16	40	19.3	13	80	37.4	2	2	1.0
16	3	30	14.8	2	21	10.5	0	40	19.3	3	83	38.8	0	2	1.0
17	1	31	15.3	0	21	10.5	0	40	19.3	4	87	40.6	0	2	1.0
18	3	34	16.8	0	21	10.5	2	42	20.3	5	92	43.0	1	3	1.4
19	1	35	17.2	0	21	10.5	2	44	21.3	4	96	44.9	0	3	1.4
20	12	47	23.4	10	31	15.4	14	58	28.0	6	102	47.6	5	8	3.9
21	5	52	25.6	4	35	17.4	4	62	30.0	4	106	49.5	5	13	6.3
22	6	58	28.6	1	36	17.9	7	69	33.4	1	107	50.0	4	17	8.2
23	2	60	29.6	2	38	19.0	4	73	35.3	1	108	50.5	4	21	10.1
24	7	67	35.0	5	43	21.4	6	79	38.2	1	109	51.0	4	25	12.1
25	13	80	39.4	12	55	27.4	19	98	47.3	13	122	57.0	21	46	22.2
26	3	83	40.9	1	56	27.8	4	102	49.3	4	126	58.9	5	51	24.6
27	1	84	41.4	0	56	27.8	3	105	50.7	3	129	60.3	5	56	27.0
28	4	88	43.4	4	60	29.8	4	109	52.6	3	132	61.6	5	61	29.4
29	3	91	44.8	2	62	30.8	2	111	53.6	4	136	63.6	4	65	31.4
PLAN TOTALS:	203			201			207			214			207		

N = number of separation times in given bandwidth.
C = cumulative number of separation times up to stated value.
C% = cumulative percentage of separation times up to stated value.

TABLE 8 GATE TIMETABLE RELIABILITY OBTAINED BY SIMULATION.

INPUT DELAY DISTRIBUTION.		GATE TIMETABLE RELIABILITY %				
MEAN	STD.DEV.	UAL 1	UAL 2	UAL 3	UAL 4	UAL 5.
10	2	96.8	97.1	95.1	97.6	99.1
10	5	96.1	96.7	94.3	96.3	98.9
10	10	91.8	93.9	89.2	88.5	96.9
10	15	85.3	91.4	86.0	83.2	93.6
12	2.2	95.1	96.3	93.9	96.1	99.3
12	5.5	94.7	95.8	92.5	93.6	99.1
12	11.0	87.8	92.7	87.8	86.7	93.9
12	16.4	83.5	89.3	83.1	79.9	89.8
14	2.4	95.3	95.2	92.5	96.0	98.9
14	5.9	93.4	94.5	91.7	91.3	97.1
14	11.8	85.3	91.3	86.2	81.5	93.0
14	17.6	81.0	88.2	79.5	76.2	85.4
MSST Minutes		45.0	70.3	43.1	36.7	46.7
STD.DEV. of Sep.times		40.7	74.7	43.0	42.8	32.1
Relative Dispersion		0.90	1.06	1.00	1.17	0.69

TABLE 9 DEPARTURE PUNCTUALITY OBTAINED BY SIMULATION.

INPUT DISTRIB'S.		UAL 1			UAL 2			UAL 3			UAL 4			UAL 5		
MEAN	S.D.	MEAN DELAY	S.D.	%≥10 LATE	MEAN DELAY	S.D.	%≥10 LATE	MEAN DELAY	S.D.	%≥10 LATE	MEAN DELAY	S.D.	%≥10 LATE	MEAN DELAY	S.D.	%≥10 LATE
10	2	0.6	2.94	1.0	0.6	2.57	1.1	0.6	2.56	1.1	0.6	2.59	1.1	0.6	2.60	1.2
10	5	1.8	4.18	6.5	1.7	4.07	6.0	1.7	4.04	6.6	1.8	4.23	6.3	1.8	4.12	6.2
10	10	4.1	7.05	19.4	4.0	6.81	18.8	4.0	6.96	18.8	4.1	7.06	19.9	4.1	6.98	19.2
10	15	6.0	9.49	28.0	6.2	9.68	27.9	6.0	9.49	28.3	6.0	9.50	28.2	6.1	9.62	28.6
12	2.2	2.5	3.13	1.7	2.3	2.84	1.2	2.4	3.01	1.7	2.4	2.94	1.4	2.3	2.92	1.4
12	5.5	3.4	4.70	10.3	3.4	4.66	10.9	3.4	4.73	11.2	3.3	4.69	11.1	3.3	4.63	10.6
12	11.0	5.7	7.92	27.4	5.3	7.66	14.9	5.1	7.52	24.6	5.4	7.76	26.0	5.2	7.59	25.5
12	16.4	8.1	10.72	33.8	8.1	10.84	33.8	8.1	10.71	34.5	8.3	10.95	34.5	7.9	10.72	33.3
14	2.4	4.3	2.86	1.5	4.2	2.91	1.3	4.4	3.24	2.3	4.3	3.10	1.8	4.3	3.08	1.5
14	5.9	4.7	5.55	16.8	4.8	5.47	17.0	4.6	5.23	15.2	4.6	5.62	16.8	4.8	6.11	16.7
14	11.8	7.3	9.37	34.7	6.9	8.92	32.7	6.8	8.99	32.1	7.1	9.16	33.7	7.1	9.11	34.3
14	17.6	9.1	12.27	38.7	9.2	12.18	38.1	9.8	12.92	40.5	9.6	12.84	40.4	9.5	12.81	40.1

S.D. - Standard Deviation of Delay Distribution.

TABLE 10 GATE HOLDS OBTAINED BY SIMULATION.

INPUT DISTRIB'S.		UAL 1			UAL 2			UAL 3			UAL 4			UAL 5		
MEAN	S.D.	MEAN	LOSS	FREQ.	MEAN	LOSS	FREQ.	MEAN	LOSS	FREQ.	MEAN	LOSS	FREQ.	MEAN	LOSS	FREQ.
10	2	3.3	0.64	0.19	4.9	2.88	0.58	5.2	4.24	0.82	3.4	4.05	1.20	3.8	0.45	0.12
10	5	3.3	1.66	0.51	4.8	3.26	0.67	5.3	7.05	1.33	4.0	6.92	1.74	3.4	1.21	0.36
10	10	3.7	2.87	0.78	4.0	2.93	0.73	5.2	6.39	1.23	5.2	10.09	1.94	5.2	2.63	0.51
10	15	5.3	3.68	0.69	5.3	4.43	0.83	5.6	8.72	1.55	3.8	7.51	1.97	4.1	3.00	0.73
12	2.2	2.08	0.63	0.30	7.2	4.97	0.69	4.5	5.35	1.20	3.6	8.24	2.32	3.1	0.69	0.22
12	5.5	4.1	2.48	0.60	6.8	5.04	0.74	5.0	6.99	1.40	4.2	9.68	2.32	4.7	1.33	0.28
12	11.0	5.0	3.45	0.69	5.5	4.46	0.81	5.4	7.0	1.29	3.5	6.85	1.94	4.8	2.51	0.52
12	16.4	4.7	4.31	0.9	5.6	4.79	0.86	5.5	8.15	1.48	4.9	13.86	2.82	5.5	4.67	0.85
14	2.4	4.1	2.87	0.69	6.3	5.40	0.86	5.7	7.08	1.25	4.5	12.08	2.69	3.0	0.63	0.21
14	5.9	4.4	5.09	1.16	4.8	3.91	0.81	7.1	11.11	1.55	5.1	11.71	2.32	3.9	2.16	0.55
14	11.8	4.3	4.63	1.07	6.8	6.32	0.93	4.5	7.65	1.70	5.4	9.68	1.81	3.6	2.57	0.72
14	17.6	5.5	7.50	1.36	5.9	4.55	0.77	6.3	10.90	1.73	6.0	13.22	2.21	5.3	7.04	1.33

KEY - MEAN - Mean length of hold, in minutes.
FREQ - Number of holds per 100 departures.
LOSS - Number of minutes held per 100 departures, i.e. loss of available ground time per 100 departures.

CORRELATION OF GATE HOLD FREQUENCY WITH NUMBER OF SEPARATION TIMES $\leq$ X MINUTES.

TABLE 11.

Value of X	Mean / S.dev } Input Distrib.	10 2	10 5	10 10	10 15	12 2.2	12 5.5	12 11.0	12 16.4	14 2.4	14 5.9	14 11.8	14 17.6
5		.11	.05	-.14	-.03	-.12	-.07	-.08	-.32	-.16	-.11	.16	-.36
6		.07	-.27	-.17	-.08	-.16	-.10	-.12	-.36	-.19	-.13	-.16	-.39
7		.04	-.02	-.19	-.11	-.19	-.12	-.14	-.38	-.20	-.14	.11	-.41
8		.0	-.03	-.20	-.13	-.21	-.14	-.16	-.39	-.22	-.13	.12	-.38
9		.03	.006	-.14	-.10	-.17	-.09	-.11	-.34	-.17	-.07	.16	-.34
10		.91	.93	.98	.90	.96	.98	.97	.95	.99	.98	.89	.78
11		.89	.92	.98	.90	.95	.97	.96	.96	.99	.98	.88	.81
12		.88	.91	.98	.89	.96	.97	.96	.97	.99	.97	.85	.81
13		.88	.91	.98	.89	.96	.97	.96	.97	.99	.97	.85	.82
14		.88	.91	.98	.90	.96	.97	.96	.97	.99	.97	.86	.82
15		.90	.94	.99	.91	.95	.98	.97	.95	.98	.99	.91	.81
16		.89	.92	.98	.89	.94	.97	.96	.94	.98	.99	.90	.80
17		.88	.91	.98	.88	.94	.96	.96	.94	.98	.98	.89	.80
18		.87	.91	.98	.88	0.93	.96	.95	.94	.97	.99	.88	.81
19		.87	.91	.98	.88	.93	.96	.95	.95	.98	.99	.89	.82
20		.86	.91	.96	.87	.91	.95	.94	.91	.95	.99	.91	.79

Linear correlation coefficients are shown.

TABLE 12

95% Confidence Limits of % GTR

Input Distrib.		UAL1		UAL2		UAL3		UAL4		UAL5	
Mean	S.D.	GTR_L	GTR_U	GTR_L	GTR_U	GTR_L	GTR_U	GTR_L	GTR_U	GTR_L	GTR_U
10	2	96.2	97.4	96.6	97.6	94.3	95.9	97.1	98.1	98.7	99.5
10	5	95.6	96.6	96.2	97.2	93.7	94.9	95.3	97.3	98.5	99.3
10	10	90.6	94.0	93.3	94.5	88.1	90.3	86.8	90.2	96.2	97.6
10	15	83.7	86.9	90.4	92.4	84.9	87.1	81.2	85.2	92.7	94.5
12	2.19	93.9	96.3	95.7	96.9	93.3	94.5	94.4	97.8	99.0	99.6
12	5.48	93.7	95.7	95.2	96.4	91.5	93.5	91.7	95.5	98.8	99.4
12	10.95	85.6	90.0	91.6	93.8	86.3	89.3	84.3	89.1	92.2	95.5
12	16.35	81.1	85.9	87.9	90.7	81.6	84.6	77.7	82.1	87.9	91.7
15	2.36	94.1	96.5	94.1	96.3	91.7	93.3	94.6	97.4	98.0	99.8
15	5.91	90.7	96.1	93.5	95.5	90.7	92.7	89.1	93.5	95.3	98.9
15	11.8	83.0	87.6	90.1	92.5	84.4	88.0	79.3	83.7	91.0	95.0
15	17.6	78.7	83.3	86.6	89.8	77.8	81.2	73.4	79.0	83.3	87.5

Let S = standard deviation of sample.
Let N = number of days in sample.
Let $\hat{\sigma}$ = estimate of standard deviation of distribution of sample means.

$$\text{then } \hat{\sigma} = \frac{S}{\sqrt{N - 1}}$$

$$\text{and } GTR_L = \overline{GTR} - t\hat{\sigma}$$

$$GTR_U = \overline{GTR} + t\hat{\sigma}$$

Where t is obtained from the Student-t distribution with N-1 degrees of freedom and at the 0.05 level of significance.

FIGURE 1

GATE PLAN UAL1

CHICAGO O'HARE JUNE '69

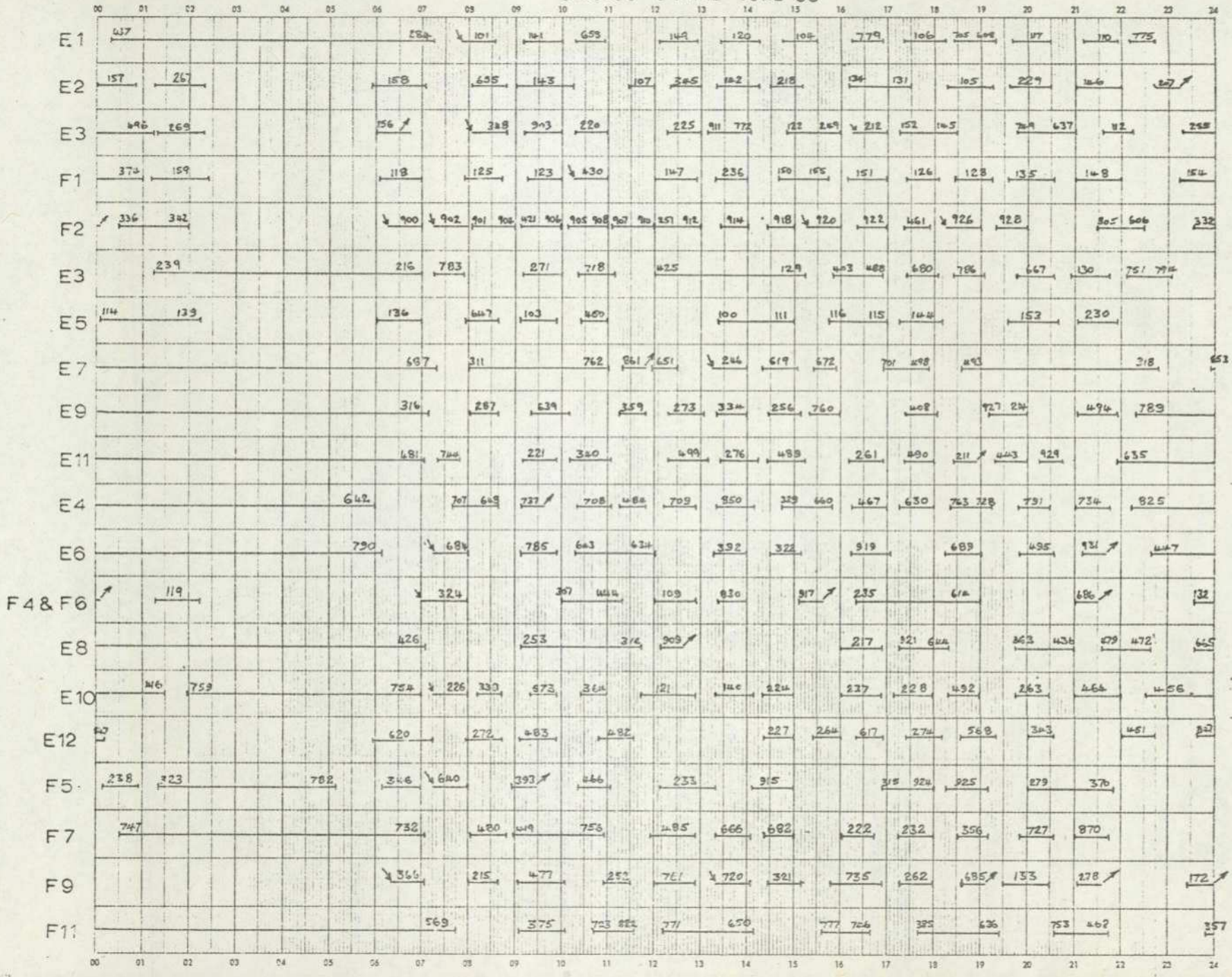


FIGURE 2

GATE PLAN UAL 2

CHICAGO O'HARE

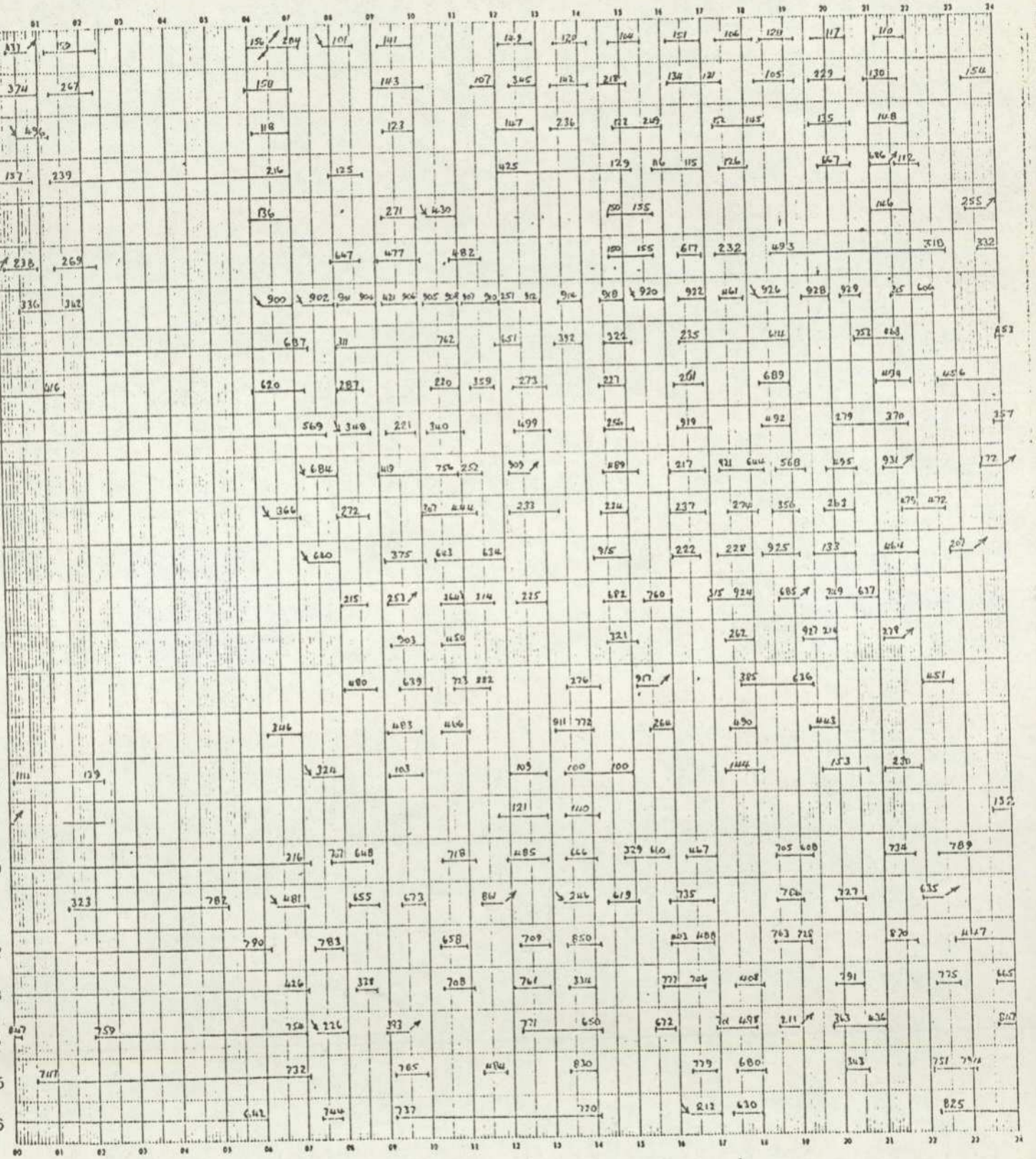


FIGURE 3

GATE PLAN UAL 3

CHICAGO O'HARE

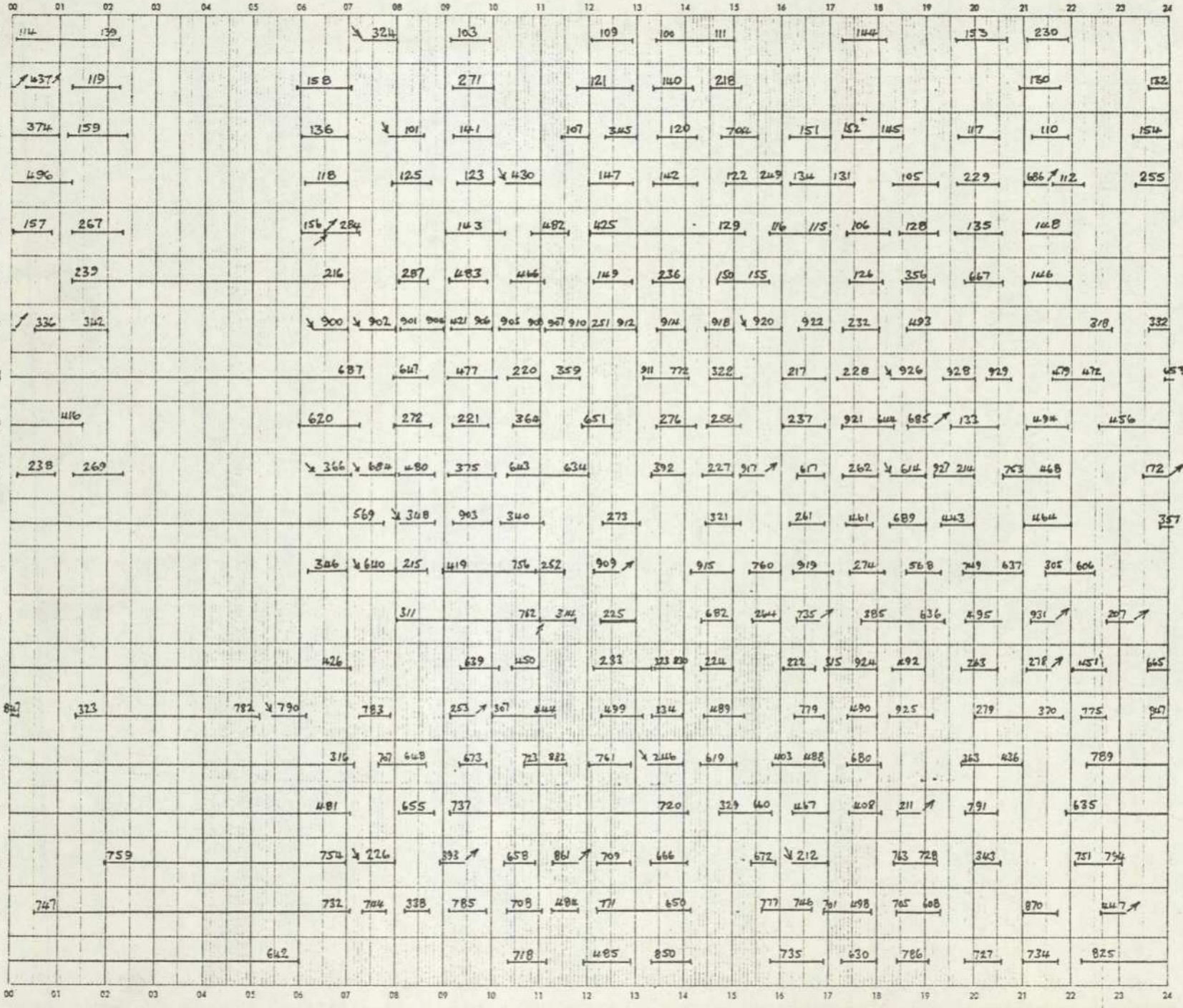


FIGURE 4

GATE PLAN UAL4

CHICAGO O'HARE

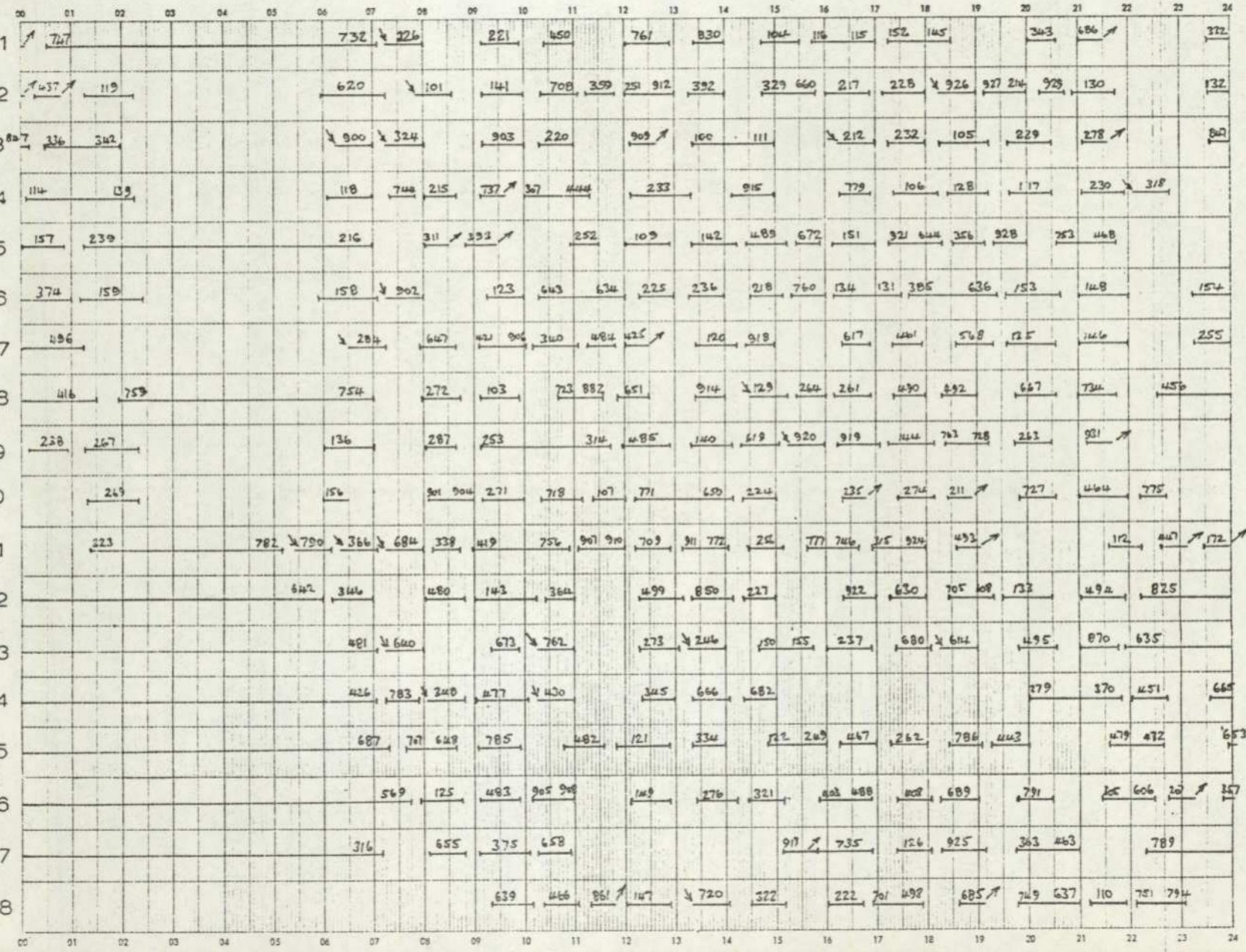
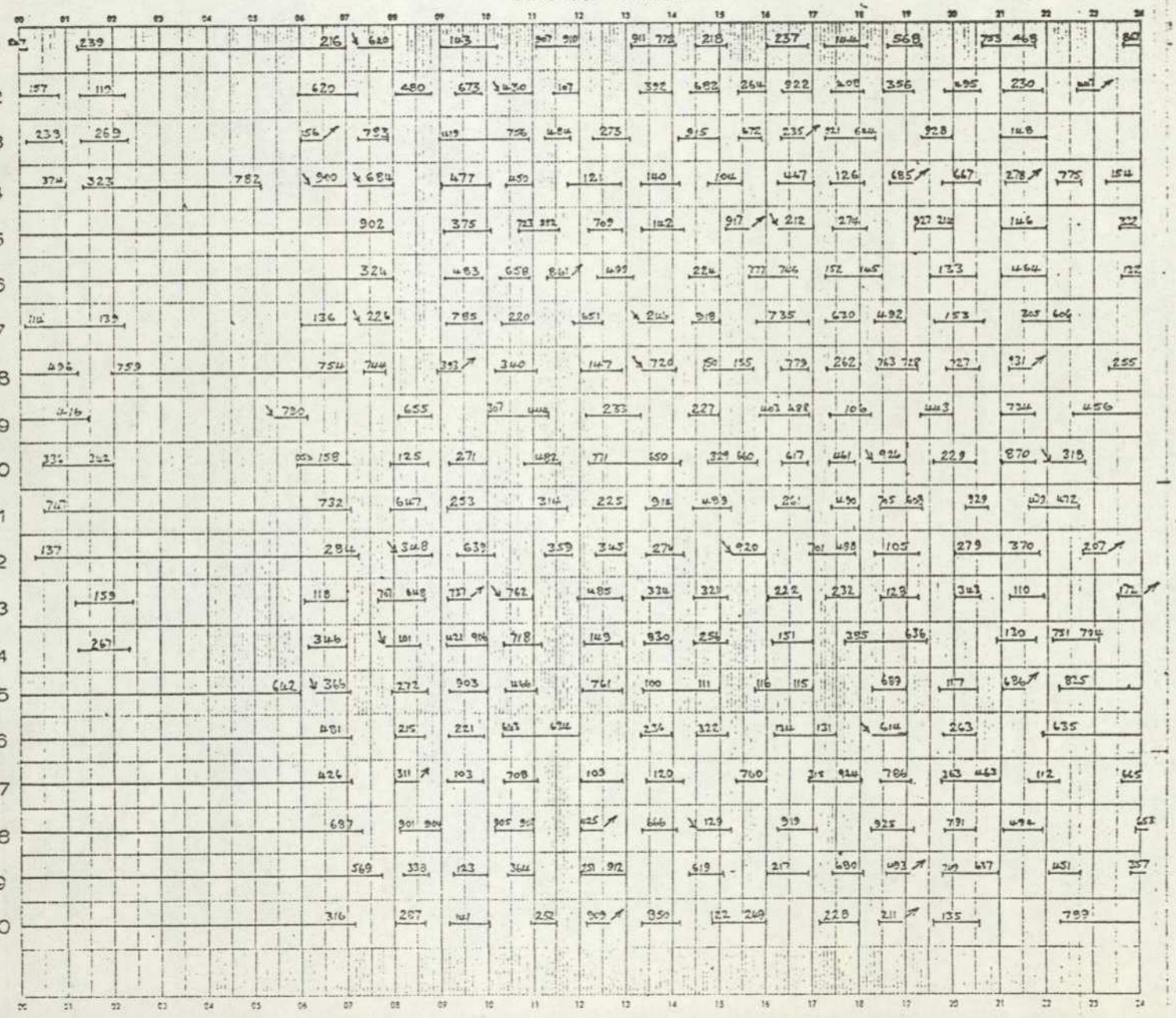


FIGURE 5

GATE PLAN UAL5

CHICAGO O'HARE



CUMULATIVE DISTRIBUTION OF SEPARATION TIME VALUES.
(Using variable time span).

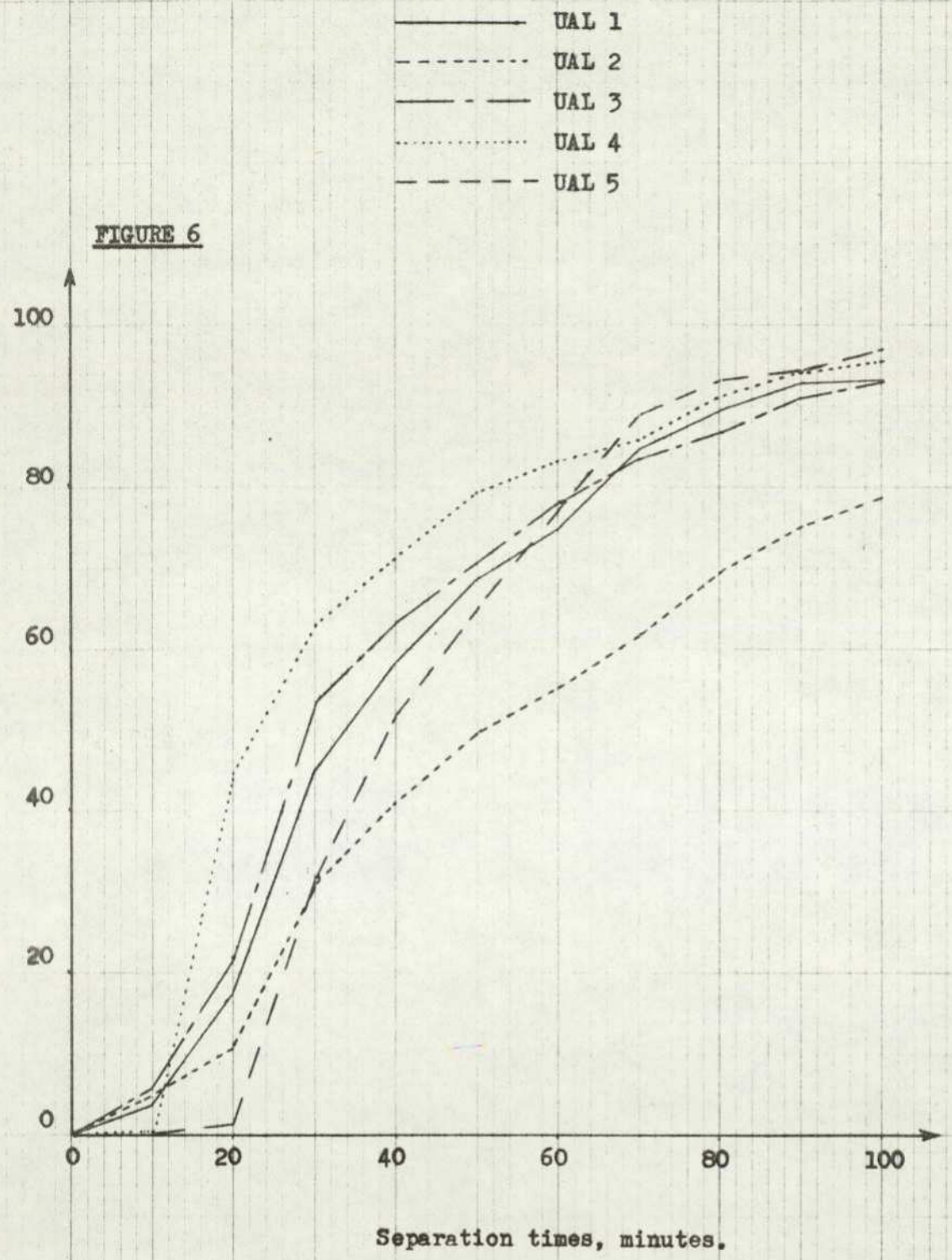


FIGURE 6

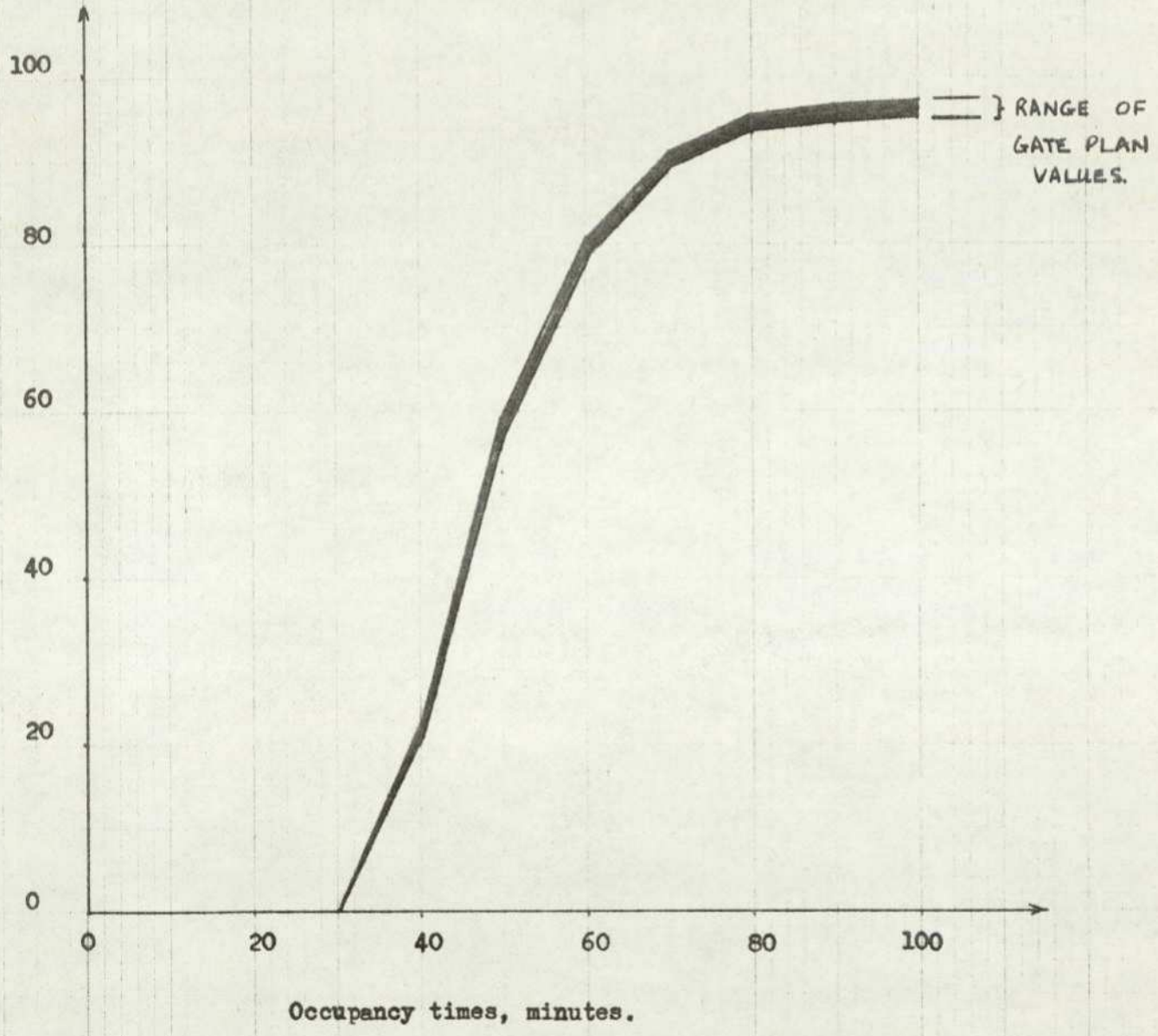
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CUMULATIVE DISTRIBUTION OF GATE OCCUPANCY TIMES.

(Using variable time span).

UAL 1
UAL 2
UAL 3
UAL 4
UAL 5

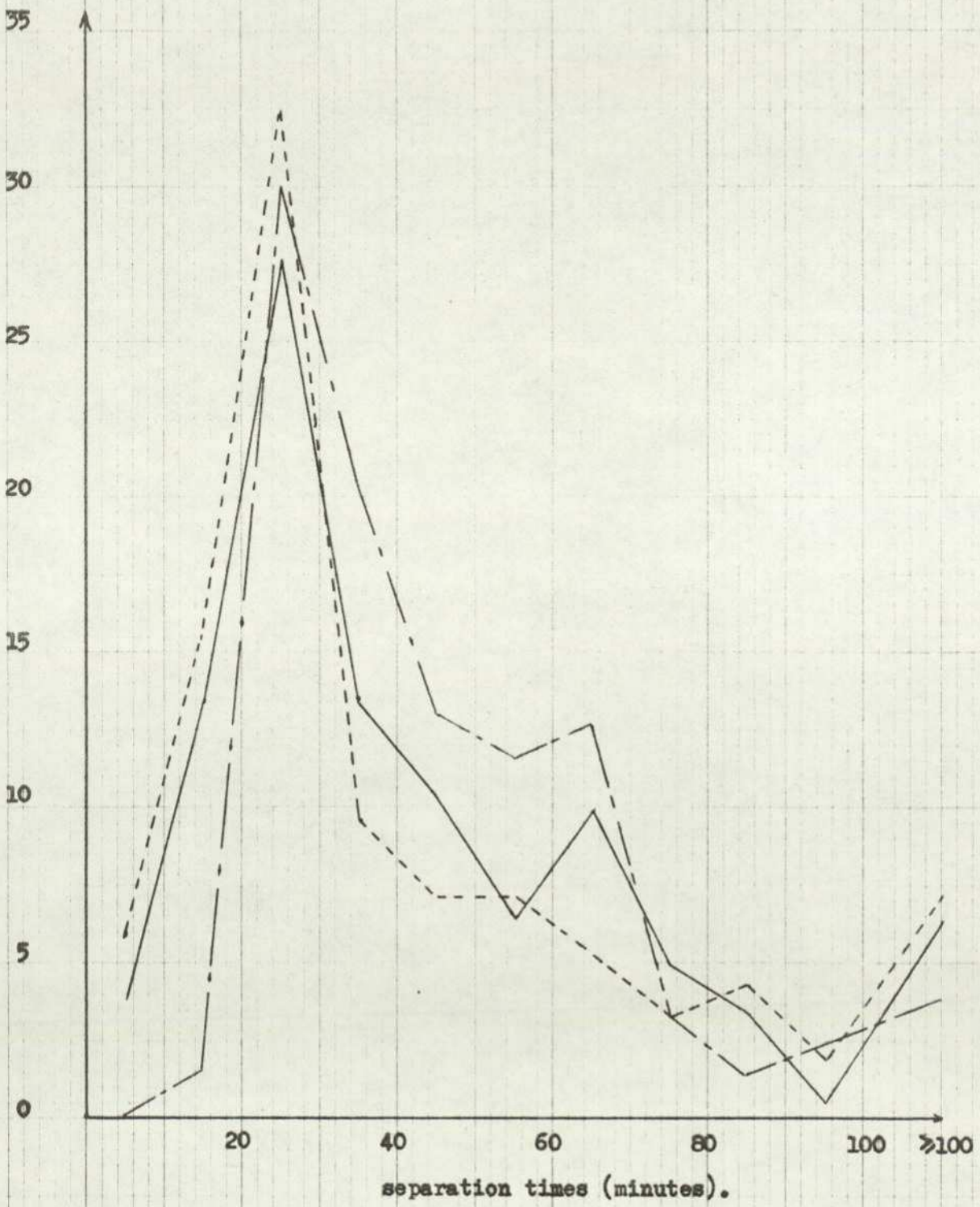
FIGURE 7.



DISTRIBUTION OF SEPARATION TIMES

——— UAL 1
- - - - - UAL 3
—·— UAL 5

FIGURE 8.



DISTRIBUTION OF OCCUPANCY TIMES USING VARIABLE TIME SPAN.

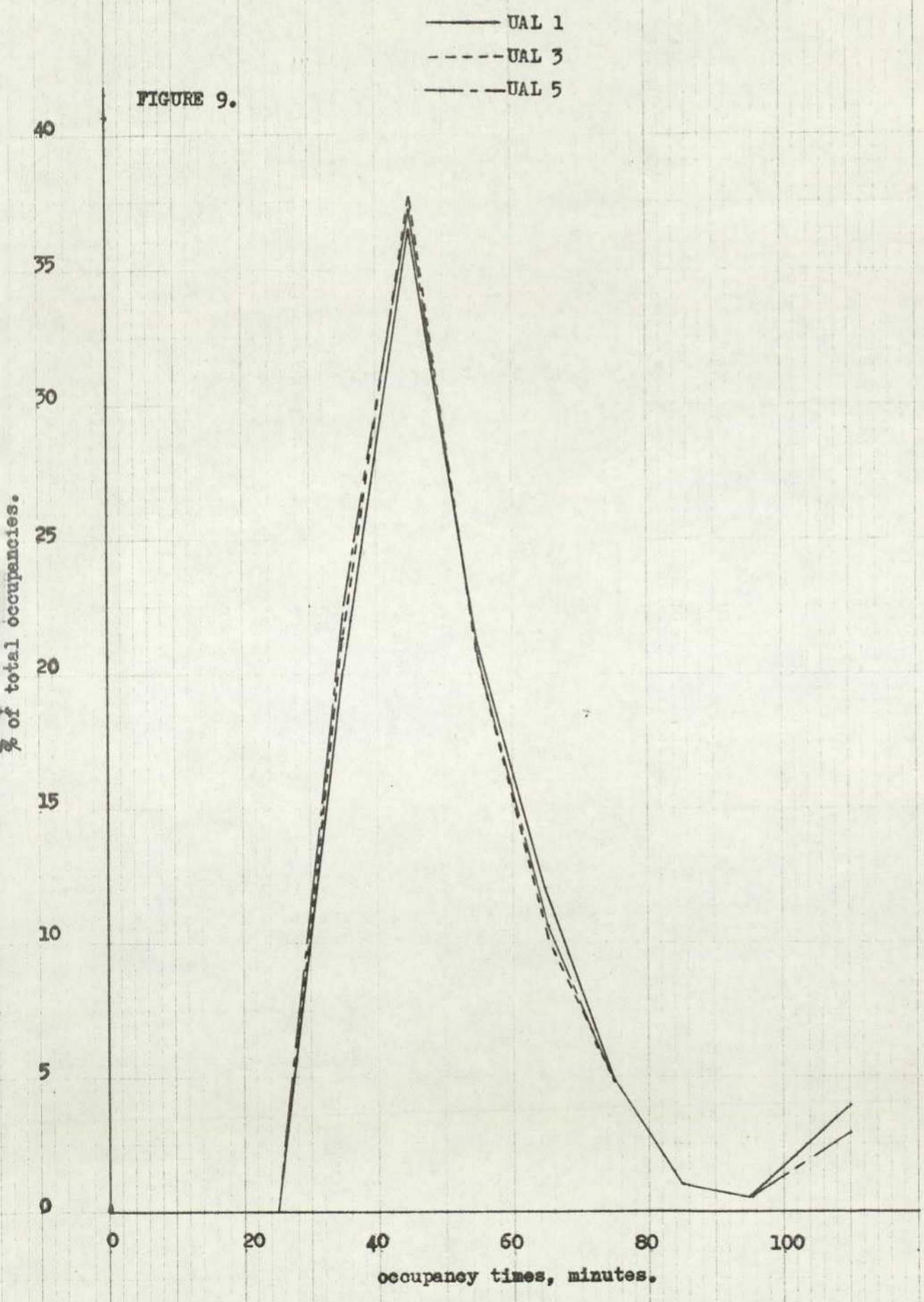


FIGURE 9.

VARIATION OF G.T.R. WITH MEAN STATION SEPARATION TIME.

FIGURE 10.

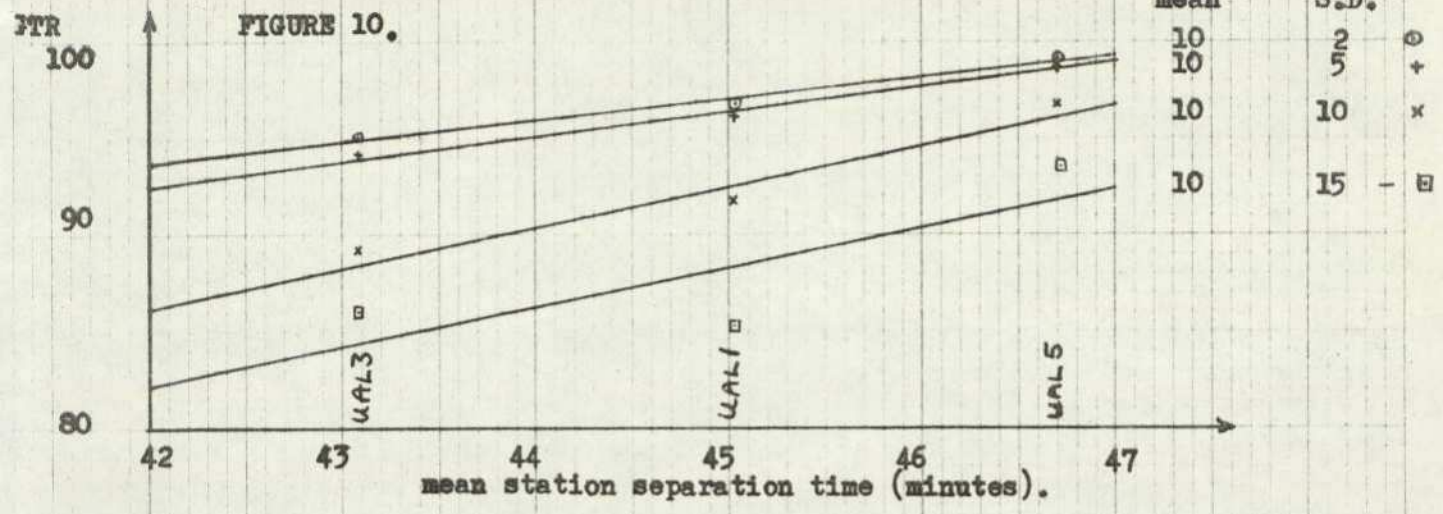


FIGURE 11.

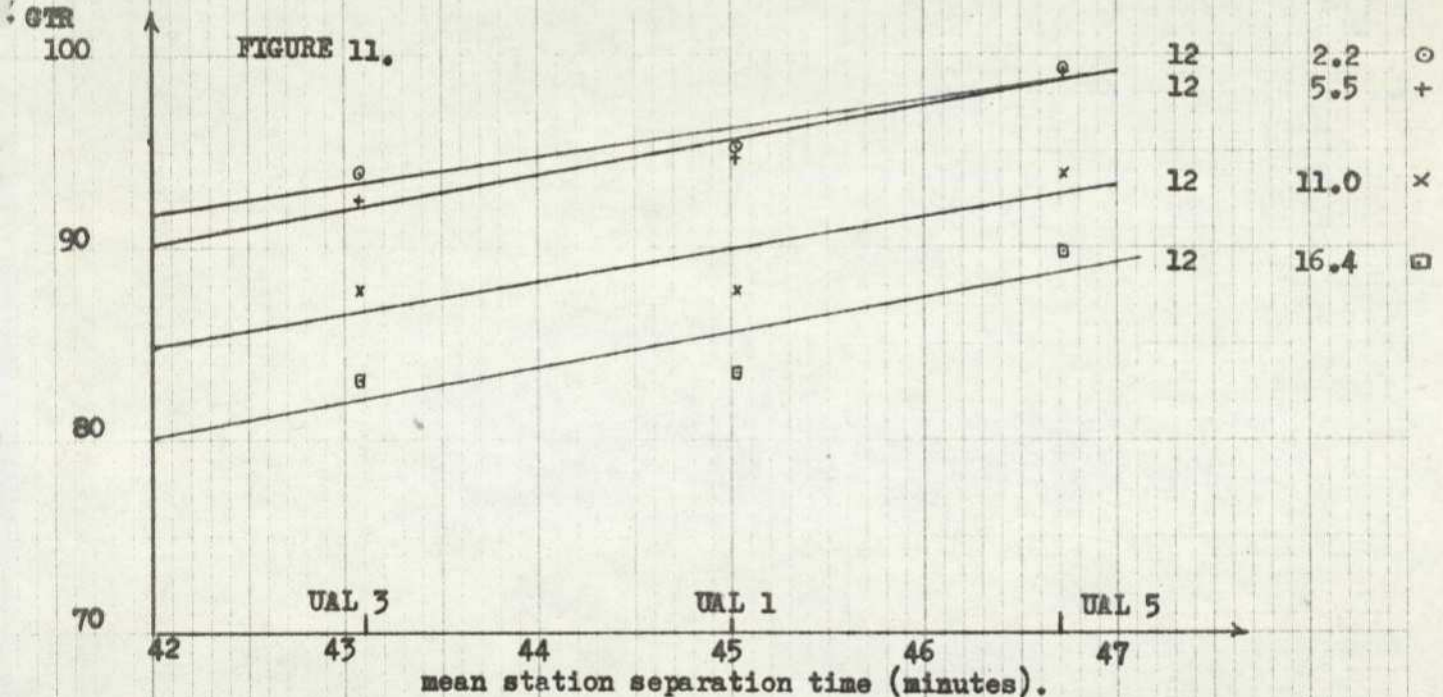
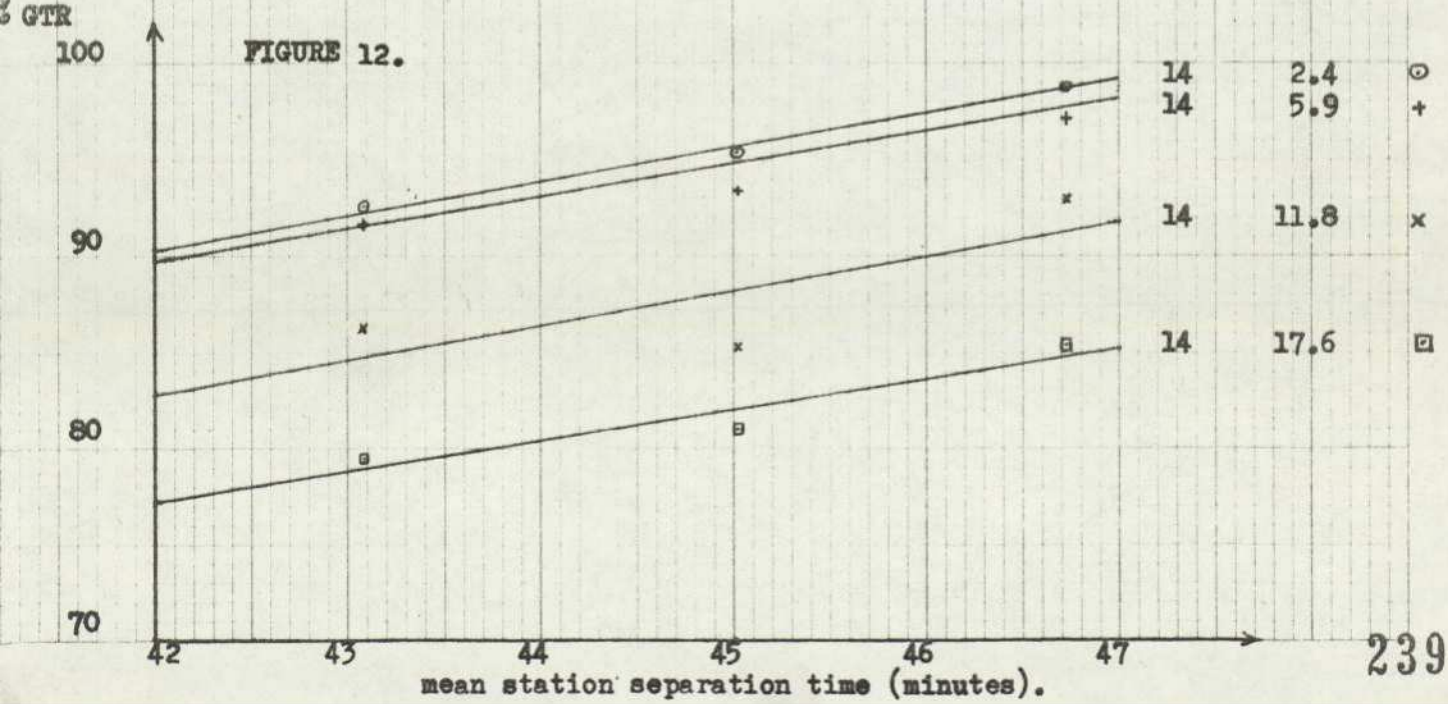
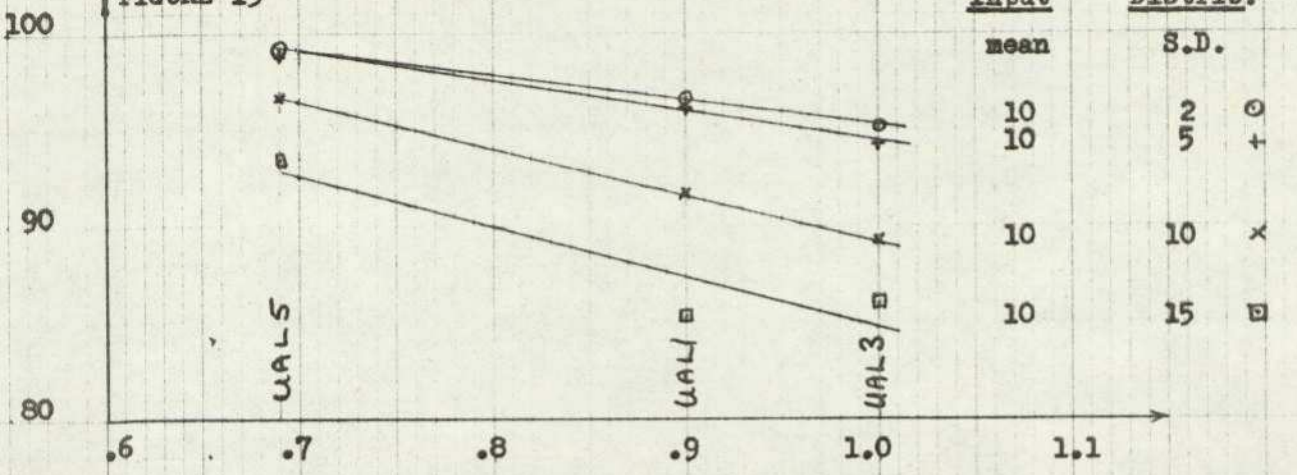


FIGURE 12.



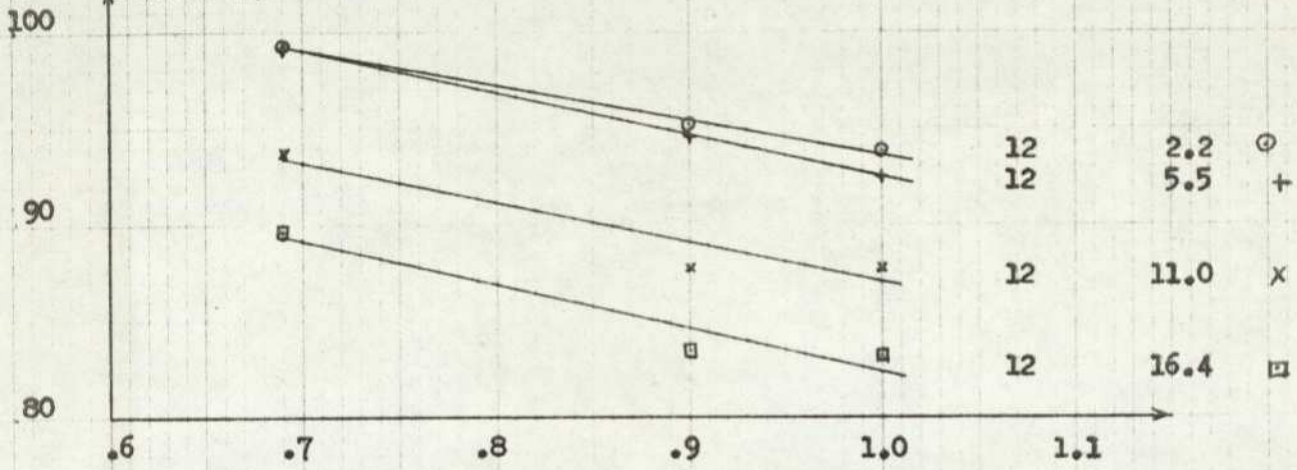
VARIATION OF G.T.R. WITH RELATIVE DISPERSION OF SEPARATION TIMES

FIGURE 13



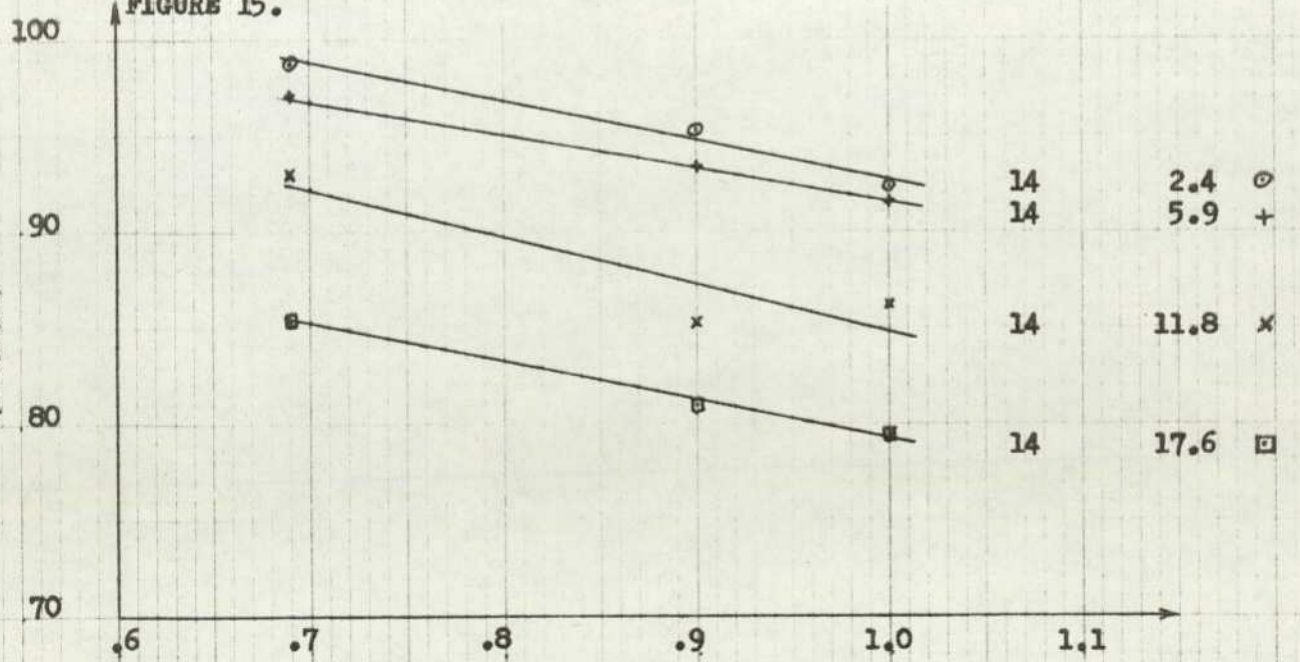
Input mean	Distrib. S.D.	
10	2	⊙
10	5	+
10	10	×
10	15	⊡

FIGURE 14.



Input mean	Distrib. S.D.	
12	2.2	⊙
12	5.5	+
12	11.0	×
12	16.4	⊡

FIGURE 15.



Input mean	Distrib. S.D.	
14	2.4	⊙
14	5.9	+
14	11.8	×
14	17.6	⊡

VARIATION OF MEAN DELAY PER DEPARTURE WITH MEAN STATION SEPARATION TIME.

FIGURE 16.

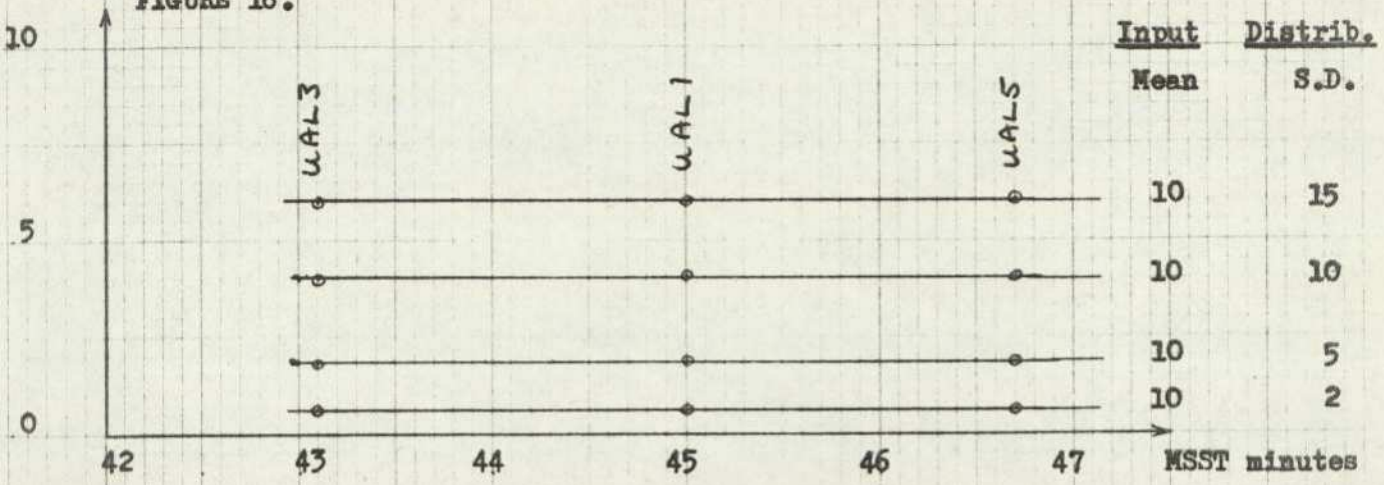


FIGURE 17.

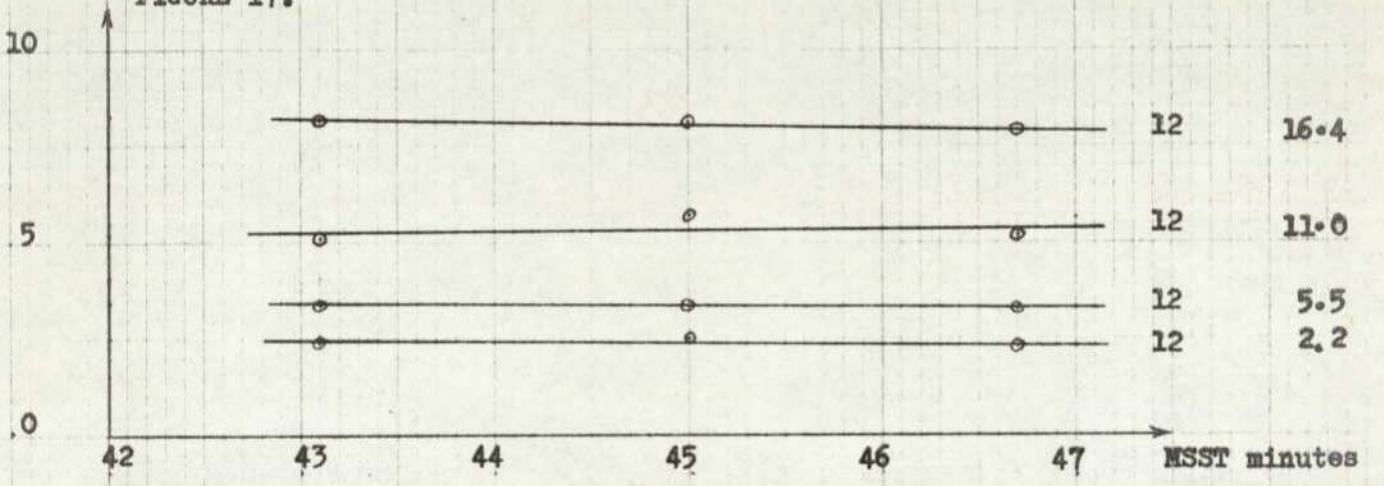
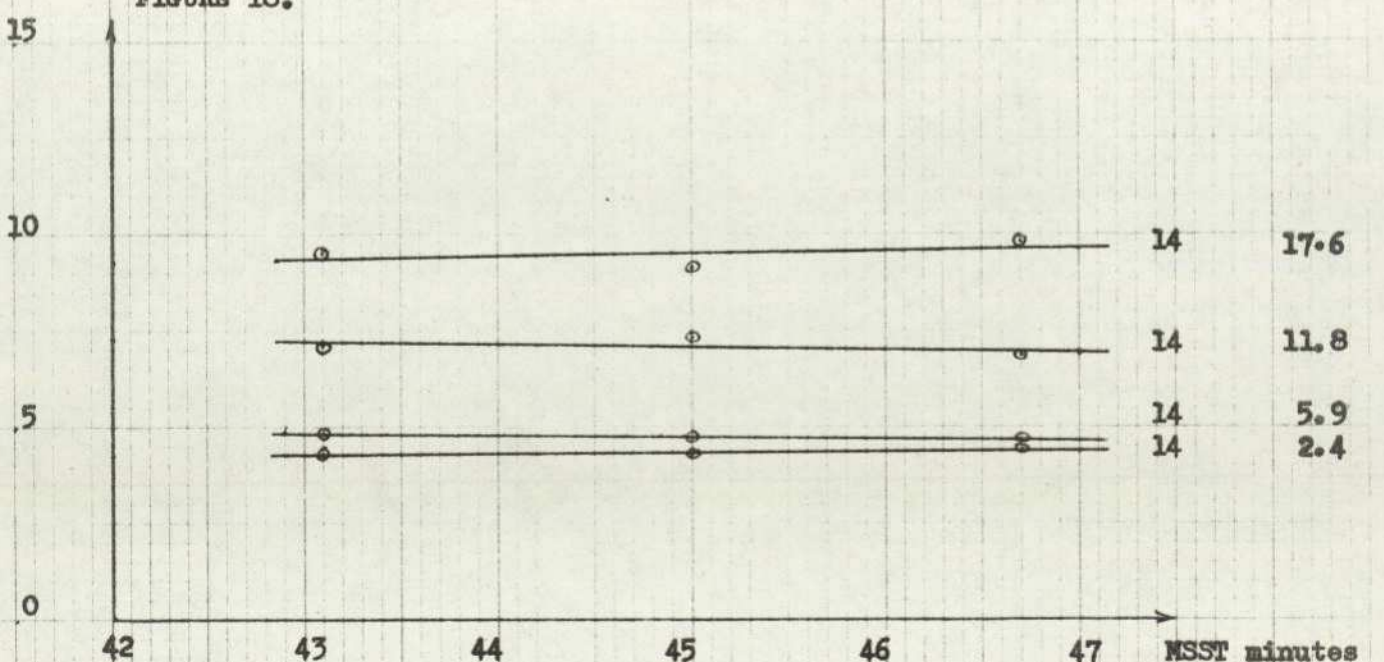


FIGURE 18.



VARIATION OF FREQUENCY OF GATE HOLDS WITH MEAN STATION SEPARATION TIME.

FIGURE 19.

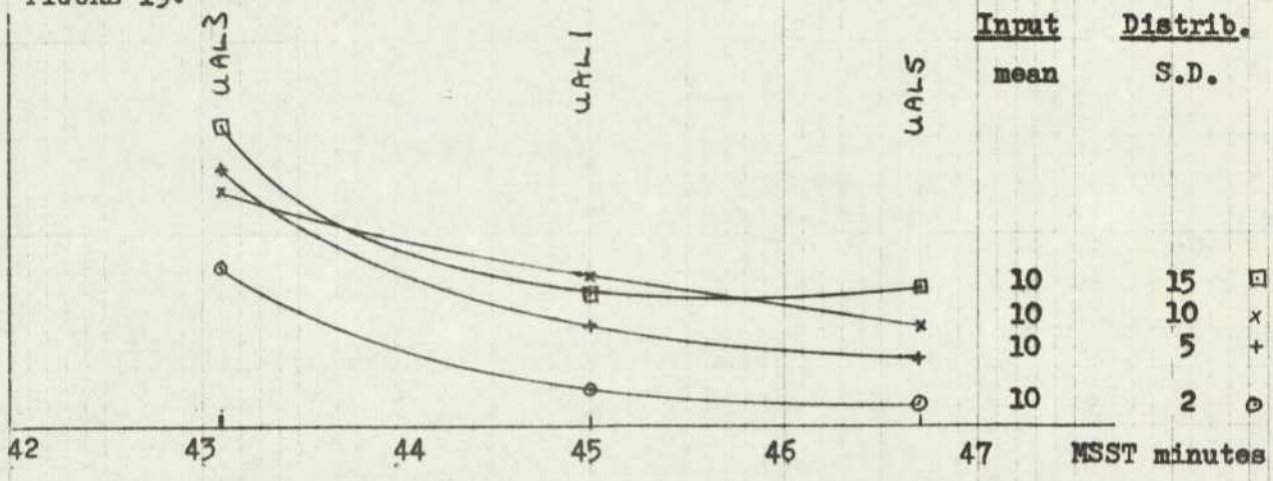


FIGURE 20.

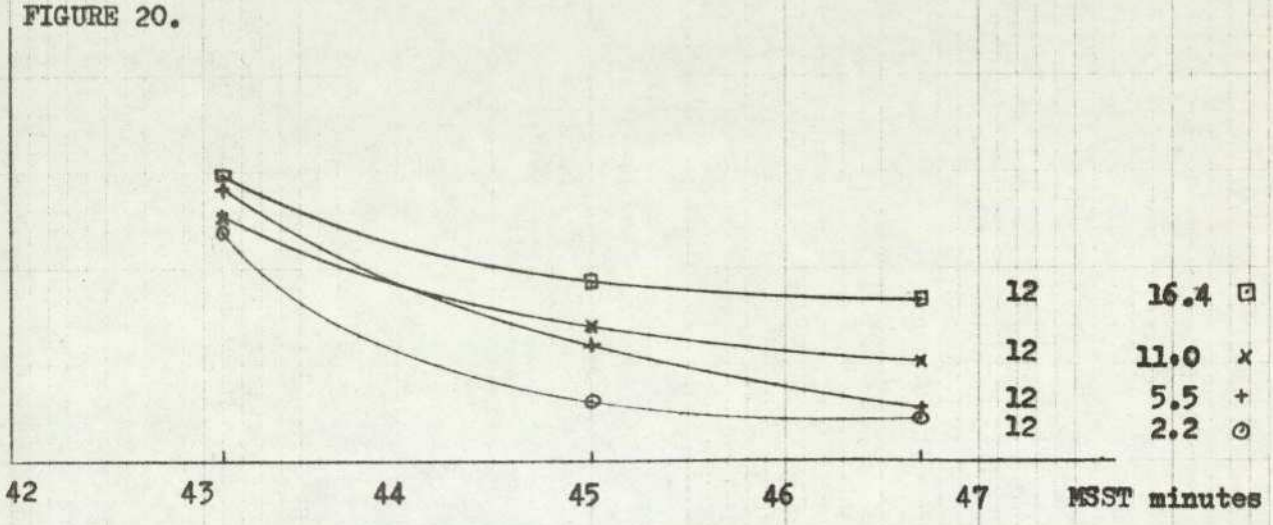
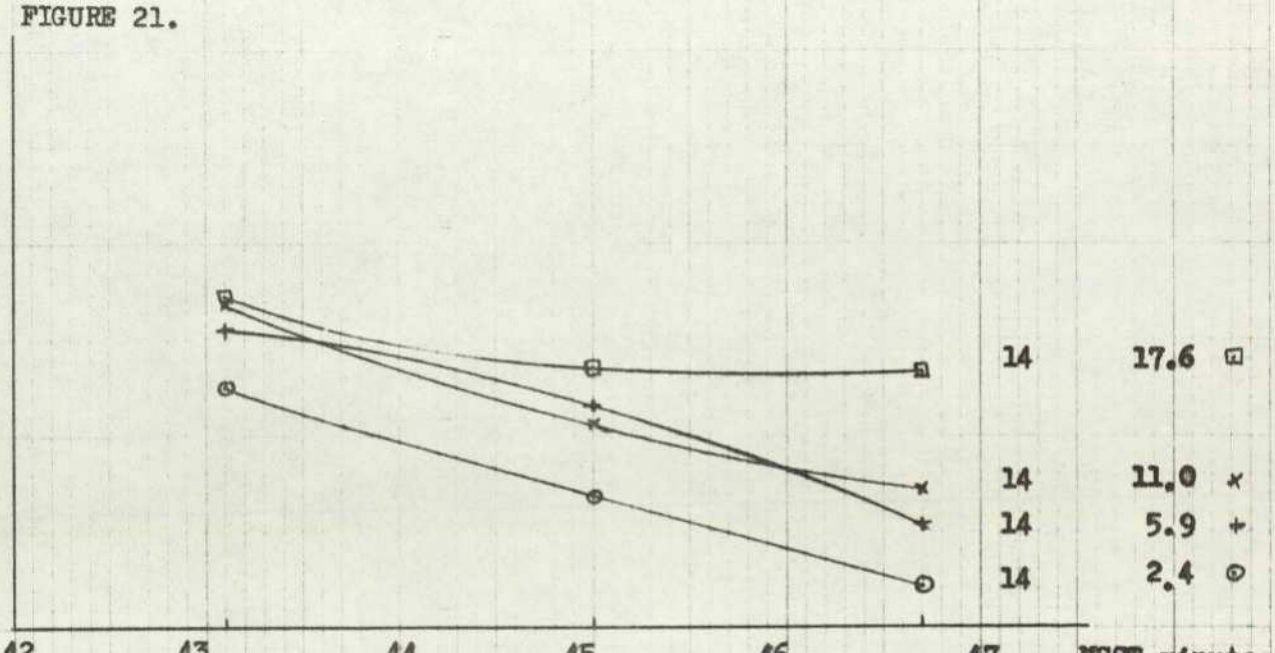


FIGURE 21.



VARIATION OF MINUTES HELD PER 100 DEPARTURES WITH MEAN STATION SEPARATION TIME.

FIGURE 22.

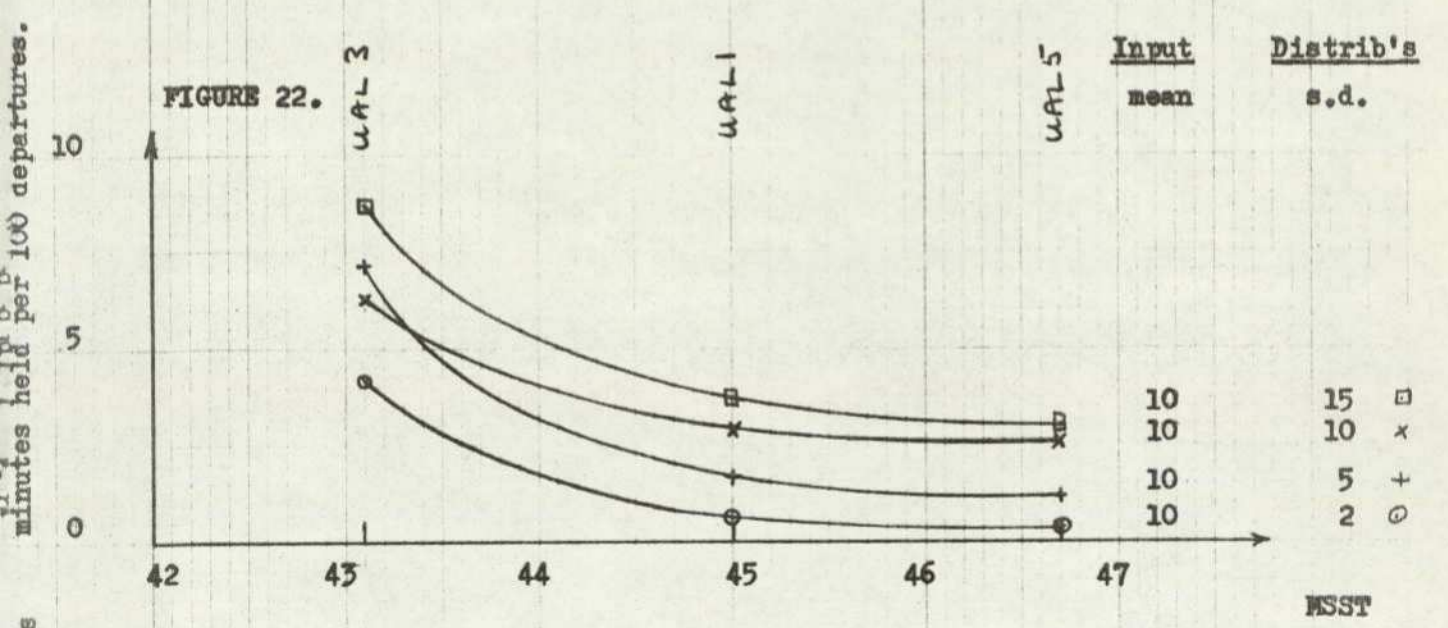


FIGURE 23

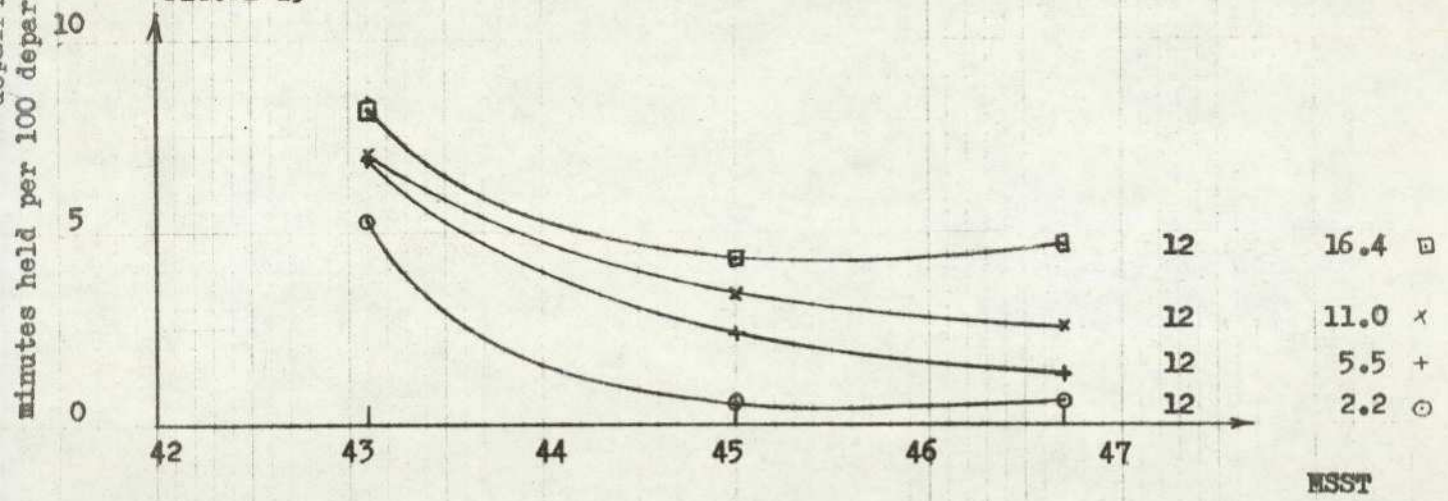


FIGURE 24.

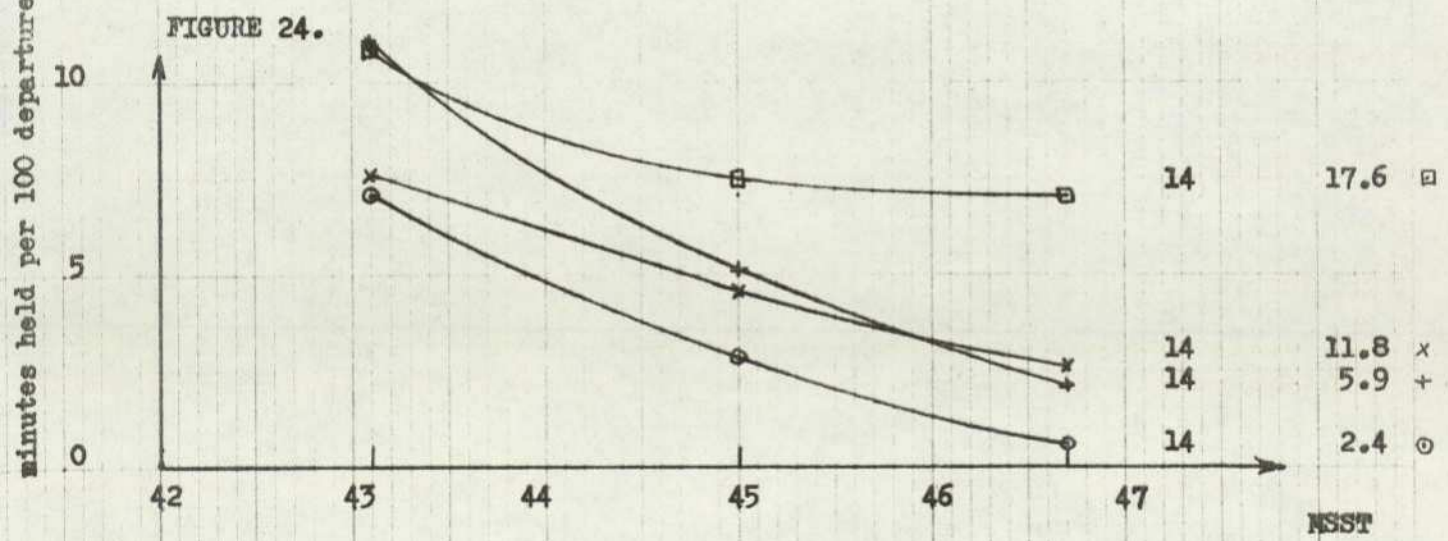


FIGURE 25.
Variation of no. of holds per 100 departures with mean delay per departure.

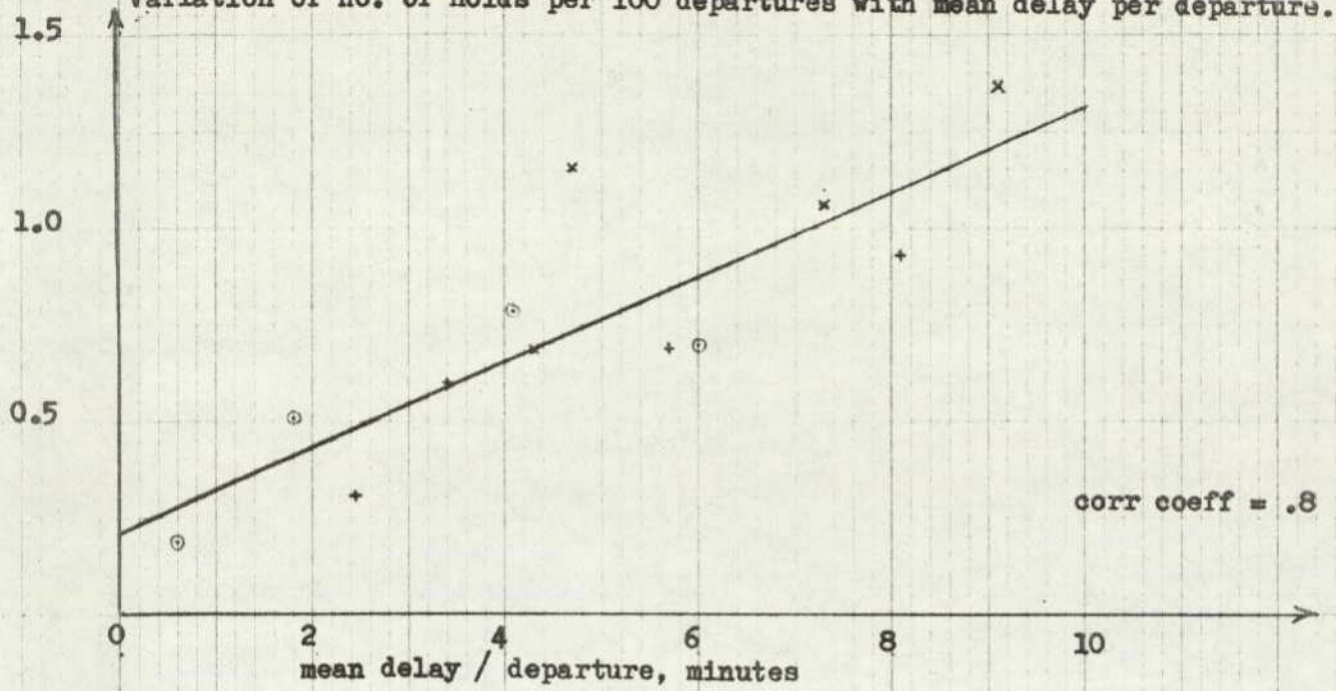


FIGURE 26.
Variation of minutes held per 100 departures with mean delay length per departure.

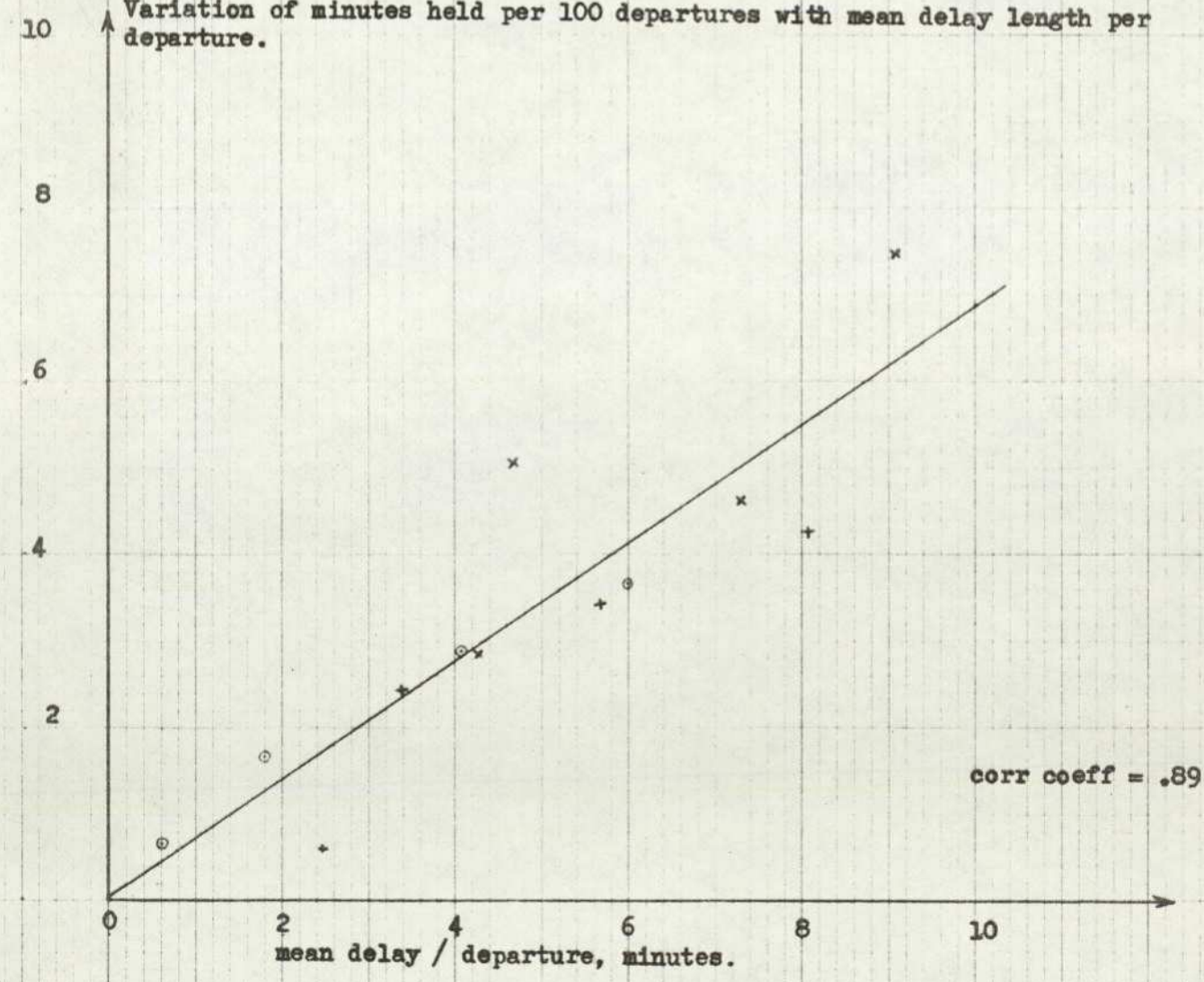


FIGURE 27.
Variation of no. of holds per 100 departures with mean delay per departure.

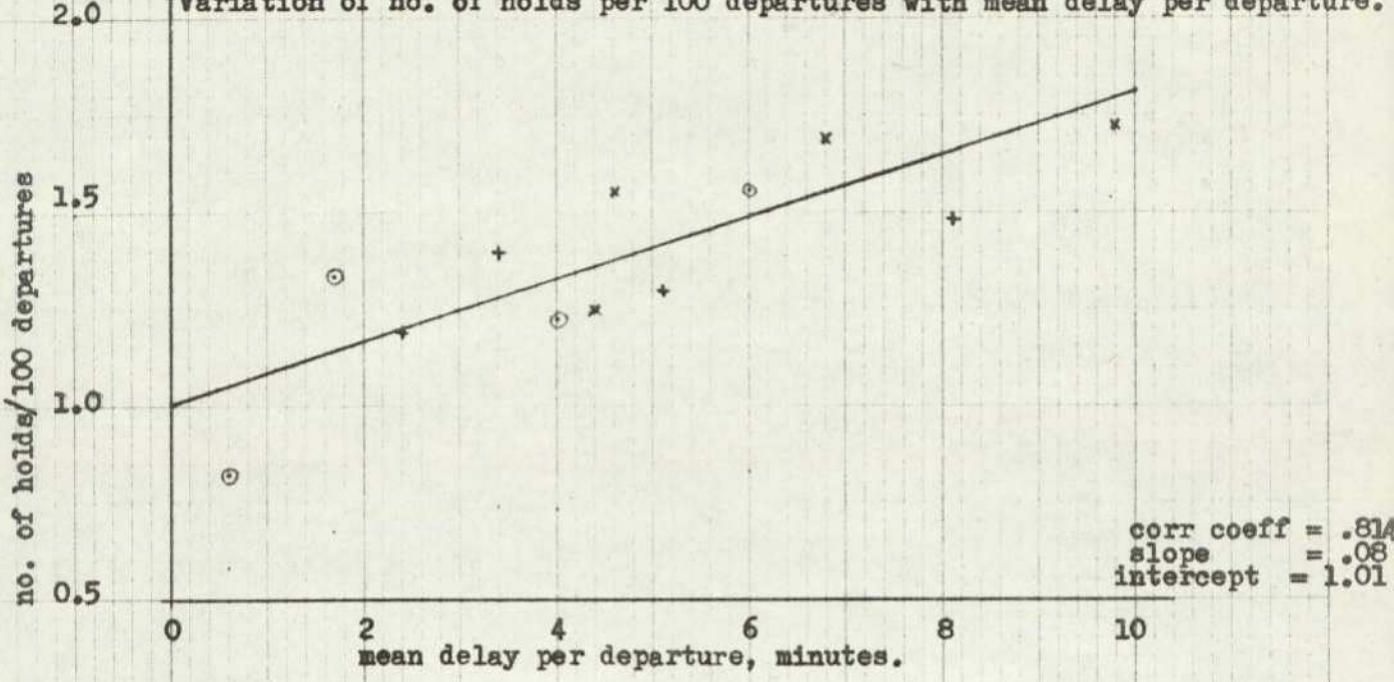


FIGURE 28.
Variation of minutes held per 100 departures with mean delay per departure.

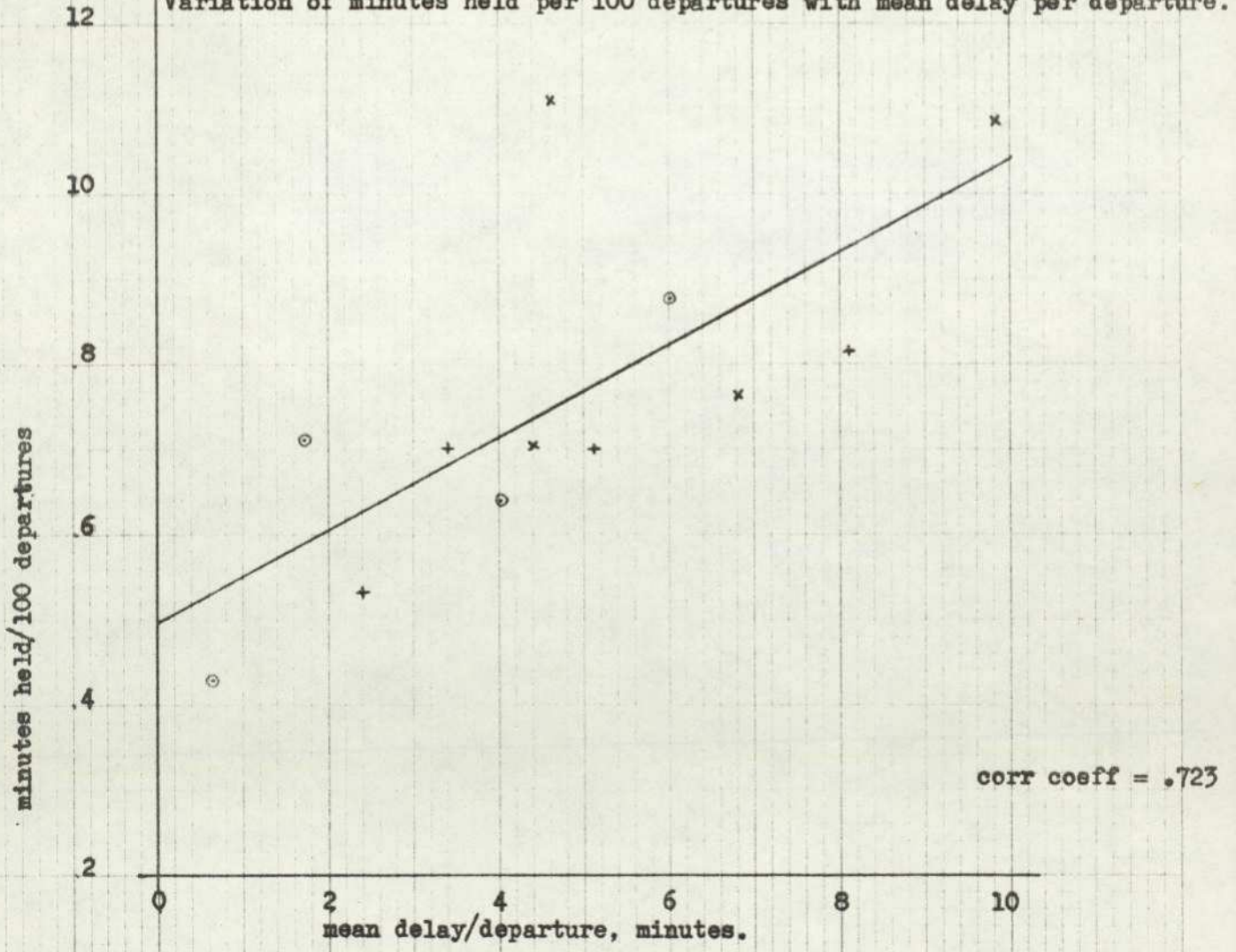


FIGURE 29.

Variation of no. of holds per 100 departures with mean delay per departure.

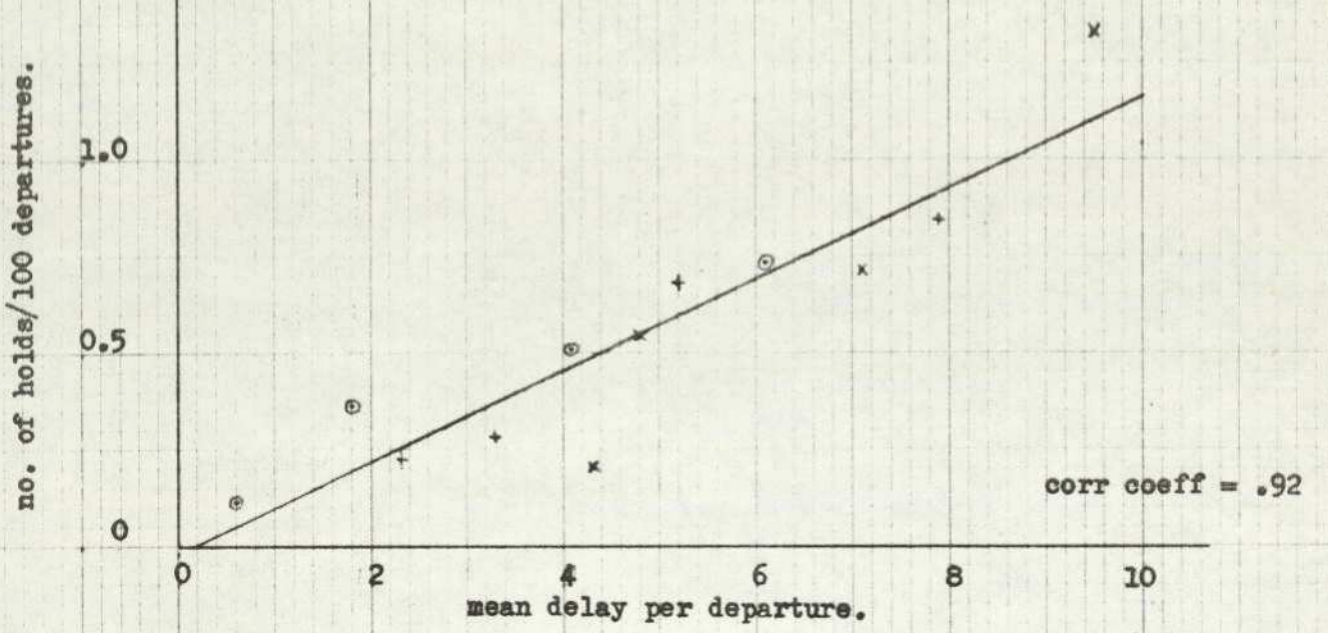
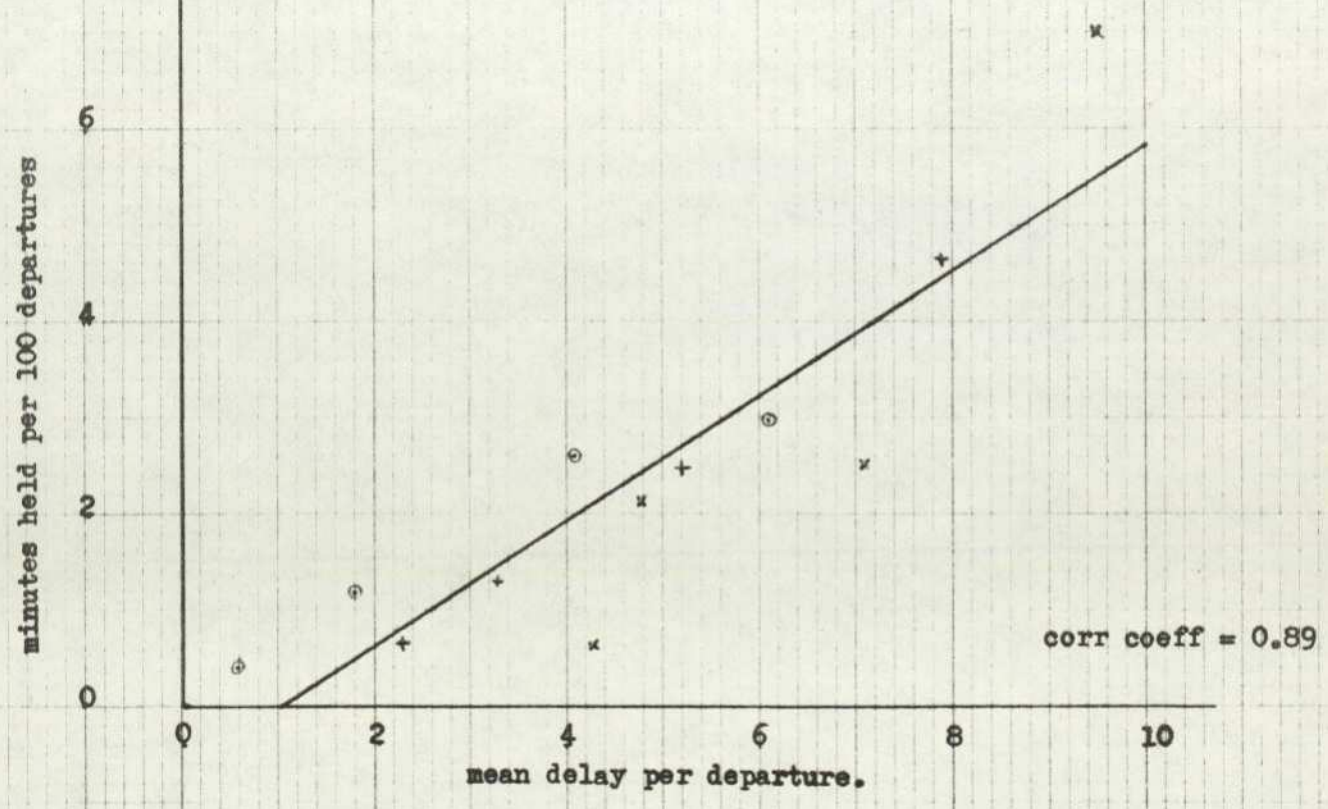


FIGURE 30.

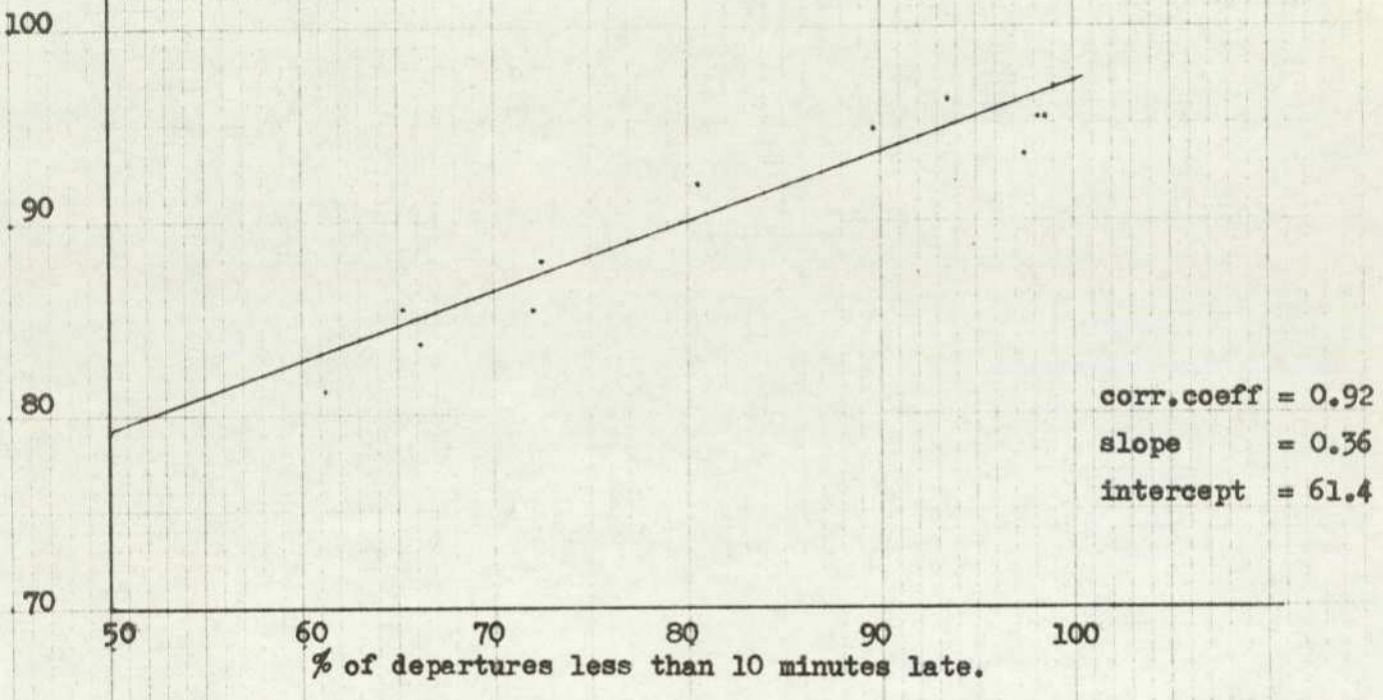
Variation of no. of minutes held per 100 departures with mean delay per departure.



VARIATION OF % GTR WITH DEPARTURE PUNCTUALITY WITHIN A GIVEN GATE TIMETABLE.

UAL 1

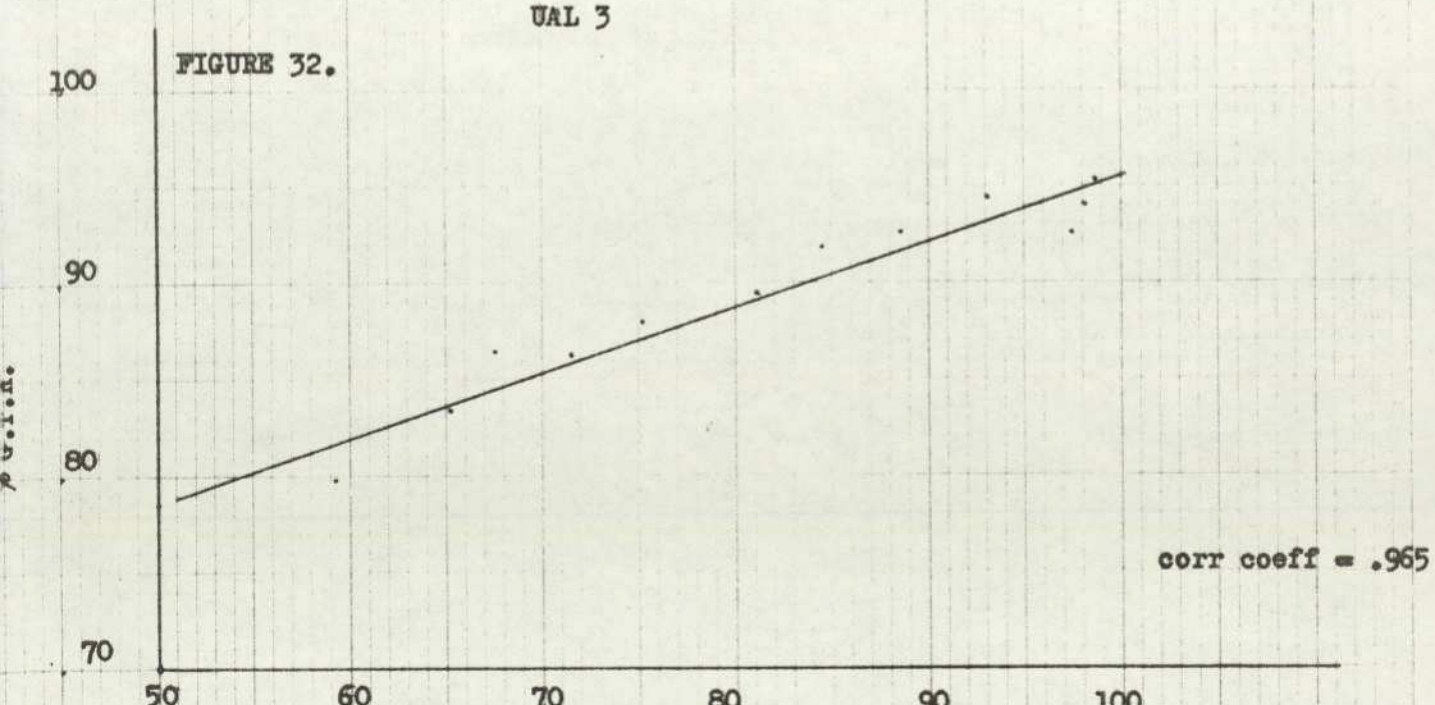
FIGURE 31.



% of departures less than 10 minutes late.

UAL 3

FIGURE 32.



% departures less than 10 minutes late.

FIGURE 33. UAL 5

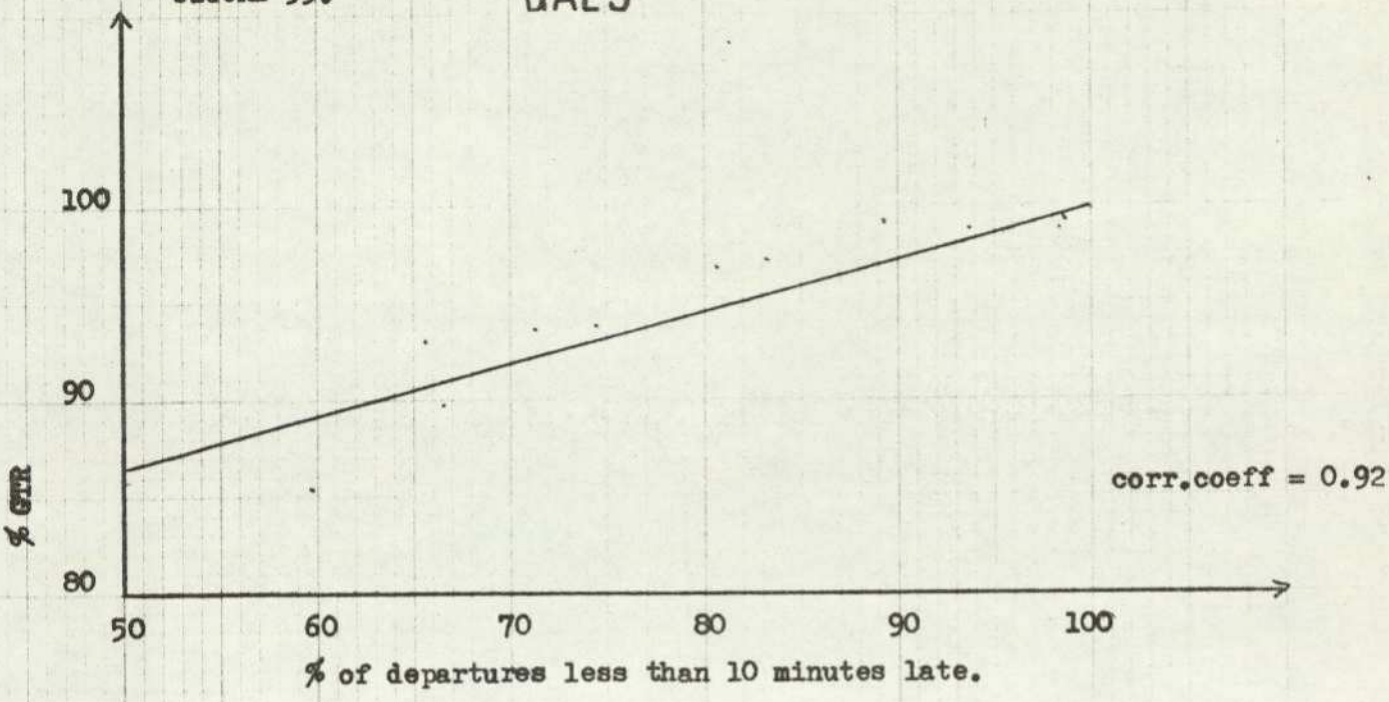
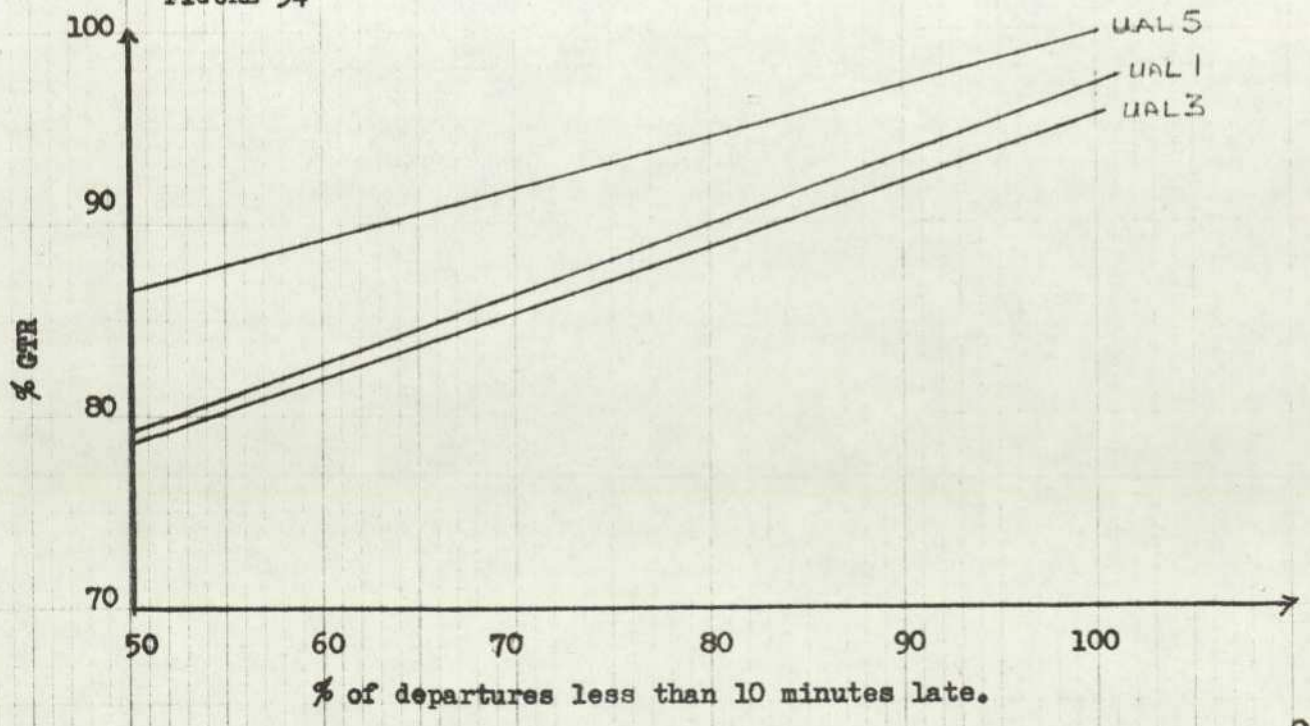


FIGURE 34



DISTRIBUTION OF OCCUPANCY TIMES

FIGURE 35.

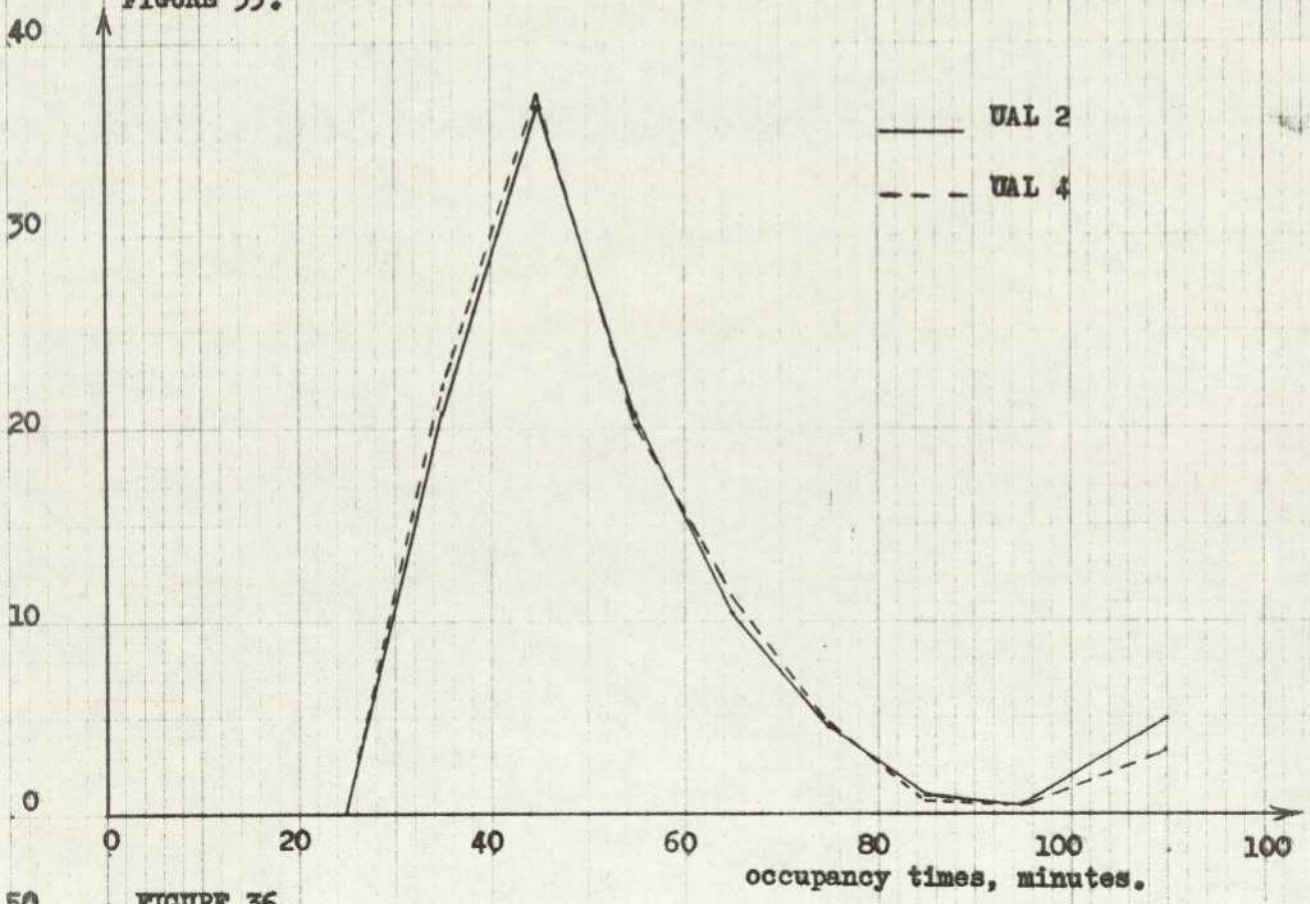
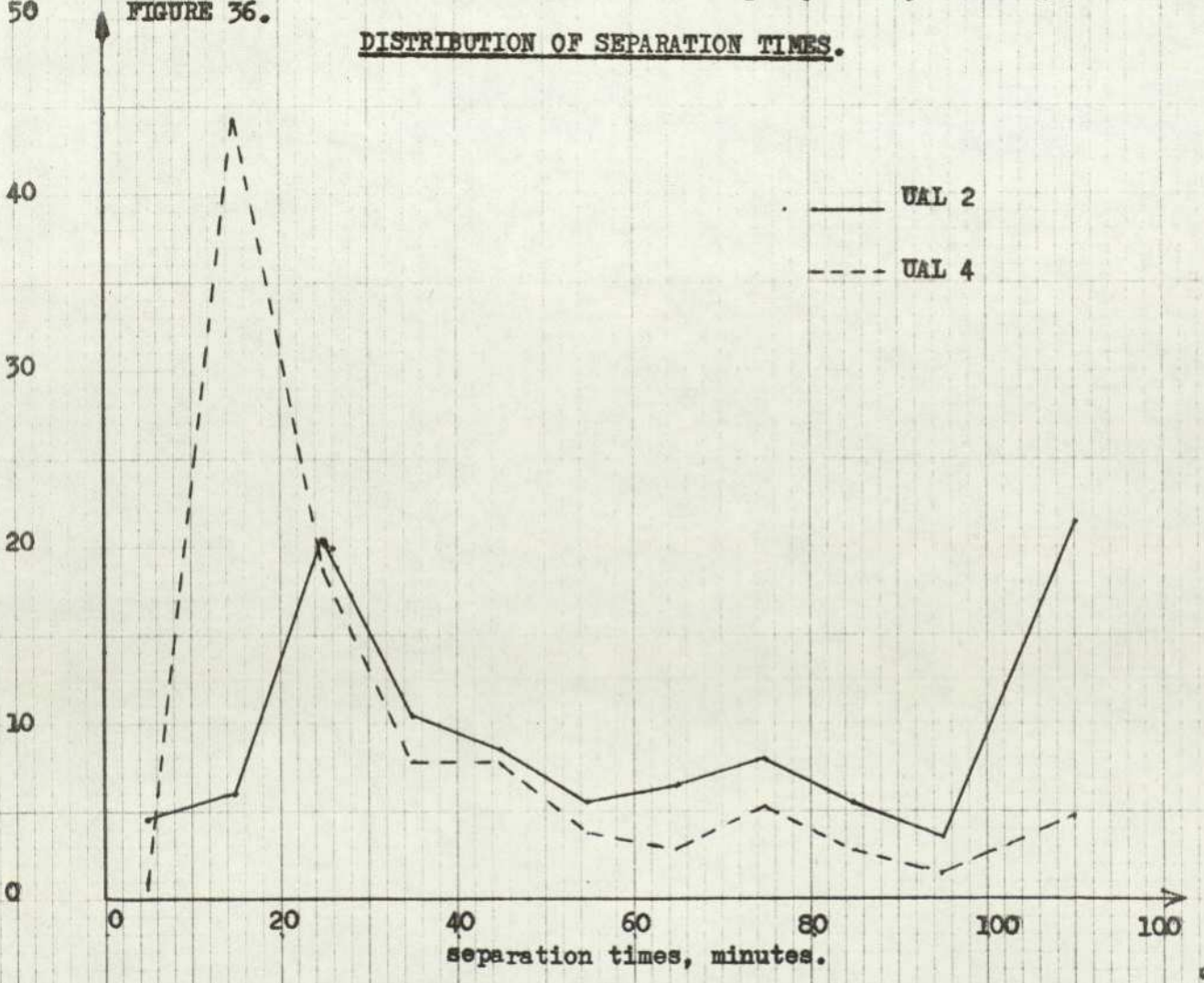


FIGURE 36.

DISTRIBUTION OF SEPARATION TIMES.



GATE PLAN UAL 2.

Variation of number of holds per 100 departures with mean delay per departure.

FIGURE 37.

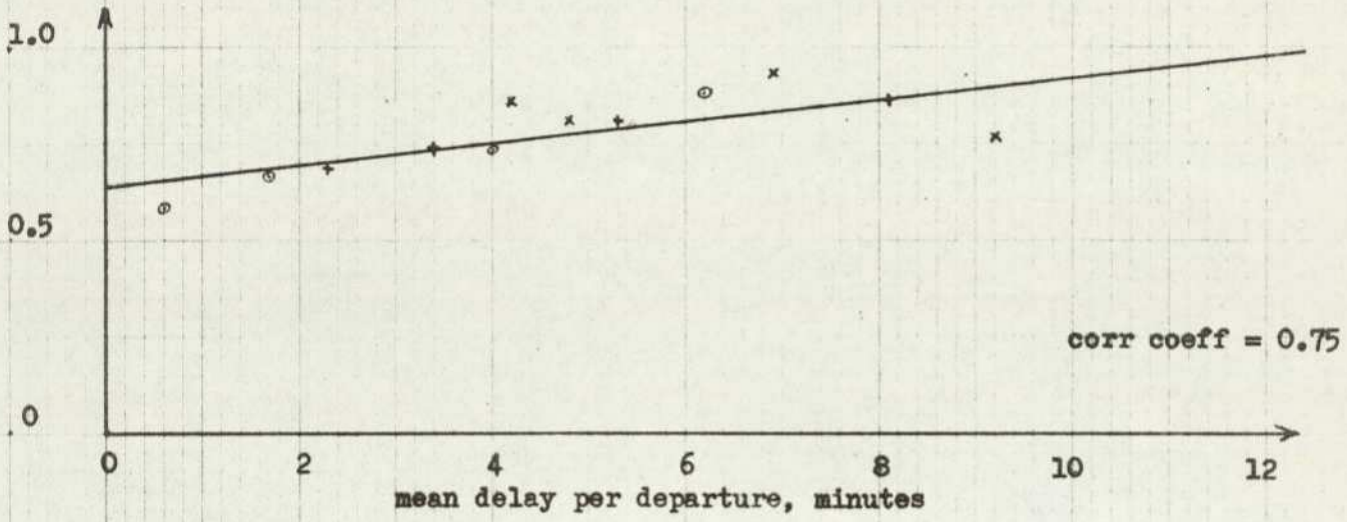
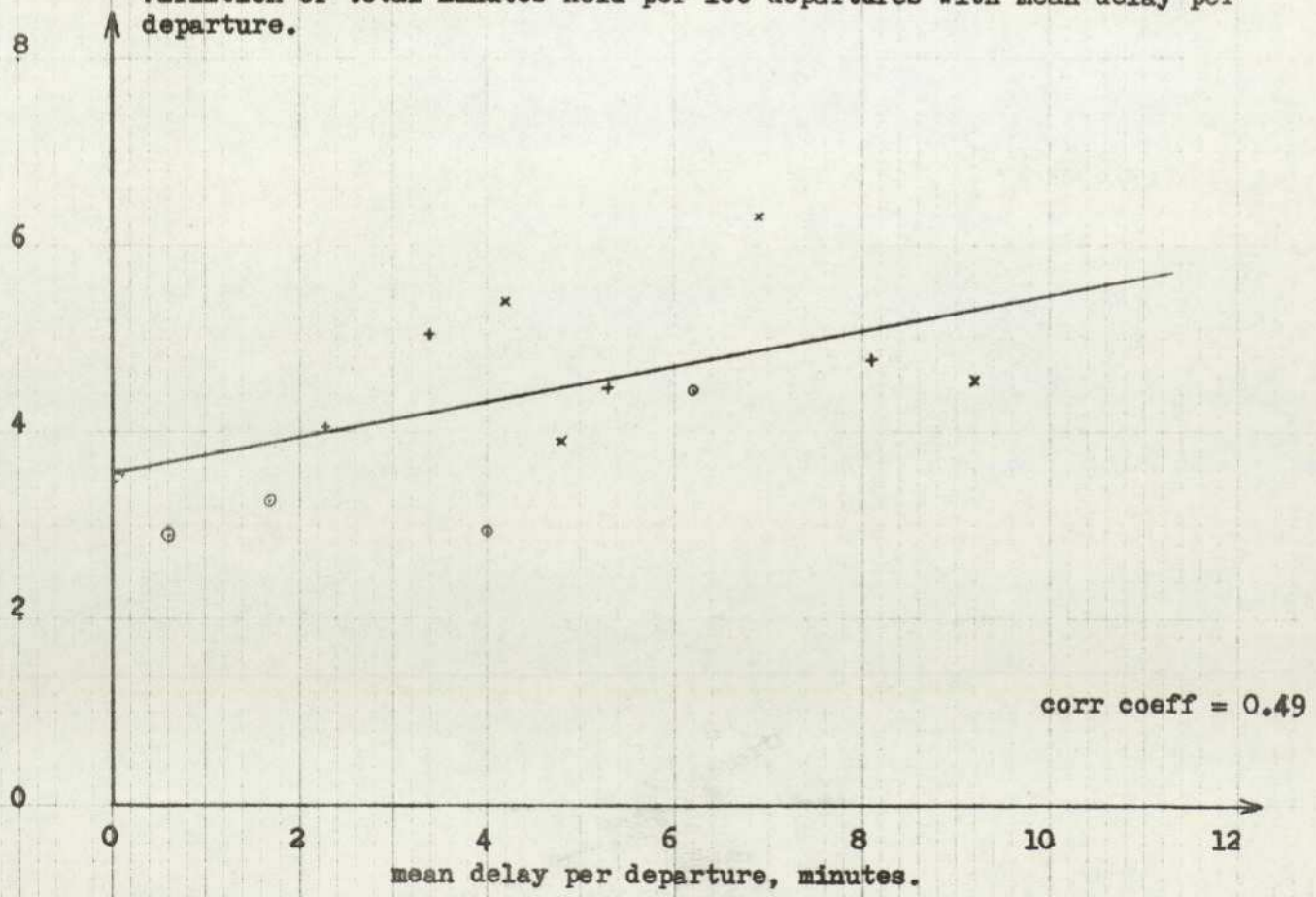


FIGURE 38.

Variation of total minutes held per 100 departures with mean delay per departure.



riation of number of holds per 100 departures with mean delay per departure.

FIGURE 39.

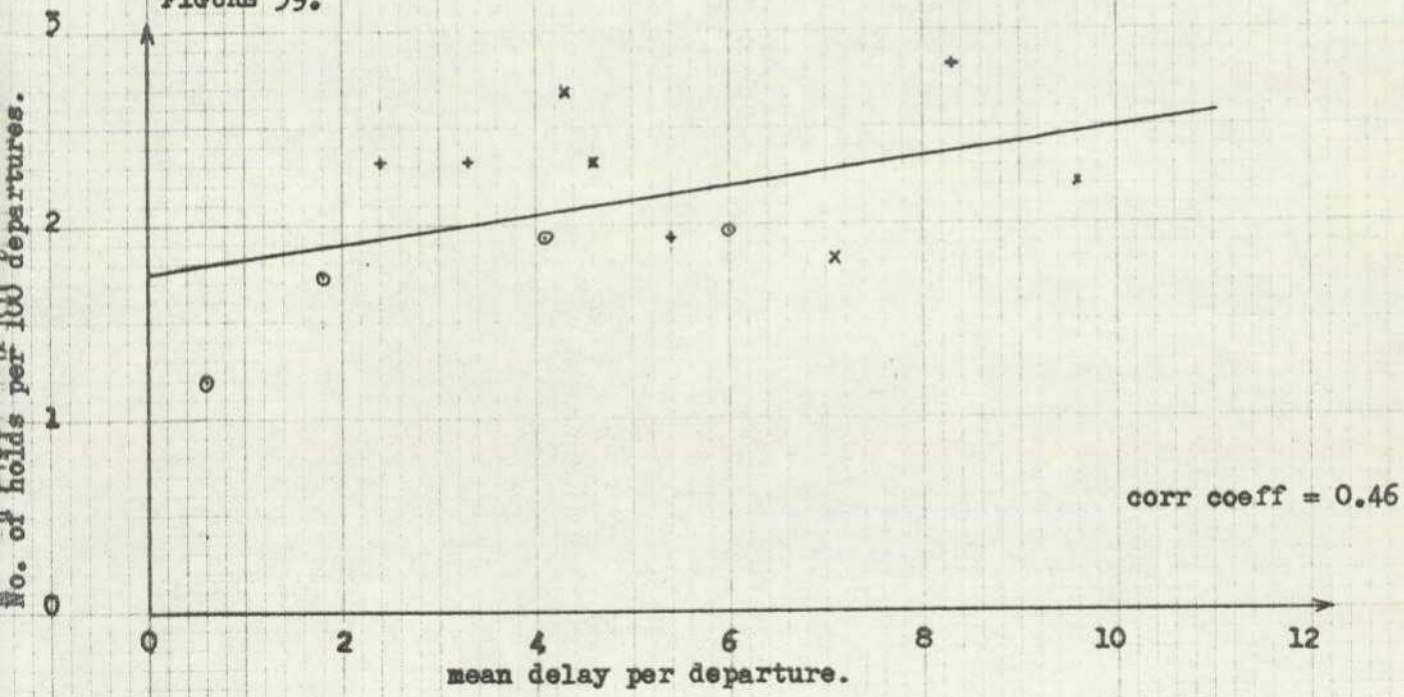


FIGURE 40.

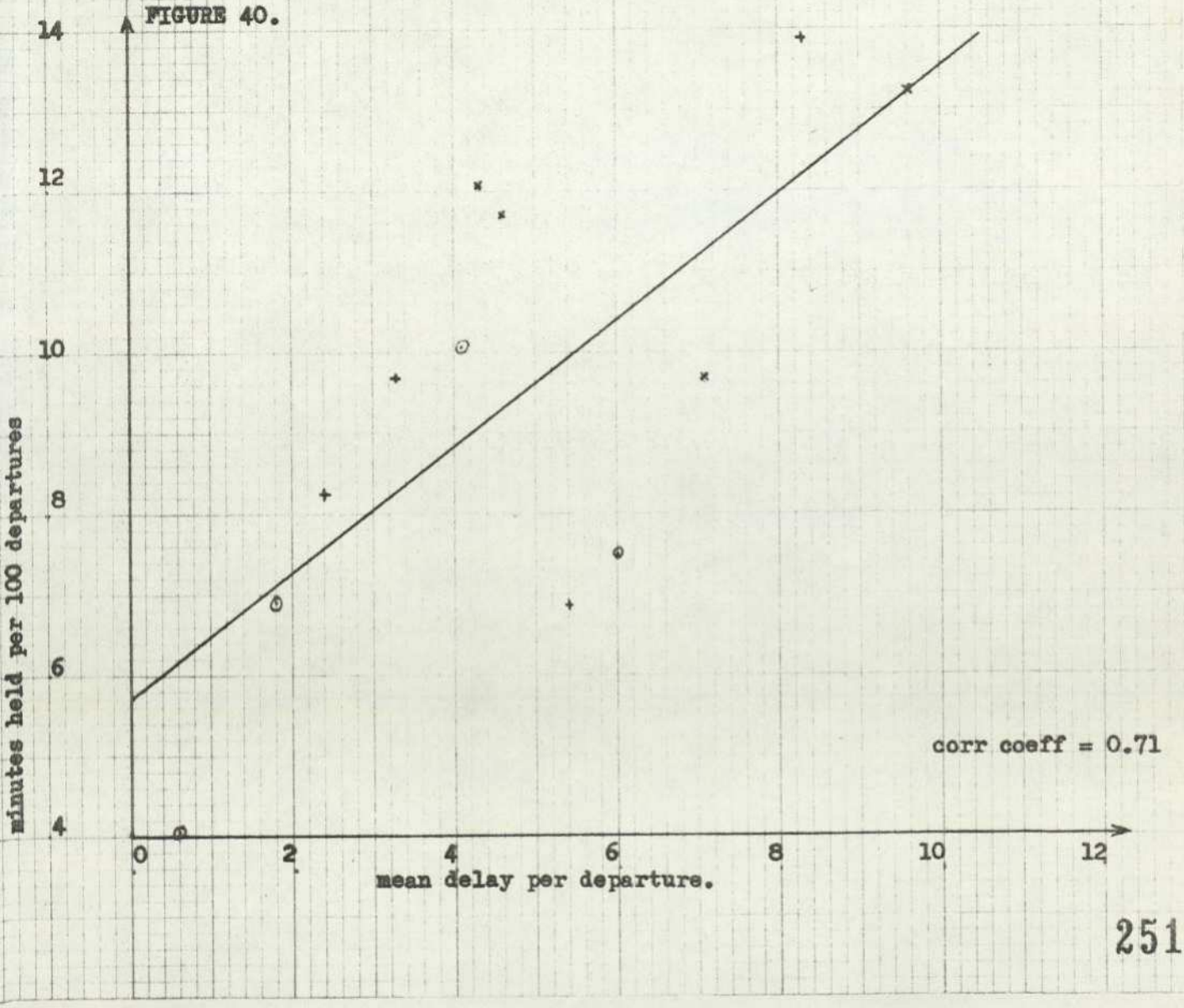


FIGURE 41. UAL 2

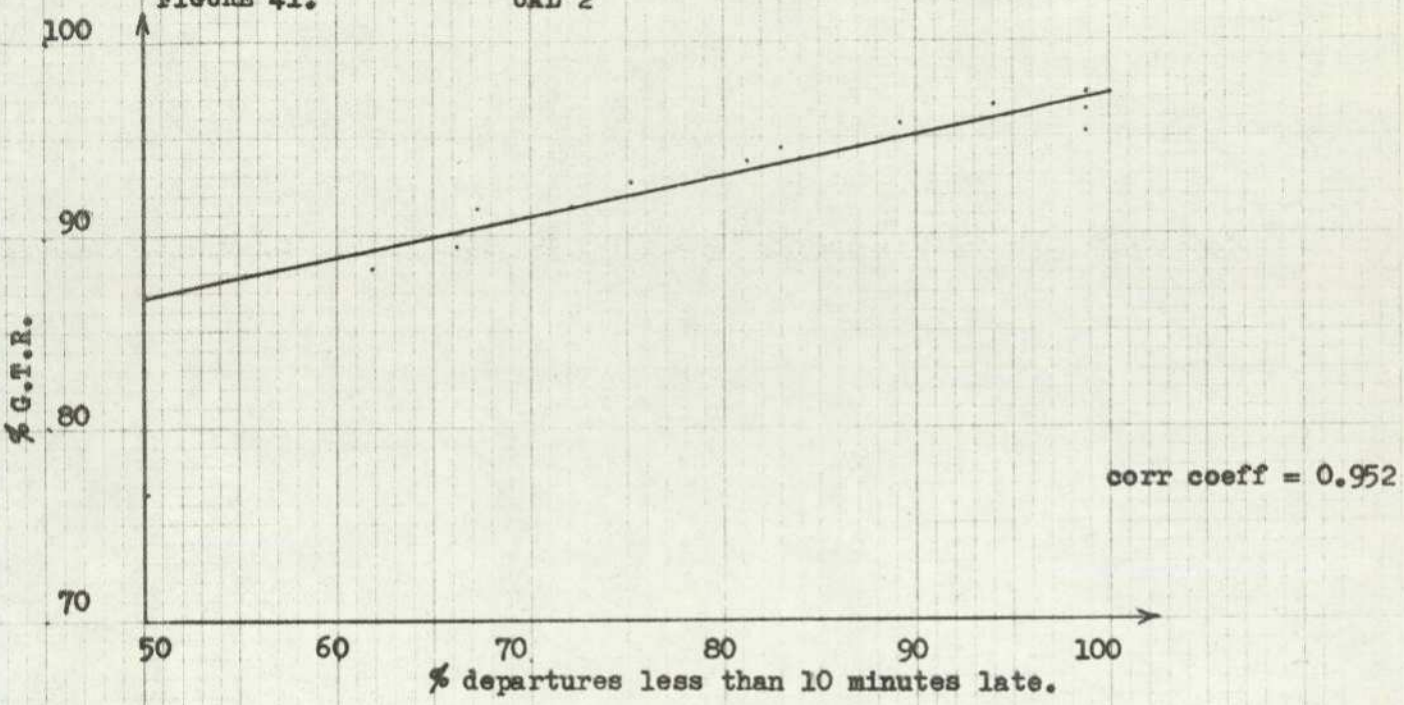
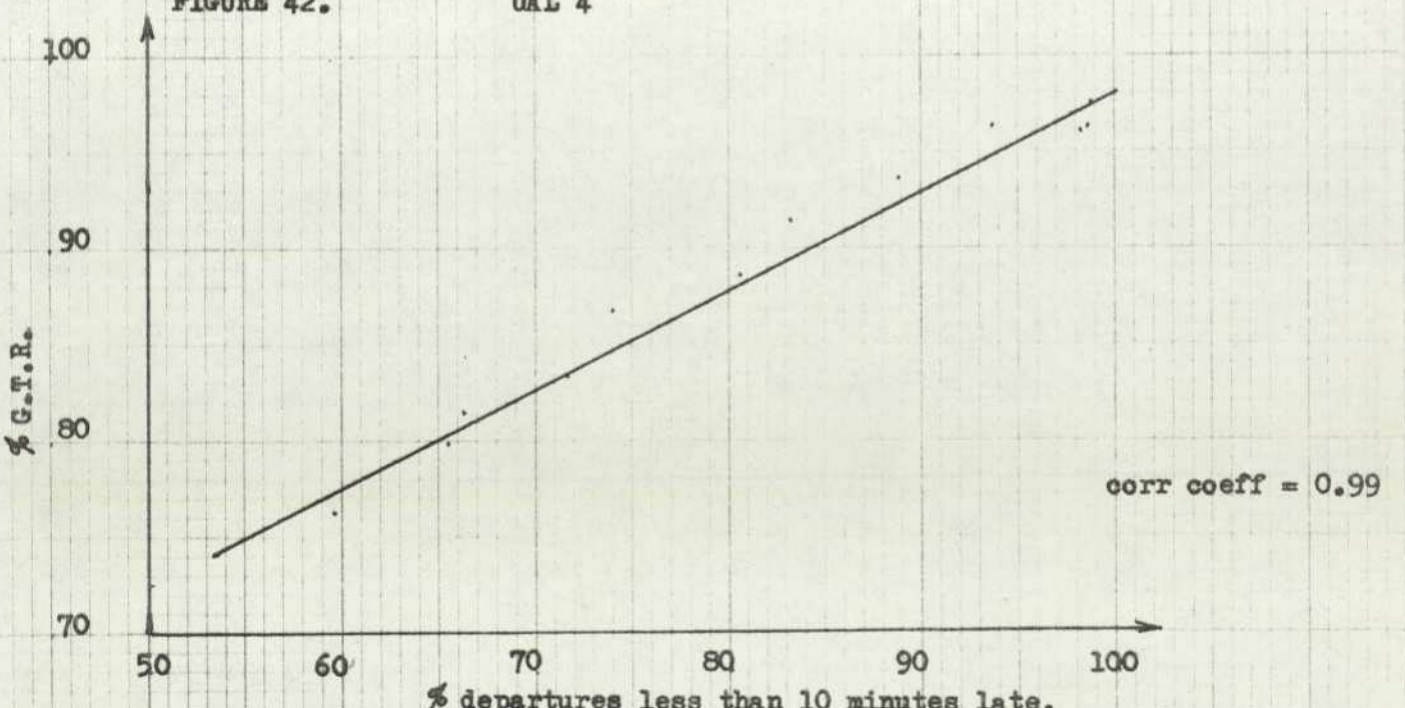


FIGURE 42. UAL 4



VARIATION OF FREQUENCY OF GATE HOLDS WITH MSST

FIGURE 43.

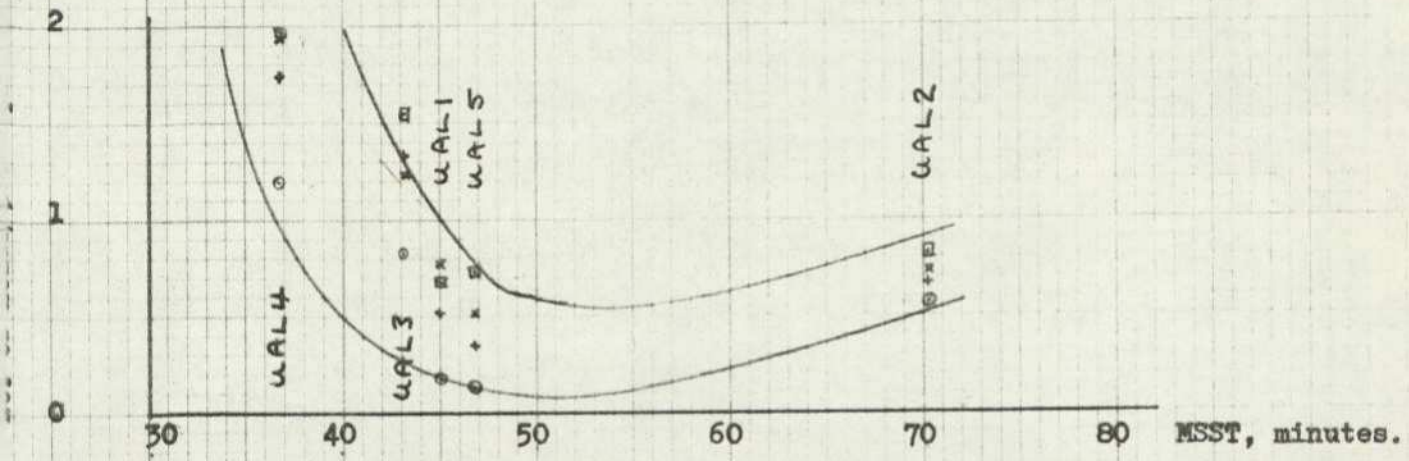


FIGURE 44.

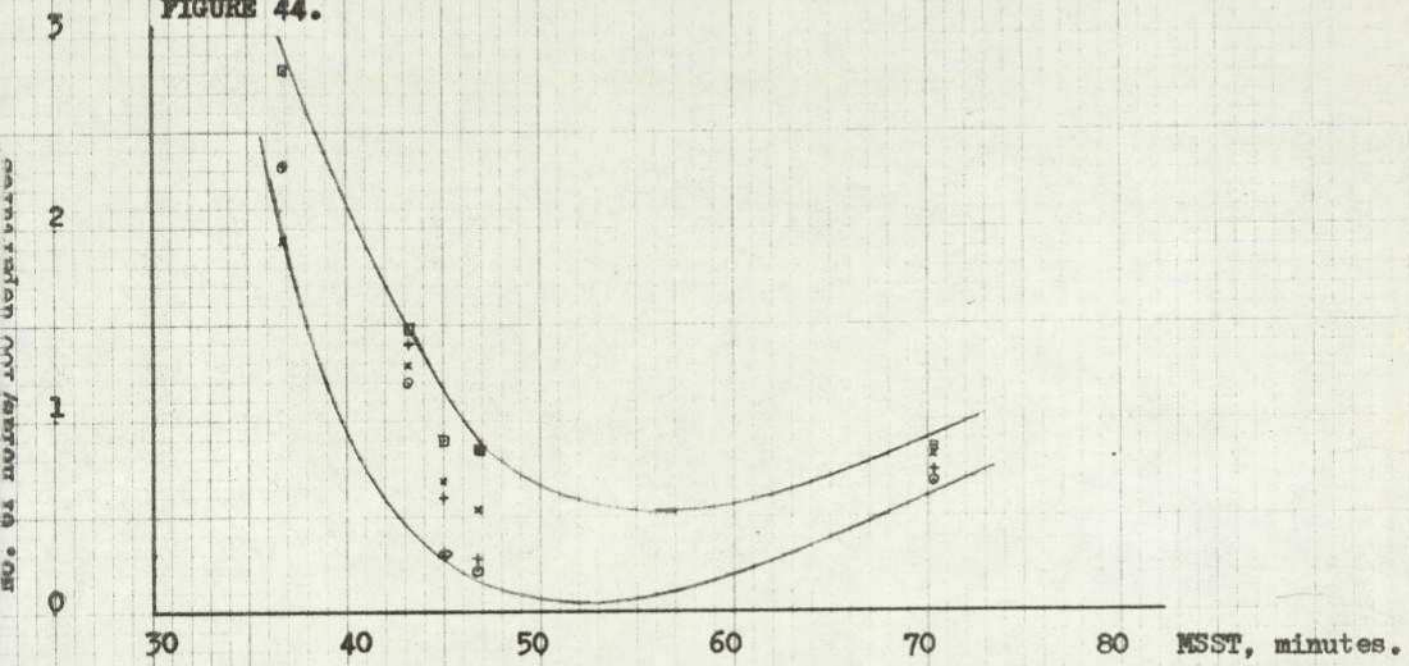
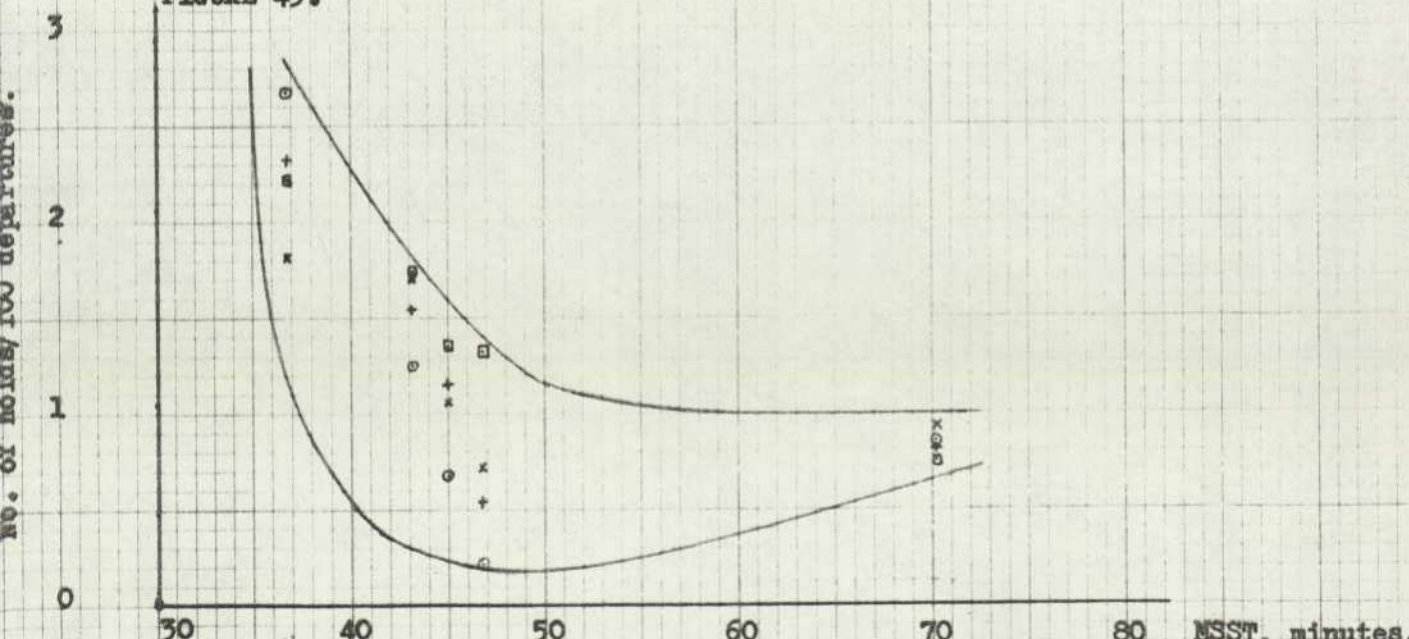


FIGURE 45.



VARIATION OF FREQUENCY OF GATE HOLDS WITH RELATIVE DISPERSION OF SEPARATION TIMES

FIGURE 46.

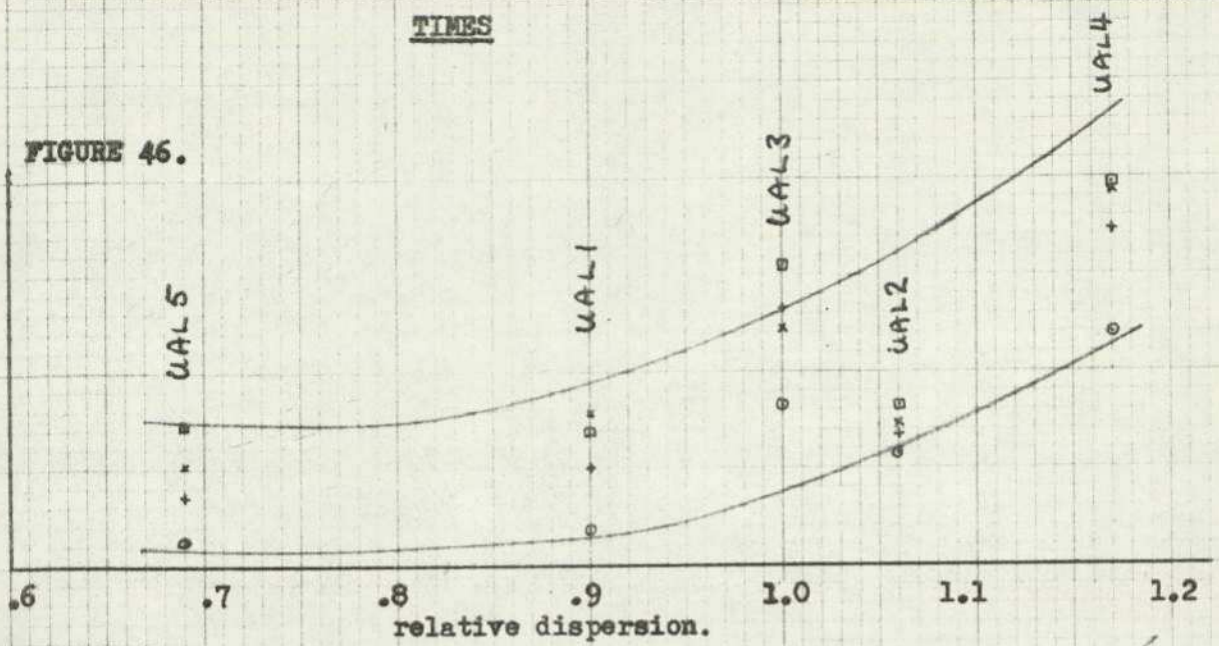


FIGURE 47.

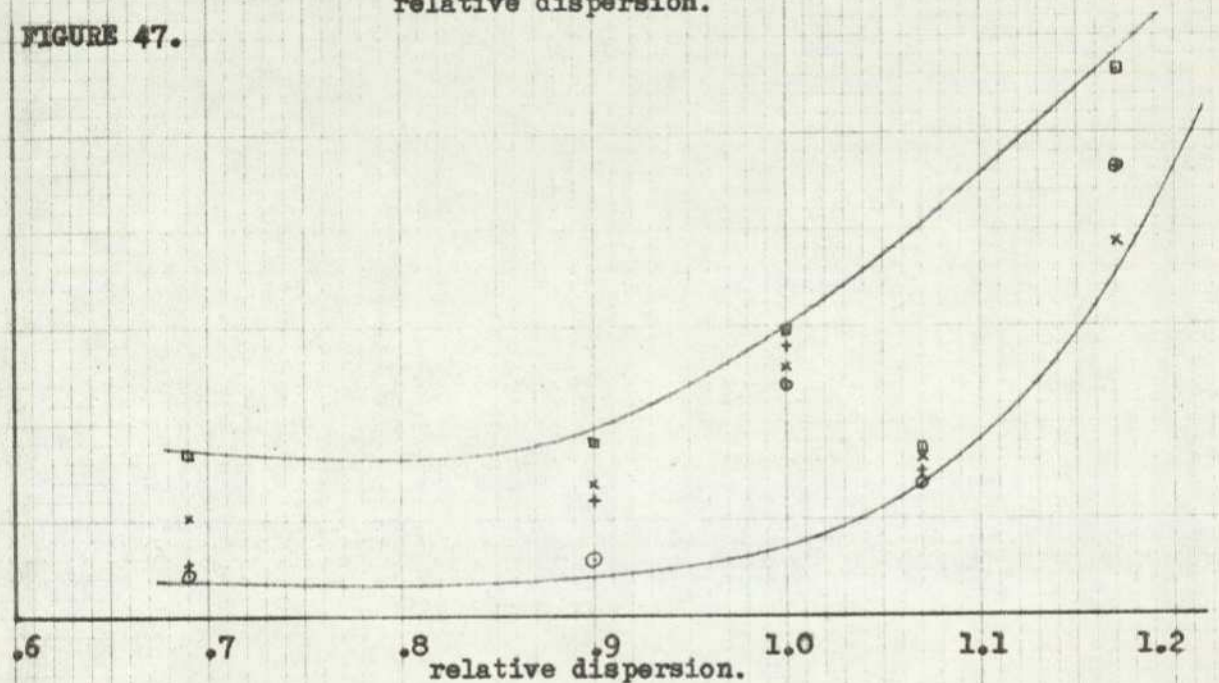
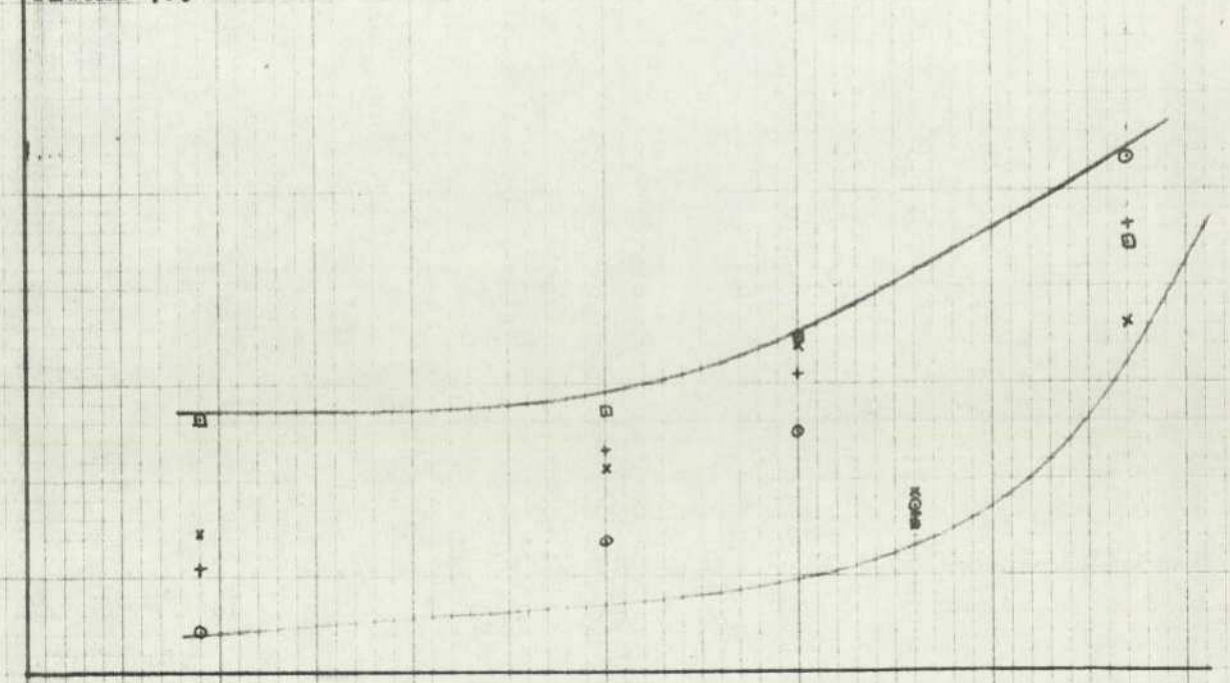
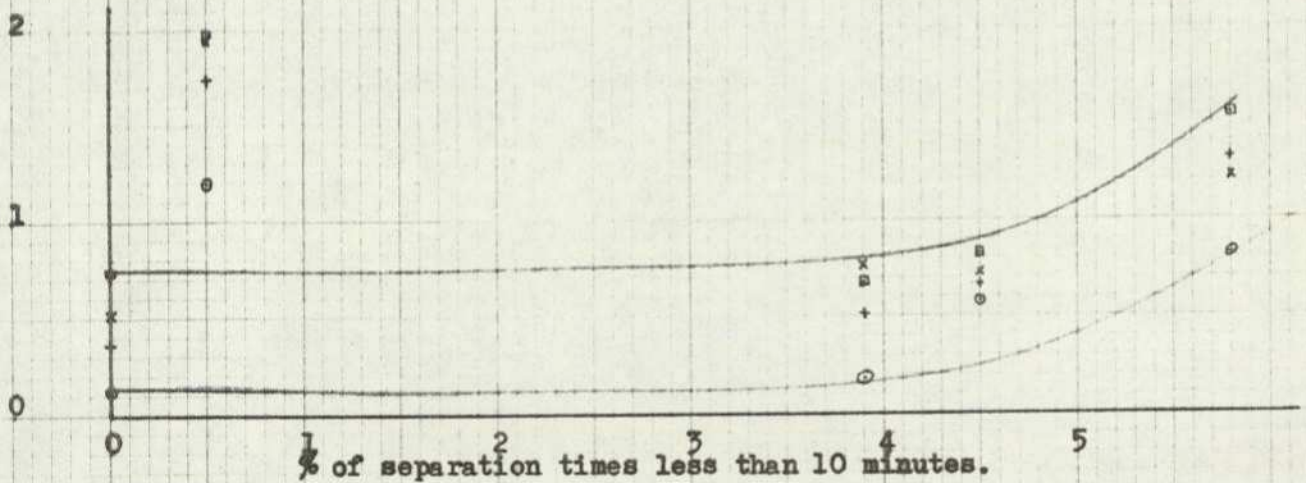


FIGURE 48.



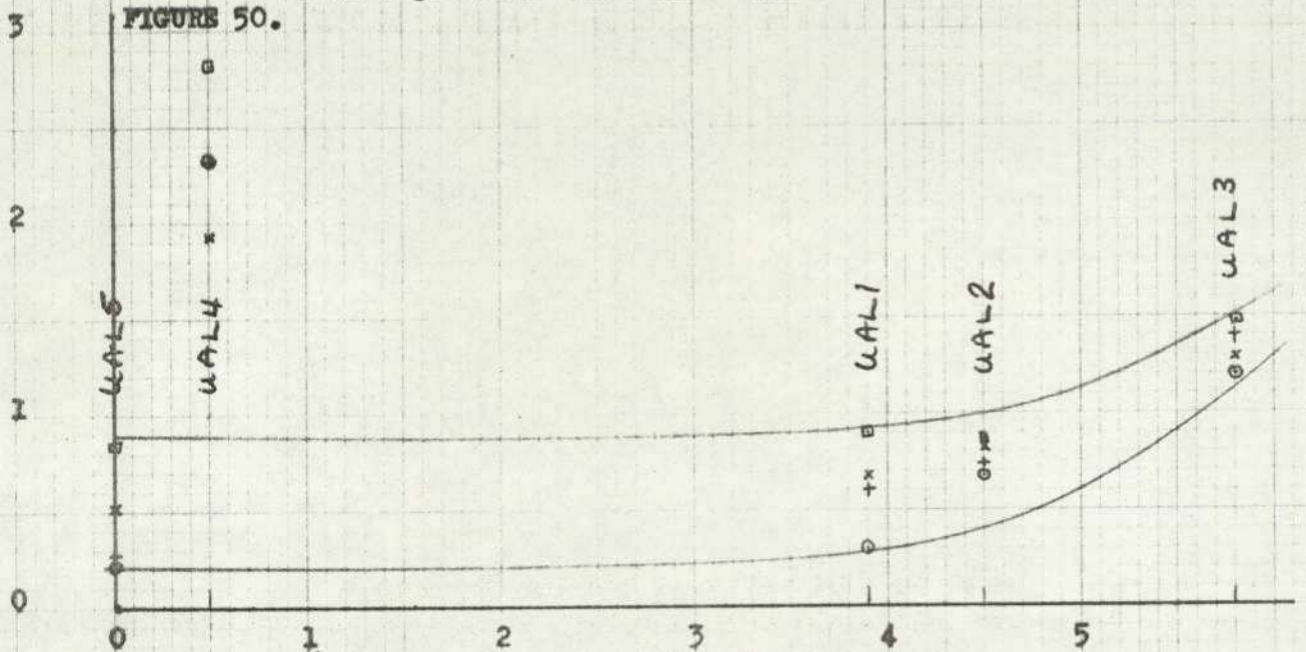
VARIATION OF FREQUENCY OF GATE HOLDS WITH % OF SEPARATION TIMES LESS THAN 10 MINUTES.

FIGURE 49.



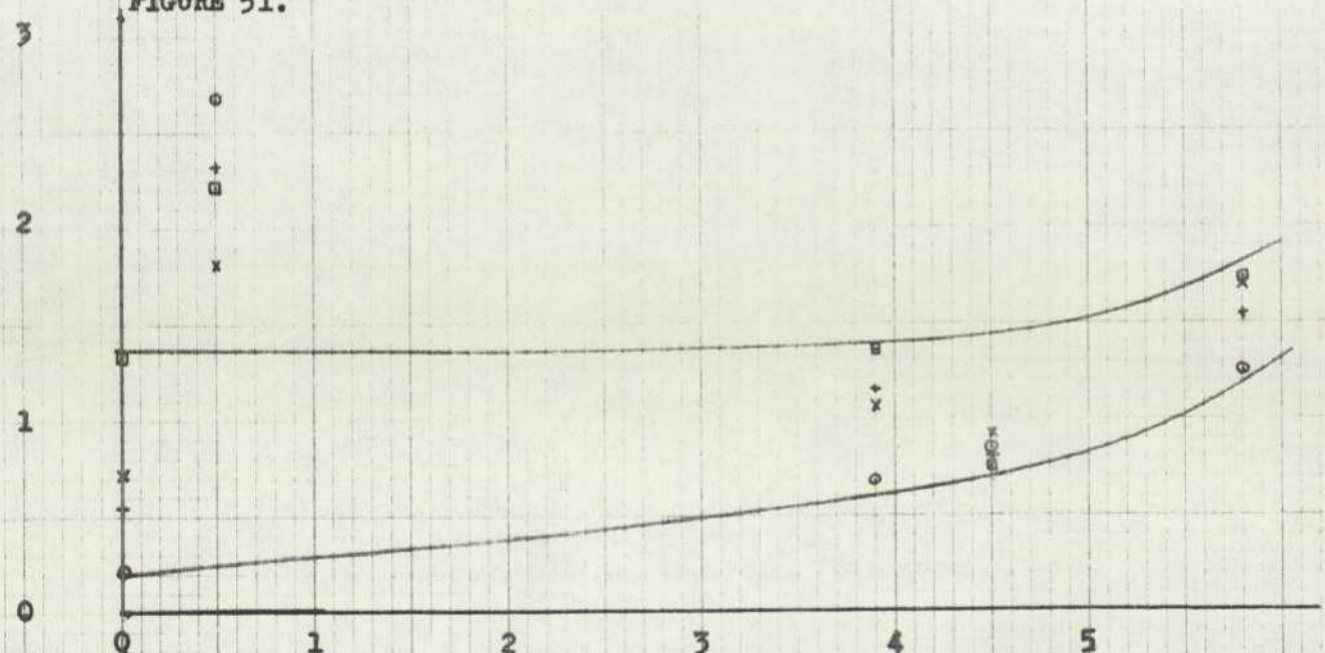
% of separation times less than 10 minutes.

FIGURE 50.



% of separation times less than 10 minutes.

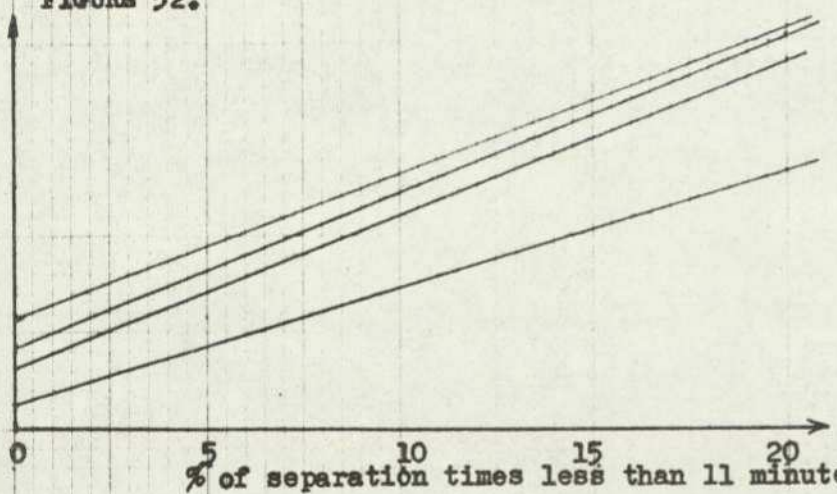
FIGURE 51.



% of separation times less than 10 minutes.

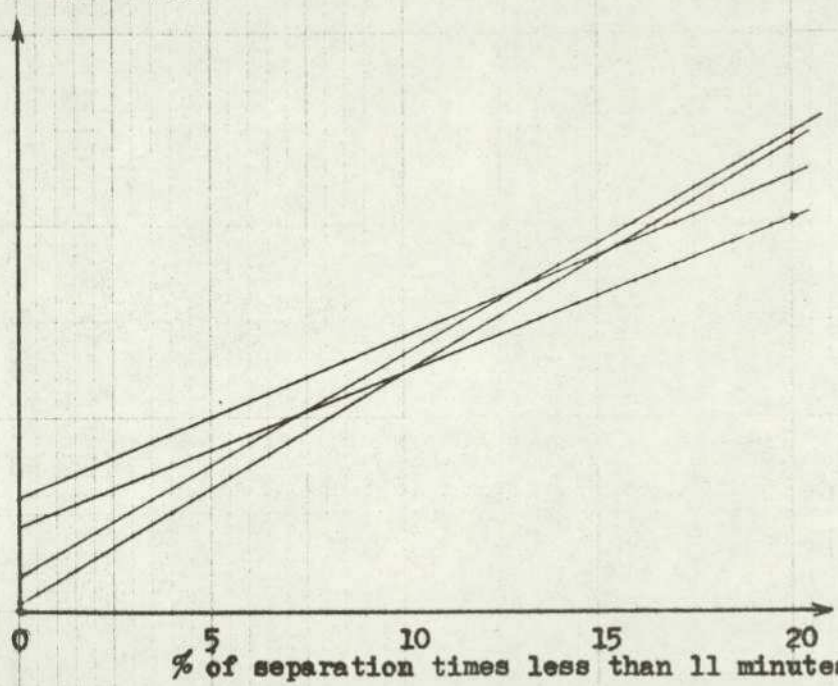
IN DURATION
(SEE TABLE II)

FIGURE 52.



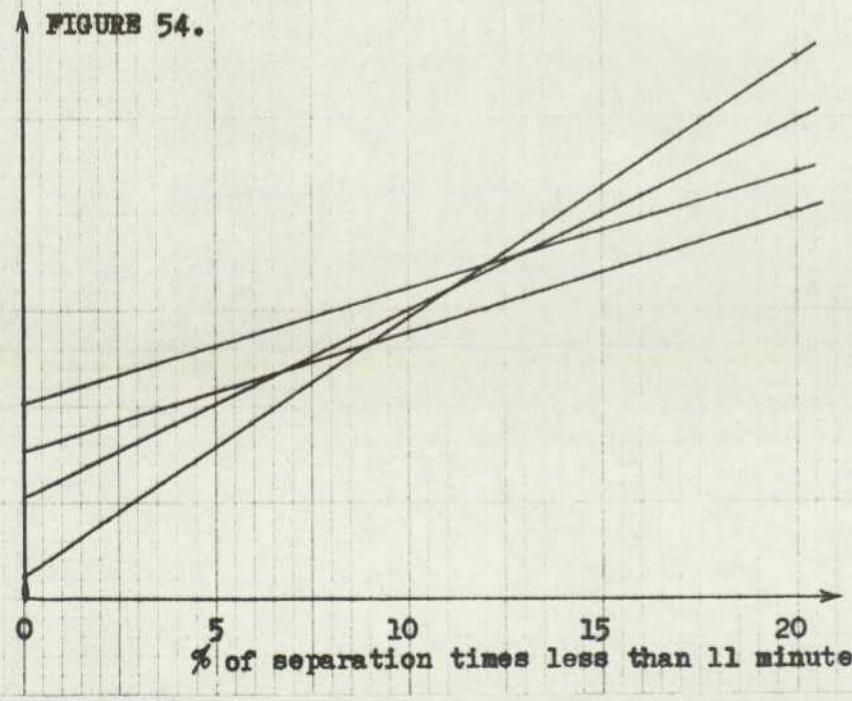
INPUT DISTRIB'S	
MEAN	S.D.
10	15
10	10
10	5
10	2

FIGURE 53.



12	5.48
12	2.19
12	16.43
12	10.95

FIGURE 54.



14	2.27
14	5.9
14	17.6
14	11.8

CHAPTER 10.

SIMULATION OF OPERATION OF BEA AT LONDON HEATHROW AIRPORT.

10.1 BEA as a choice.

10.2 Comparison of BEA and UAL gate plans.

10.3 Conditions of simulation for BEA.

10.4 Variation of % GTR between BEA1 and 2.

10.5 Effect of gate timetable on gate holds.

10.6 Relationship between departure punctuality and gate holds.

10.7 Effect of departure punctuality on % GTR.

10 SIMULATION OF THE OPERATION OF BRITISH EUROPEAN AIRWAYS AT LONDON HEATHROW AIRPORT.

10.1 A summary of the methods currently practised by BEA is given in chapter 14, but it is necessary to state here that gate timetables are not in operational use at Heathrow although they are used extensively in the resource planning stage. The reasons for this and the alternative are also given in chapter 14. Simulation of a BEA gate plan was undertaken with the following in mind:-

10.1.1 The operational timetable used by United appears to be less congested than either FOFI or a LOFI timetable constructed from BEA's schedule. Nevertheless, within BEA, attempts to implement such a plan were singularly unsuccessful. It is considered that this failure can be attributed to one or more of the following:-

i) The flight schedules, although resulting in gate plans, comparable to UAL, may be compiled from totally different aircraft integrations.

ii) The flight punctuality exhibited by BEA may be poorer than UAL.

iii) BEA's flight punctuality may be achieved at the expense of creating a large number of unscheduled turnrounds. i.e. the aircraft cycles lacked operational integrity.

iv) The methods used by the airline may not be suited to the use of a gate plan.

With the exception of iv), each of the above can be investigated by simulation and by comparing the results to those obtained for United.

10.1.2 In chapter 9, it was shown that relationships developed from plans UAL1, 3 and 5 did not always apply when the gate resource level was altered as in plans UAL 2 and UAL 4.

However, it was the mean and relative dispersion of the separation times and not the number of gates that were used to describe these relationships. It can be argued that the discontinuities were not caused by a change in resource level, per se, but that the same discontinuities would be achieved under constant resource condition provided the mean and relative dispersion could still reach the extreme values as obtained from UAL 2 and 4. Although this argument appears

10.1.2 to be of academic interest alone, it is worth recording that the simulation cannot prove either hypothesis correct. However, if the aircraft integrations are altered such that a gate timetable can be constructed with descriptors within the bounds of those applicable to UAL 1, 3 and 5, and if the results are consistent with the established relationship, it can be claimed that it is not the overall resource level which controls the timetable reliability. By inference, it could be claimed that the above discontinuities are caused by the extreme values of gate plan descriptors, as opposed to a change in resource level.

The simulation of BEA's operation is an opportunity to assess such a condition since the aircraft integrations are different from United's, and the total number of gates differ but the gate plan parameters are of the same magnitude as those of UAL 1, 3 and 5.

10.1.3 It was emphasised in 9.7 that this simulation provides a reasonable method of comparing gate plans but that it should not be regarded as being capable of forecasting the operational result of one plan, in isolation. It was claimed that most airlines with an operation sufficiently large to warrant a gate timetable, do in fact operate one. The simulation can then be used to investigate the effect of a different one provided that both the old and the new are simulated. BEA is the exception, having no operational gate plan, so the expected actual values of GTR can only be estimated as follows:-

i) Using United's data, the achieved GTR is compared to the simulated one, under the same punctuality conditions if possible and the difference explained.

ii) If similar arguments apply to BEA's case, a corresponding "correction" can be made to the result of BEA's simulated GTR.

iii) If additional restraints apply solely to BEA, extra correction must be made.

Obviously these correction factors tend to be based on qualitative judgement and require intimate knowledge of the operation to which they are being applied. BEA has been used as the example, but the same approach is required for any airline which cannot supply historical information about its current gate timetable.

10.2 Two gate plans were prepared to accommodate BEA's summer 1969 operation. BEA1 was constructed under the FOFI principle using 24 gates, while BEA2 required 23 gates under the LOFI policy. In section 10, the two plans are compared in a manner similar to that adopted for United in section 9, but the absolute values of GTR which can be expected after the introduction of either of the gate plans is not discussed until chapter 17. Table 10.1 below shows the main descriptors of the two plans while table 3 in appendix 10 at the end of the chapter shows the distribution of separation and occupancy times.

Plan	Policy	No. of Gates	Separation Times		Occupancy Times	
			Mean.	Std. Deviation	Mean.	Std. deviation
BEA1	FOFI	24	59.2	36.9	59.5	34.1
BEA2	LOFI	23	46.7	71.6	62.7	37.9

Table 10.1

10.2.1 The gate timetables are shown in bar chart form in figures 1 and 2 of appendix 10, while tables 1 and 2 provide the analysis summaries as output by procedure ANALYSE. Figures 3 and 4 show the cumulative frequency distributions of separation and occupancy times of both plans. The same information is given in histogram form in figures 5 and 6.

10.2.2 Since BEA's operation comprises domestic and international services, it is necessary to separate the two types of passengers. At Heathrow, their are two main concourses or piers, one serving domestic passengers and the other linked directly to passport control and customs etc. It is obviously highly desireable to position the aircraft according to the type of flight being operated. When a turnround involves a domestic arrival and international departure, or vice-versa, and insufficient time exists to reposition the aircraft, the departure is given priority.

In BEA1 and BEA2 two types of gates were created, in line with this policy. It was found that the total number of gates required could be reduced by one if one gate was permitted to have a mixed type of operation. This was accepted because of the ease with which the gate nearest the terminal building on the domestic pier can be connected to the passport control area. As with United's plans, the gate types are separated only at the planning stage, but during the simulation, are regarded as homogeneous.

10.2.3 BEA1 is a FOFI type gate plan, exhibiting a mean station separation time of 59.2 minutes and a standard deviation of 36.9. This is considerably higher than the 46.7 minutes MSST of UAL 5, the corresponding FOFI plan for United. The relative dispersion value of 0.62 also indicates a less diverse range of separation times than UAL 5.

If these descriptors are used to estimate a value for GTR under BEA1, it must first be shown that the operating conditions are similar to those for the United plans. Flight punctuality and its reactionary effect together with gate hold procedures must be comparable. When these apply, a given input delay distribution would be expected to result in BEA1 achieving a higher value of GTR than UAL 5. It is suggested that a more realistic method of estimation of GTR is provided by comparing the percentage of separation times which are less than a given value. Since BEA1 has only 9% less than 21 minutes, 6.9% less than 16, and 2% less than 11, it would be expected on this basis that UAL 5 would achieve a better GTR value.

10.2.4 BEA2, being a LOFI policy plan, has a lower MSST value than BEA1, and a larger value of relative dispersion. Similarly the number of short separation times is considerably higher, with 27.7% being less than 11 minutes. It is reasonable to expect that like United, the LOFI policy will result in a poor gate timetable reliability. 46.7 minutes is the value of MSST for both UAL 5 and BEA2 while the relative dispersions are 0.69 and 1.53 respectively.

10.2.5 When gate plans are compiled from different schedules the most realistic and useful comparison is considered to be that of the respective LOFI plans. This is so because the LOFI policy is independent of the number of available gates, only the minimum number are used. FOFI on the other hand can be expanded into any number of gates. UAL 5 for example has 2 more than the minimum, but BEA1 has only one more. Consequently, there should be relatively more slack in UAL 5 than in BEA1, if the LOFI plans are used as the basis. BEA2 is compared with UAL 4 in table 10.2 below.

10.2.5 Table 10.2.

	MSST	rel.dispersion	% of separation times < X minutes			
	minutes		11	16	21	26
BEA2	46.7	1.53	27.6	43.2	53.4	58.8
UAL4	36.7	1.17	18.7	37.4	47.6	57.0

It must be repeated that UAL 4 was restricted to a minimum separation time of 10 minutes in an attempt to reduce the effect of BEA's policy of scheduling only in multiples of 5 minutes. From table 10.2 it would seem reasonable to expect BEA2 to exhibit the lower value of GTR. Unfortunately there is one feature on BEA2 not applicable to UAL4. As seen from table 2 in appendix 10, one gate has been ignored by procedure ANALYSE because only one occupancy occurs generated by a departure at 07.50 hours. Thus for the remainder of the day, the gate can be regarded as an overflow one to reduce the effect of the large number of short separation times. If the gate had been included in the analysis, the relative dispersion would have had an even higher value, suggesting a relatively worse performance if compared to UAL 4. In practice, the effect of this gate is expected to reduce the difference between the two plans and may even permit BEA2 to show a better reliability.

10.3 As stated above it is necessary to ascertain if the same conditions apply to a simulation of BEA's schedule as did to Uniteds.

10.3.1 Gate holds are controlled by the simulation programme and were not altered to adhere more closely to BEA's current methods.

10.3.2 The distribution of departures throughout the day varies considerably between BEA and UAL, but more significantly, 64% of BEA's turnrounds at LHR are formed by aircraft which have performed at least one earlier departure from the same station on the same day. The comparable figure at O'Hare for UAL is 35%. This suggests that large delays at the main station will have a greater reactionary effect at LHR than at O'Hare. If the schedule is unable to absorb this, it will be reflected in poorer departure punctuality.

The departure punctuality performances for BEA1 and BEA2 are shown in table 5 of appendix 10, while those of the United plans are listed in table 9 of appendix 9. It is considered

10.3.2 that the percentage of departures having a delay in excess of ten minutes is the most realistic parameter with which to compare the performances. BEA1 and BEA2 do not produce identical results, but neither plan is consistantly better over the complete range of input distributions. The differences are considered to be due in the main to the fact that BEA1, especially, was simulated over too few daily cycles and the steady state condition was not achieved. This also applies to BEA2 when the mean of the input distribution was fourteen minutes. Although there appears to be a tendancy for the BEA plans to be slightly less punctual than the United ones, this is not borne out by the sampling analysis shown in appendix 10. It is seen that all seven plans have punctuality rates which may be considered to have been drawn from the same population, for a given input distribution.

This merely means that any increase in reactionary delays experienced by the BEA schedule is not significantly manifest in the end product, i.e. the delay rate. It may well involve an increase in aircraft changes. Nevertheless, aircraft changes are requested under the same circumstances as for United. Since a gate timetable is basically the flight integrations presented in a different format, the flexibility of a schedule must be reflected in the gate plan and its parameters. For example, if integration changes are frequently required in order to reduce the delay rates, these changes must themselves generate only small if any delays. This implies that aircraft ground times coincide to a large extent and as far as the gate plan is concerned, the unscheduled occupancies can most probably be accommodated by switching the arrival gates, thus involving no penalty in terms of GTR.

It is therefore considered that even though an increase in unscheduled turnrounds could be shown, this in itself should not be taken as a reason for lowering the expected value of GTR, provided the departure punctuality rate is not considerably poorer than that achieved by other flight schedules under the same input disturbances. Conversely, if the departure delay rate is poorer, despite an increase in aircraft changes, it can fairly be claimed that a lower value of GTR should apply. This does not appear to be the case with BEA.

10.3.3 As far as the simulation is concerned, it appears that BEA's operation is treated in exactly the same manner as United's and that the delay rates produced for both operators are comparable. This does not imply that their operational procedures or priorities are similarly comparable.

10.4 Variation of GTR between BEA1 and BEA2.

Table 4 shows the recorded values of GTR for both plans under twelve input delay distributions. BEA2 is seen to be consistantly less reliable as would be expected from the results of United's simulation. Although their relative performances comply with figures 10 to 15 in appendix 9, in which GTR is plotted against MSST and relative dispersion of separation times, the absolute values bear little resemblance to the results of extrapolating the graphs. Only in the case of figures 14 and 15 at the two high delay rates in each graph, does a reasonable amount of agreement appear in BEA1's case above. The high relative dispersion value of 1.53 in BEA2 does not produce as large a reduction in GTR as the graphs suggest. Similarly, if the percentage of separation times of x minutes or less is used as the basis of comparison, the difference in GTR is again smaller than would be expected. Figures 7, 8 and 9 in appendix 10 show GTR plotted against this percentage for all seven gate plans.

Although there is obviously no linear correlation between the variables, a definite trend of decreasing GTR with increasing frequency of short turnrounds is apparent up to an X axis value of around 15%. This is important since the points within this range result from FOFI or pseudo FOFI gate plans while the seemingly inconsistent points higher in the scale represent LOFI plans. The BEA1 plan does not exhibit an extra-ordinary discontinuity while the BEA2 one is in accord with the inconsistency of UAL4.

In sections 9.3.3 and 9.6.1, one of the design aims of a LOFI plan was stated to be the creation of some very long separation times which would be utilised as overflow gates without disturbing other occupancies. While the number of demands for a gate change may well be high, the total disruption would be minimised. BEA2 and UAL4 have shown that this is precisely what occurs, but that the frequency of demands is so high that the resultant GTR is lower than the true FOFI plan. If these plans had been FOFI ones but retained the same values for MSST, relative dispersion and percentage of separations less than eleven minutes, the expected GTR would be very low and may well be estimated by extrapolation of the first half of the curves shown in figures 7, 8 and 9.

10.5 Effect of gate timetable on frequency and duration of gate holds.
The frequency of gate holds and the total loss in ground time caused by them are shown in table 6 of appendix 10. BEA2 is seen to have the consistently poorer performance as expected from the comparison trends identified using United's plans.

Using United data, the frequency of gate holds was plotted against:-

i) MSST in figures 43-45 of appendix 9.
ii) Relative dispersion of separation times in figures 46-48,
iii) % of separation times less than 11 minutes as shown in figures 52-54.

The results of BEA1 and BEA2 are added to this data, producing figures 10 to 18 of appendix 10. The scatter of points is such that there is no merit in identifying those generated by the same input delay distributions. It is considered sufficient to show the mean of the input distributions. The BEA results are seen to be not inconsistent with the others but the figures should still only be allocated the following interpretations:-

i) The frequency of gate holds tends to decrease with increasing MSST and decreasing relative dispersion of gate separation times.
ii) The alteration of a schedule does not affect the above basic tendancy.
iii) The variation of gate holds with the percentage of separation times less than a specified length is considered to be valuable when studying one flight schedule but the same relationship need not necessarily apply to an altered schedule.

These interpretations can be illustrated by reference to BEA2. Although the frequency of gate holds appears to be high for an MSST value of 46.7 minutes, it is of the correct order and can be accepted as conforming to i) and ii) above. The plots shown in figures 52 to 54 of appendix 9, indicate a gate hold frequency per 100 departures of around 1.6 minimum to about 3.5 maximum should be expected for BEA2 if the same relationship can be applied. Obviously it cannot since these figures are too high by a factor of between 2 and 9. It is considered that one underlying reason for this lies in the considerable difference in the type of flight schedules operated by BEA and UAL.

BEA's operation was seen to be predominantly "hub and spoke" resulting in arrivals being very dependent on prior conditions at the same station for their punctuality. This high element of reactionary delays

10.5 tends to reduce the probability of an early arrival coinciding with a late departure, and creating a gate hold situation. This is emphasised by the fact that United's arrival punctuality is marginally better than BEA's, although the departure performances were seen to be similar.

In addition, the variable time span method of analysing gate timetables limits itself to the busy periods of each gate, and can ignore significant time spans with no planned occupancies. This is of course the intention of the procedure ANALYSE and the utilisation of the 24 hour day is not of interest to it. However, when referring to the percentage of separation times smaller than a specific size, the total number of occupancies in the time span is important. With BEA, the time spans tend to be smaller than United's reflecting its smaller numbers of early morning and late at night turnrounds. In the United plans these tend not to produce short separation times and merely have the effect of decreasing the above percentage. This effect is not present with BEA so it is unrealistic to compare the percentage values and to use them as an estimate of gate hold frequency. For example, the mean time span studied per gate ranges from 966 to 1044 minutes for the United plans, but is only 717 and 704 minutes for BEA1 and BEA2 respectively. Taking the mean United span to be 1000 minutes, a difference of almost 300 minutes per gate exists between the two airlines. Now the mean gate time per aircraft (i.e. separation plus occupancy time)is 110 minutes for BEA2 . This means that the MSST value for BEA2 would not be altered by the addition of three mean occupancy and separation times to each gate, but that the total time span now studied would be comparable with Uniteds.

This results in an extra sixty nine separation times in BEA2, and reduces the percentage of separation times less than eleven minutes in length from 27.6 to 18.9. Although in the right direction, this reduction still does not allow the recorded gate hold data for BEA2, to agree with that plotted for United in figures 52 to 54 of appendix 9. A further reduction would appear necessary.

There appears to be no justification for this until it is noted that a reduction in MSST for BEA2 would result in a better fit of the data relating MSST with GTR and with the frequency of gate holds. This reduction can be brought about in theory by notionally utilising the time periods made available by equalising the analysed spans of BEA2 and the United plans with occupancies having a smaller than mean, total

10.5 gate time. This could reduce the above percentage figure to around 17%. Even this however is not sufficient to make the BEA gate hold data agree with figures 52 to 54.

It is seen from the above that the concept of using the percentage of small separation times as a yardstick for gate hold performance is fraught with difficulty when different flight schedules are being compared and is in fact not considered to be relevant under these circumstances.

10.6 Relationship between departure punctuality and gate hold frequency and duration.

Figures 19 and 21 show the frequency of gate holds plotted against mean delay per departure for BEA1 and BEA2 respectively. The variation of the loss in available ground time due to gate holds with the mean delay is shown in figures 20 and 22. BEA1 is seen not only to be less likely to incur gate holds at low delay rates but also to improve its relative performance with BEA2 as the delay rate increases. This is inconsistent with UAL4 and 5 the United LOFI and FOFI plans respectively, where the plan with the larger number of gate holds at the zero delay condition (UAL4) is less affected by a change in punctuality. It is considered that this is caused by the "hub and spoke" operation of BEA, discussed previously. Although reactionary delays experienced in this type of schedule tend to reduce the number of gate hold situations, the reduction decreases as the mean departure delay increases. This is reasoned below:-

i) An arrival delay of a returning aircraft is composed of three elements:-
   a) original departure delay
   b) reduction or increase in flight time
   c) reduction or increase of ground time at outstation.

ii) When the original delay is small, and the outstation arrival delay is similarly small, there is not normally sufficient operational pressure to warrant the use of substantially increased resources to reduce the ground time for an on-time outstation departure. The flight therefore retains an element of reactionary delay which offsets at least partially any reduction in return flight time. Thus early arrivals back at the main station tend to be reduced and the number of gate holds are small.

10.6 iii) When the original departure is large, the extra outstation resources are justifiable and a quick turnround can be achieved. Thus the delay on return to main station can be considerably less than the original departure delay. However, since the departure delays were generated by conditions at the main station, these are still liable to apply when the reduced delay arrival returns. Its chances of incurring a gate hold are therefore increased. This condition obviously does not apply to reactionary delays in a temporarily disrupted situation such as early morning fog, a situation which the simulation does not attempt to reproduce.

It is submitted that these points are borne out in figure 21 where it is seen that the points above a mean delay rate of five minutes if taken in isolation would provide a correlation line less steep than that shown. This suggests that if the reactionary delay factor were not present, the comparison of BEA1 with BEA2 would provide a greater resemblance to that of UAL4 and UAL5.

10.7 Effect of departure punctuality on GTR within a given gate timetable.

Figures 23 and 24 shown % GTR plotted against departure punctuality expressed as the percentage of flights which depart less than ten minutes late. The reader is referred to the comments in 9.4.6. and 9.6.6 where similar plots for the United plans were discussed.

It is seen from figures 23 and 24 that as with the United schedule, the LOFI plan, BEA2 is such that its reliability is more vulnerable to changes in delay rates than is the FOFI plan.

APPENDIX 10

TABLE	1	Analysis of gate plan BEA1
	2	Analysis of gate plan BEA2
	3	Distribution of separation and occupancy times, BEA1 and 2
	4	Gate Timetable Reliabilities
	5	Departure punctuality BEA1 and 2
	6	Gate holds obtained by simulation
	7	95% Confidence limits of GTR

FIGURE	1	Gate plan BEA1
	2	Gate plan BEA2
	3	Cumulative distribution of separation times BEA1 and 2
	4	Cumulative distribution of occupancy times BEA1 and 2
	5	Histogram of separation times BEA1 and 2
	6	Histogram of occupancy times BEA1 and 2
	7	Variation of GTR with % of separation times 11 minutes
	8	Variation of GTR with % of separation times 11 minutes
	9	Variation of GTR with % of separation times 11 minutes
	10	Variation of gate hold frequency with MSST
	11	Variation of gate hold frequency with MSST
	12	Variation of gate hold frequency with MSST
	13	Variation of gate hold frequency with relative dispersion of separation times
	14	Variation of gate hold frequency with relative dispersion of separation times
	15	Variation of gate hold frequency with relative dispersion of separation times
	16	Variation of gate hold frequency with % separations 11 minutes
	17	Variation of gate hold frequency with % separations 11 minutes
	18	Variation of gate hold frequency with % separations 11 minutes
	19	Variation of gate hold frequency with departure punctuality BEA1
	20	Variation of total time held with departure punctuality BEA1
	21	Variation of gate hold frequency with departure punctuality BEA2
	22	Variation of total time held with departure punctuality BEA2
	23	Variation of GTR with departure punctuality BEA1
	24	Variation of GTR with departure punctuality BEA2

TABLE 1 GATE PLAN BEA 1

GATE	TIME SPAN	NO OF OCCUPANCIES	SEPARATION TIMES		OCCUPANCY TIMES	
			MEAN	STAND DEV	MEAN	STAND DEV
1	1120-2010	5	58.0	20.1	48.0	18.6
2	0700-1920	7	47.1	20.5	52.9	27.6
3	1240-1925	4	36.3	7.4	65.0	52.3
4	0825-2010	4	70.0	45.6	106.3	87.8
5	0815-2105	7	46.4	39.3	63.6	28.0
6	1655-1910	2	37.5	2.5	30.0	0.0
7	0845-2135	6	58.3	35.9	70.0	30.4
8	0840-2335	7	80.0	50.2	47.9	20.3
9	0805-2055	7	55.0	25.1	55.0	25.3
10	0515-2030	8	62.5	24.1	51.9	17.5
11	0940-1925	5	55.0	28.3	62.0	30.4
12	0720-1950	6	53.3	17.0	71.7	40.2
13	0810-2015	7	44.3	25.3	59.3	42.8
14	0740-2100	9	41.7	23.3	47.2	22.9
15	0745-2135	7	64.3	24.1	54.3	11.5
16	0810-2155	7	69.3	25.1	48.6	5.2
17	0740-2210	7	67.9	35.8	56.4	23.3
18	0810-2045	6	67.5	24.3	58.3	17.7
19	0845-1935	5	41.0	16.2	89.0	50.6
20	0850-2210	6	75.8	34.3	57.5	18.7
21	0835-2005	6	55.8	14.0	59.2	27.9
22	0840-2220	7	60.7	21.6	56.4	20.7
23	0910-2315	7	60.0	19.6	60.7	32.8
24	0925-2040	3	136.7	129.7	88.3	41.9
TOTALS		145	59.2	36.9	59.5	34.1

TABLE 2 GATE PLAN BEA 2

GATE	TIME SPAN	NO OF OCCUPANCIES	SEPARATION TIMES		OCCUPANCY TIMES	
			MEAN	STAND DEV	MEAN	STAND DEV
1	1100-1910	5	40.0	18.2	58.0	19.6
2	0845-2010	6	46.7	60.8	67.5	42.5
3	0840-1925	3	170.0	51.2	45.0	0.0
4	0825-2135	6	74.2	83.6	57.5	34.1
5	0740-2215	6	44.2	54.6	101.7	78.5
6	1120-2335	6	50.8	36.7	71.7	45.2
7	0815-1920	5	60.0	69.5	73.0	40.1
8	1245-1900	6	21.7	10.3	40.8	6.7
9	0515-2015	11	29.5	31.0	52.3	16.6
10	0810-2210	8	33.8	30.9	71.3	32.8
11	0630-1925	7	43.6	36.6	67.1	23.7
12	0700-2210	12	21.3	15.3	54.6	22.5
13	0730-1905	11	18.2	12.5	45.0	8.8
14	0745-1950	8	23.1	18.7	67.5	57.7
15		ONLY ONE OCCUPANCY, NEGLECT THIS GATE				
16	0830-2030	6	65.0	48.6	55.0	27.8
17	0810-2045	4	116.3	78.5	72.5	30.5
18	0925-2315	7	30.7	24.4	87.9	41.8
19	0910-2040	1	645.0	-	45.0	-
20	0845-2135	11	24.1	22.8	45.9	12.2
21	0835-2220	5	83.0	109.4	82.0	50.1
22	0840-2155	6	56.7	36.7	75.8	33.7
23	0740-1920	8	24.4	19.8	63.1	39.4
TOTALS		148	46.7	71.6	62.7	37.9

TABLE 3 GATE PLAN OCCUPANCY AND SEPARATION TIME SUMMARY

TIME INTERVALS	BEA 1				BEA 2			
	SEPARATION TIMES		OCCUPANCY TIMES		SEPARATION TIMES		OCCUPANCY TIMES	
(Minutes)	Number	%	Number	%	Number	%	Number	%
0- 9	-	-	-	-	1	0.7	-	-
10-19	10	6.9	-	-	63	42.5	-	-
20-29	10	6.9	-	-	23	15.5	-	-
30-39	20	13.8	23	15.9	9	6.1	21	14.2
40-49	24	16.6	59	40.7	10	6.8	59	39.9
50-59	16	11.0	19	13.1	9	6.1	19	12.8
60-69	19	13.1	9	6.2	7	4.7	10	6.8
70-79	11	7.6	5	3.4	4	2.7	5	3.4
80-89	10	6.9	7	4.8	4	2.7	7	4.7
90-99	12	8.2	3	2.1	0	0.0	2	1.4
100	13	9.0	20	13.8	18	12.2	25	16.8
TOTALS	145		145		148		148	

Unlike most American airlines, it is BEA's practice to schedule their movements on a multiple of five minutes from the hour. The occupancy and separation times are therefore also multiples of five.

The following is the analysis of separation times up to twenty five minutes:

Separation time minutes	Frequency BEA 1	BEA 2
0	0	0
5	0	1
10	3	40
15	7	23
20	3	15
25	7	8

TABLE 4 - GATE TIMETABLE RELIABILITY OBTAINED BY SIMULATION

INPUT DELAY DISTRIBUTION		GATE TIMETABLE RELIABILITY %		NO. OF DAYS SIMULATED	
MEAN	STD. DEV.	BEA 1	BEA 2	BEA 1	BEA 2
10	2	98.1	96.9	31	20
10	5	97.6	95.2	31	20
10	10	95.4	91.3	21	29
10	15	92.4	87.5	12	31
12	2.2	97.8	96.3	12	20
12	5.5	96.4	95.1	12	20
12	11.0	95.5	89.0	12	19
12	16.4	90.9	81.7	12	12
14	2.4	97.4	95.0	12	12
14	5.9	96.1	92.0	12	12
14	11.8	92.5	86.8	12	12
14	17.6	87.7	80.2	12	17

TABLE 5 - DEPARTURE PUNCTUALITY OBTAINED BY SIMULATION

INPUT DELAY DISTRIBUTION		BEA 1			BEA 2		
MEAN	STD. DEV.	MEAN DELAY PER DEP	STD. DEV.	% ⩾ 10 LATE	MEAN DELAY PER DEP	STD. DEV.	% ⩾ 10 LATE
10	2	0.8	3.2	1.9	0.7	3.2	1.8
10	5	1.9	4.5	7.6	2.0	4.4	8.2
10	10	4.2	7.3	19.6	4.4	7.4	20.6
10	15	6.5	10.2	29.6	6.0	9.5	28.2
12	2.2	2.6	3.6	2.8	2.6	3.5	2.5
12	5.5	3.4	5.1	10.8	3.6	5.0	12.3
12	11.0	5.3	7.7	25.2	5.5	7.8	26.2
12	16.4	8.5	11.2	35.6	8.0	10.7	33.8
14	2.4	4.5	3.4	2.6	4.5	3.6	2.9
14	5.9	4.7	6.1	19.2	5.0	5.7	17.9
14	11.8	7.0	9.0	33.5	7.3	9.2	34.6
14	17.6	9.4	12.5	39.8	9.5	12.6	40.9

TABLE 6 GATE HOLDS OBTAINED BY SIMULATION

INPUT DELAY DISTRIBUTIONS		BEA 1			BEA 2		
MEAN	STD DEV	MEAN	LOSS	FREQ	MEAN	LOSS	FREQ
10	2	19.0	0.39	0.02	3.8	0.72	0.19
10	5	13.5	0.55	0.004	3.9	2.33	0.60
10	10	4.8	0.72	0.15	2.9	2.59	0.90
10	15	4.4	1.63	0.37	5.6	6.17	1.10
12	2.2	3.3	0.52	0.16	1.8	0.76	0.41
12	6.5	1.0	0.16	0.16	2.1	1.73	0.82
12	11.0	2.7	1.0	0.37	1.9	2.57	1.36
12	16.4	5.1	3.5	0.7	7.2	10.26	1.42
14	2.4	0	0	0	1.0	0.42	0.42
14	5.9	2.5	0.26	0.11	3.9	2.25	0.58
14	11.8	4.7	1.73	0.37	4.1	5.56	1.36
14	17.6	5.3	3.31	0.63	4.78	7.07	1.48

Key:- MEAN - mean length of hold in minutes

LOSS - number of minutes hold per 100 departures,
i e loss of available ground time per 100 departures

FREQUENCY - number of holds per 100 departures

TABLE 7

95% Confidence Limits of % GTR

Input Distributions		BEA 1		BEA 2	
Mean	S.D.	GTR_L	GTR_U	GTR_L	GTR_U
10	2	97.5	98.7	96.2	97.6
10	5	97.1	98.1	93.9	96.5
10	10	94.3	96.5	90.2	92.4
10	15	90.7	94.1	86.2	88.8
12	2.19	96.6	99.0	95.5	97.1
12	5.48	94.9	97.9	94.1	96.1
12	10.95	93.7	97.3	87.4	90.6
12	16.35	89.2	92.6	77.5	85.9
15	2.36	96.4	98.4	93.9	96.1
15	5.91	95.0	97.2	90.3	93.7
15	11.8	91.2	93.8	84.4	89.2
15	17.6	86.0	89.4	78.3	82.1

See Appendix 9, Table 12 for method of calculation.

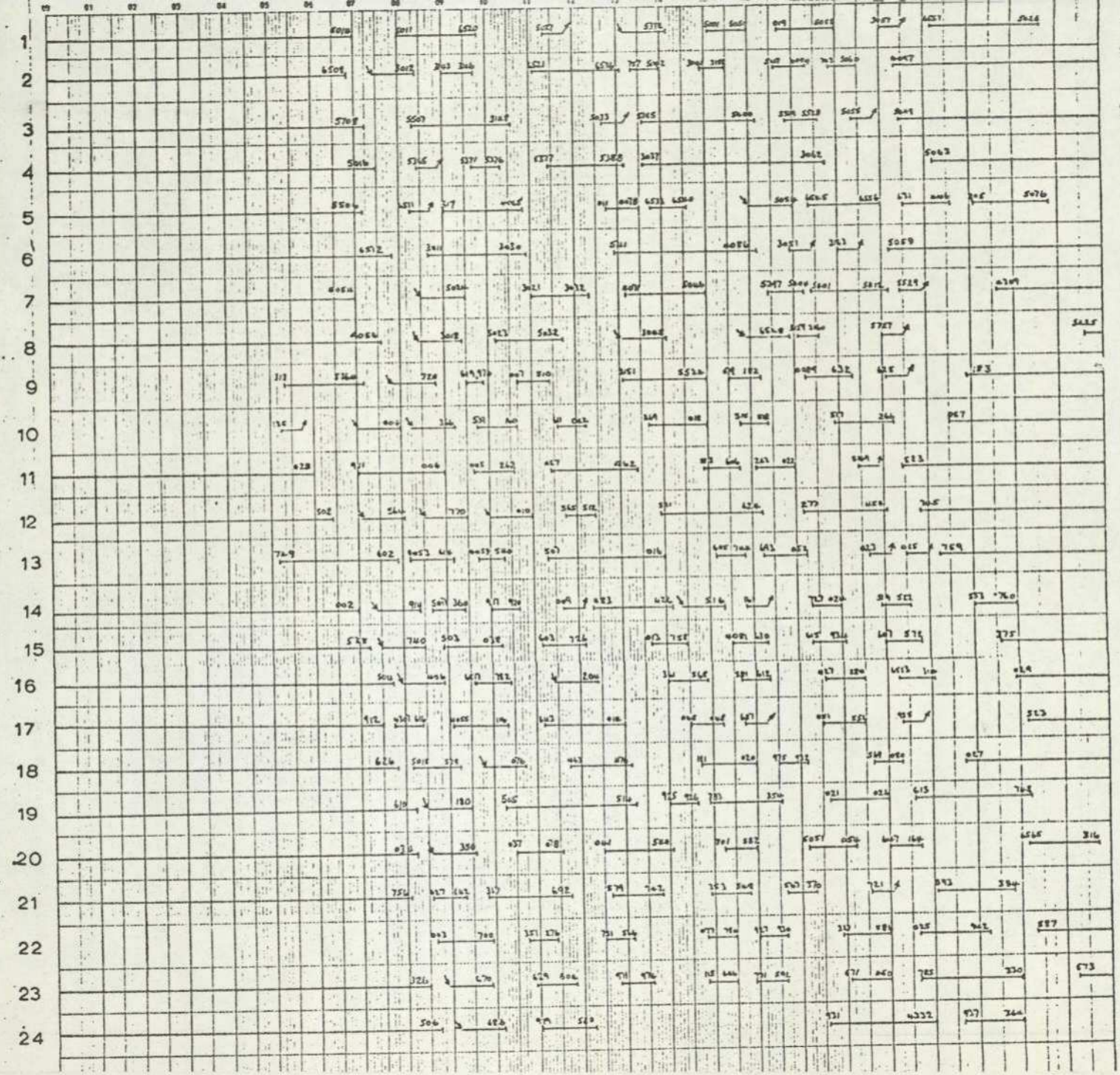


FIGURE 1

GATE PLAN BEA 2

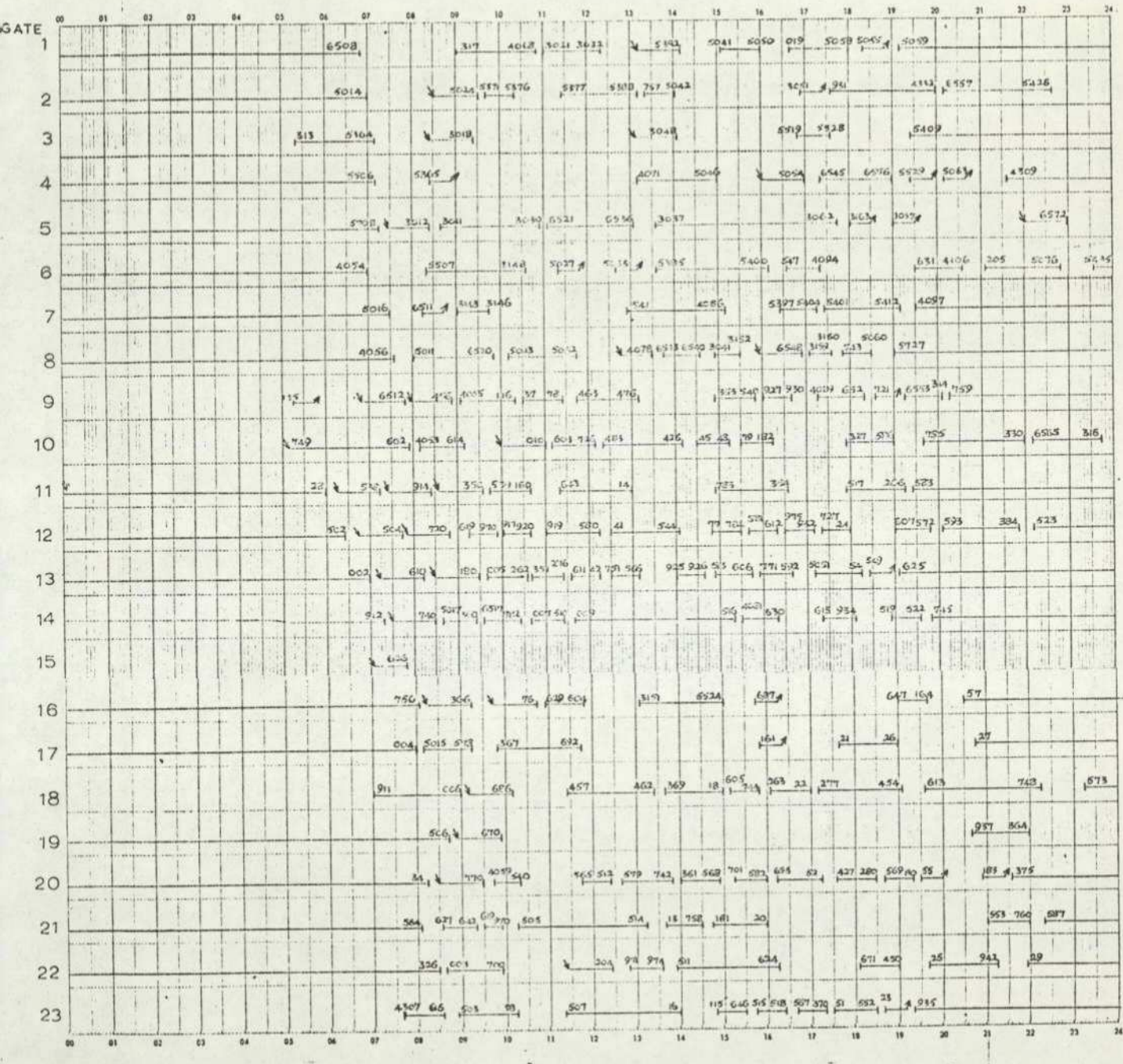


FIGURE 2

CUMULATIVE DISTRIBUTION OF
SEPARATION TIME VALUES.

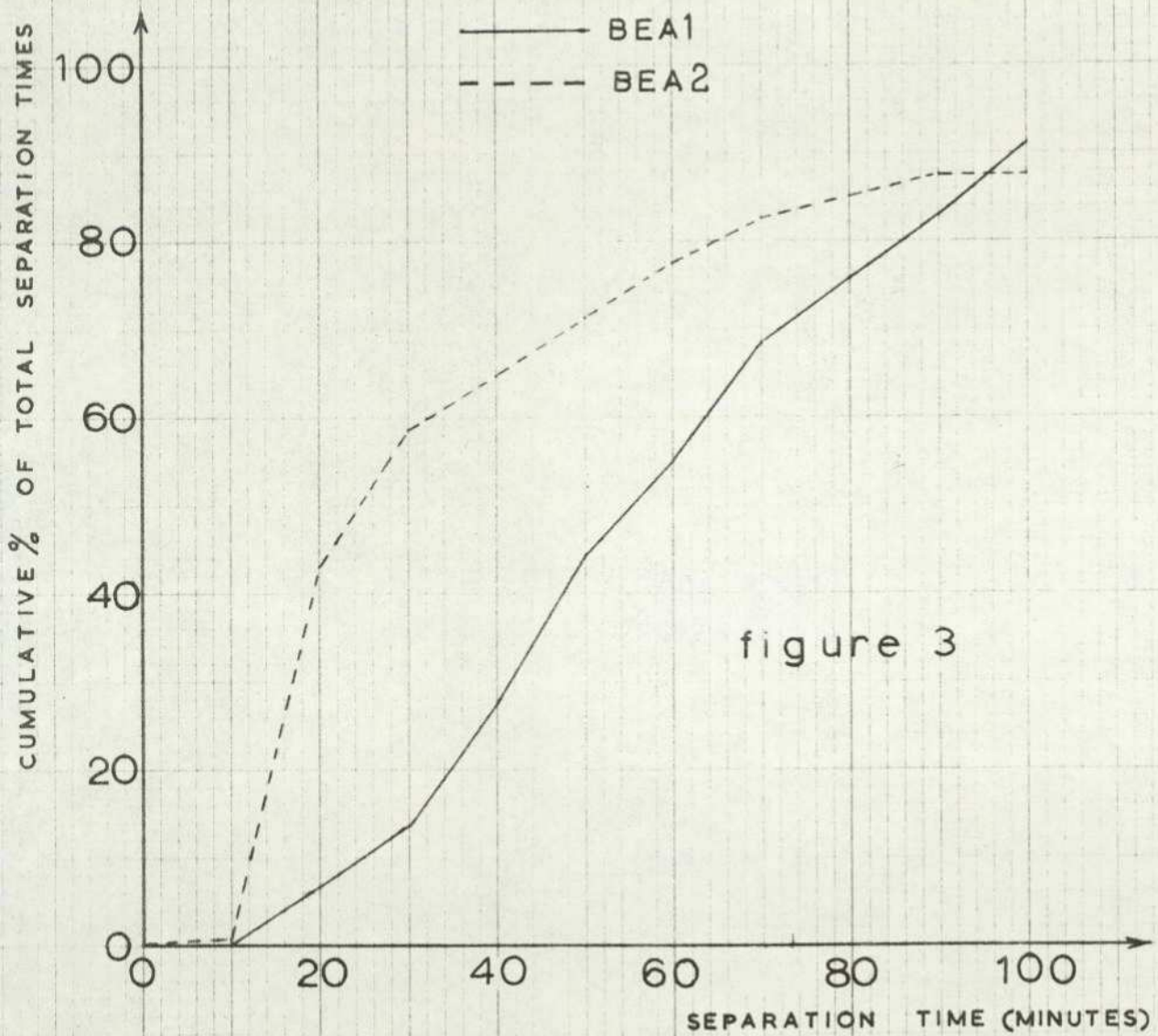


figure 3

CUMULATIVE DISTRIBUTION OF OCCUPANCY TIMES.

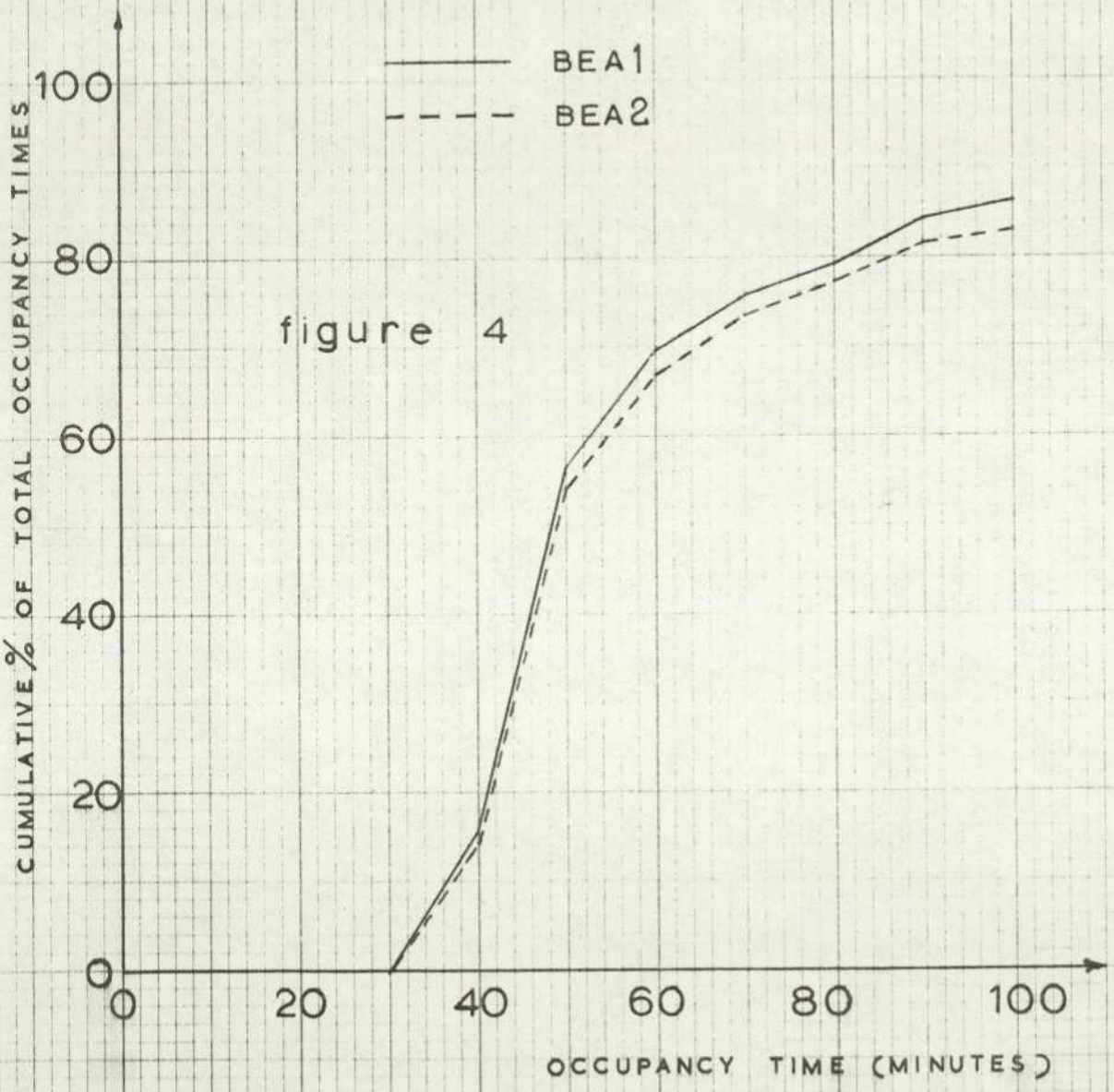


figure 4

DISTRIBUTIONS OF OCCUPANCY AND SEPARATION TIMES.

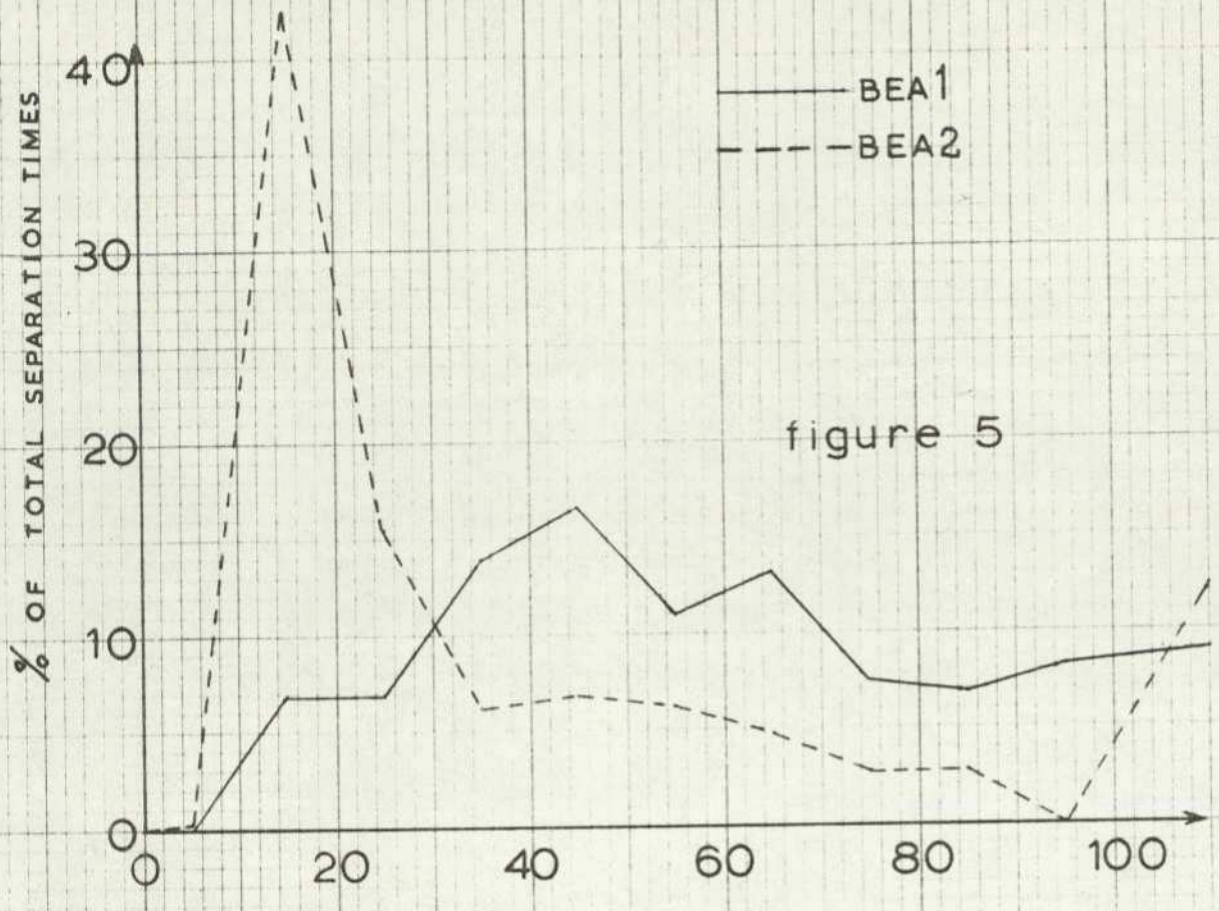


figure 5

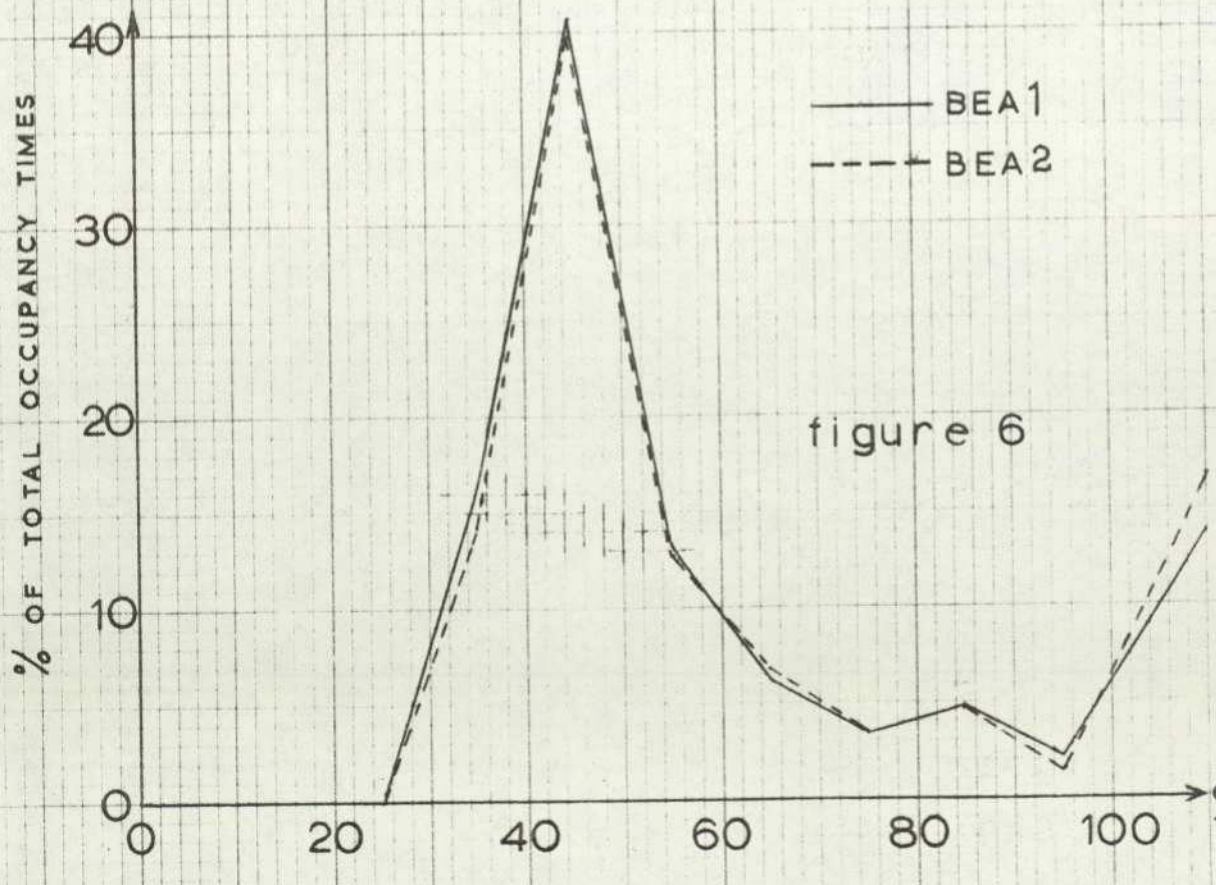


figure 6

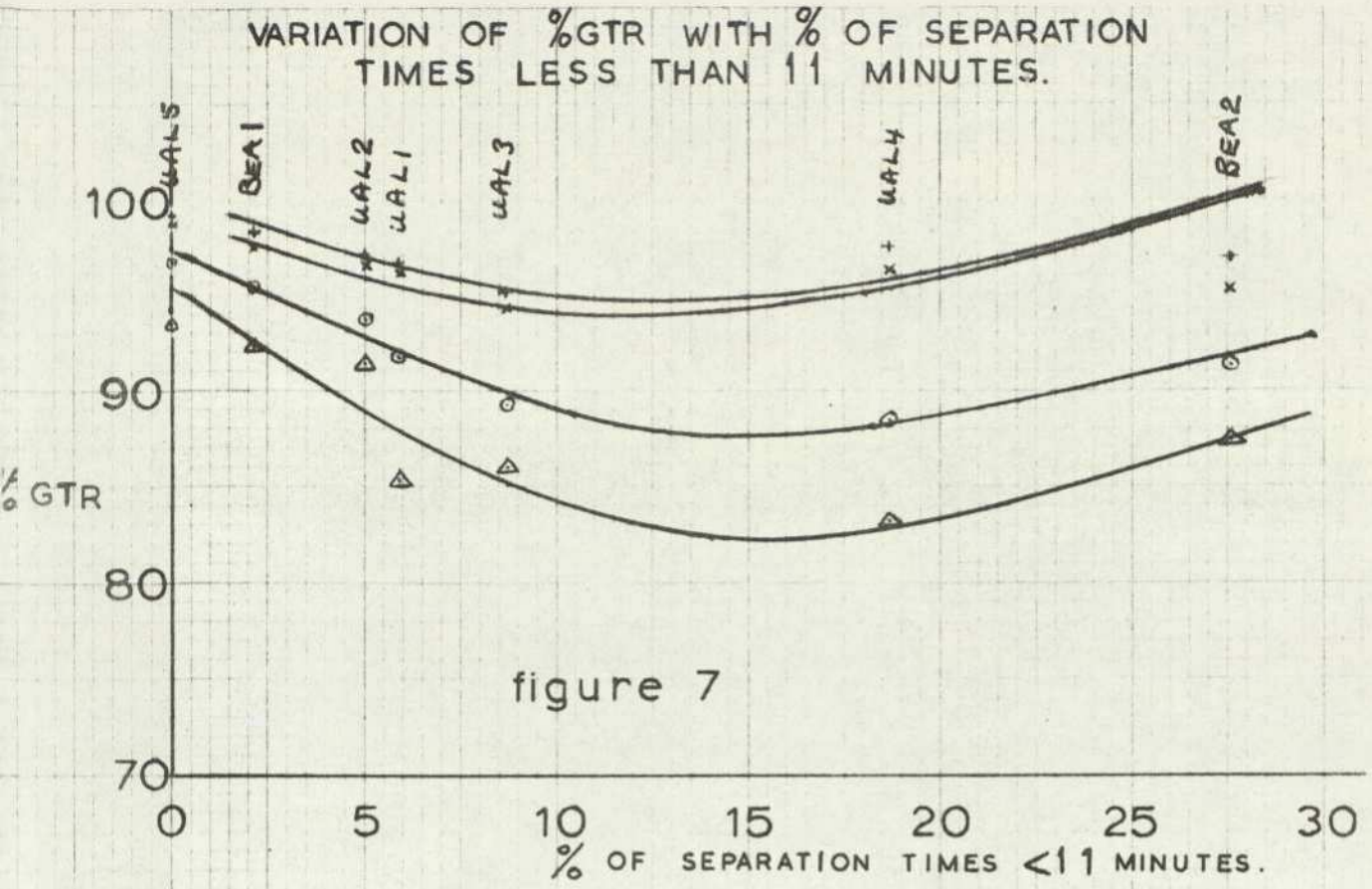


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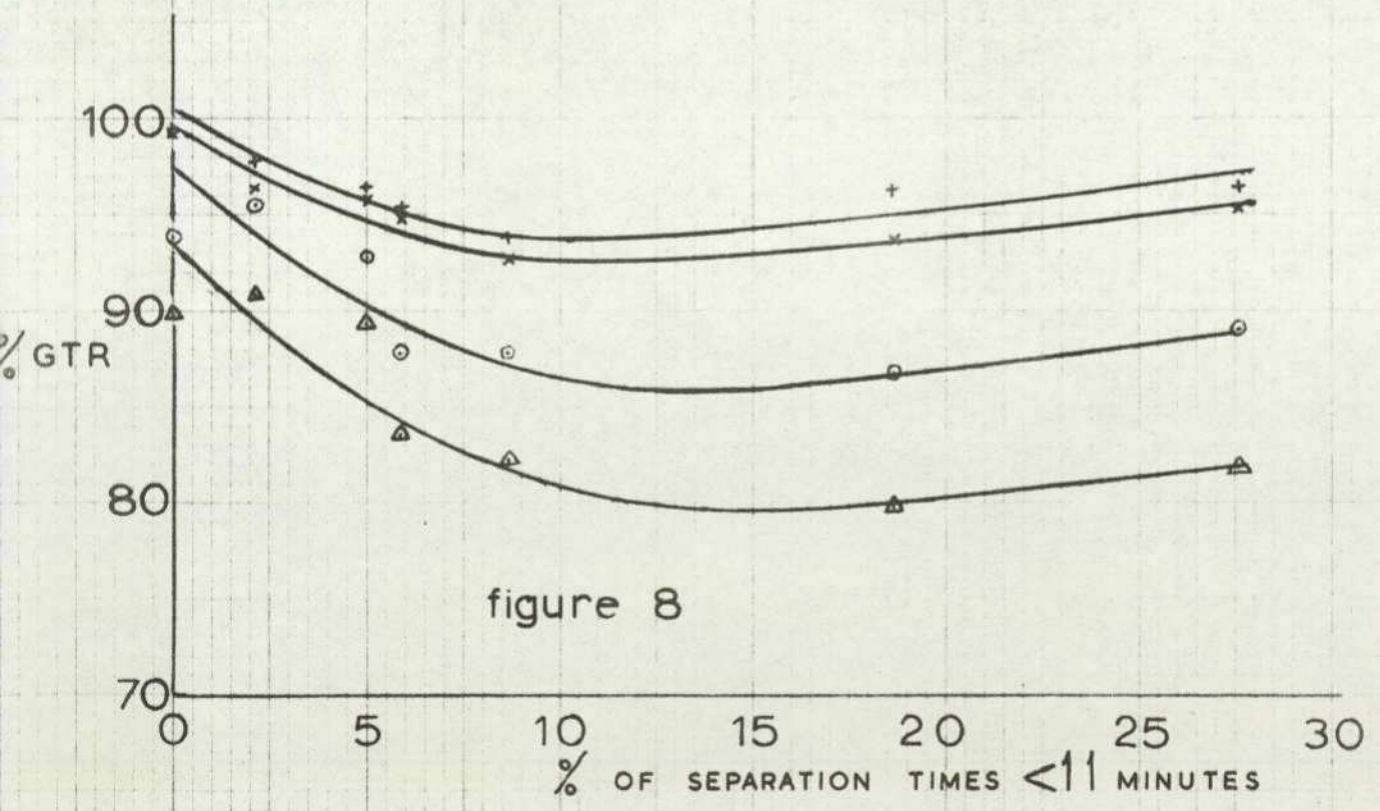
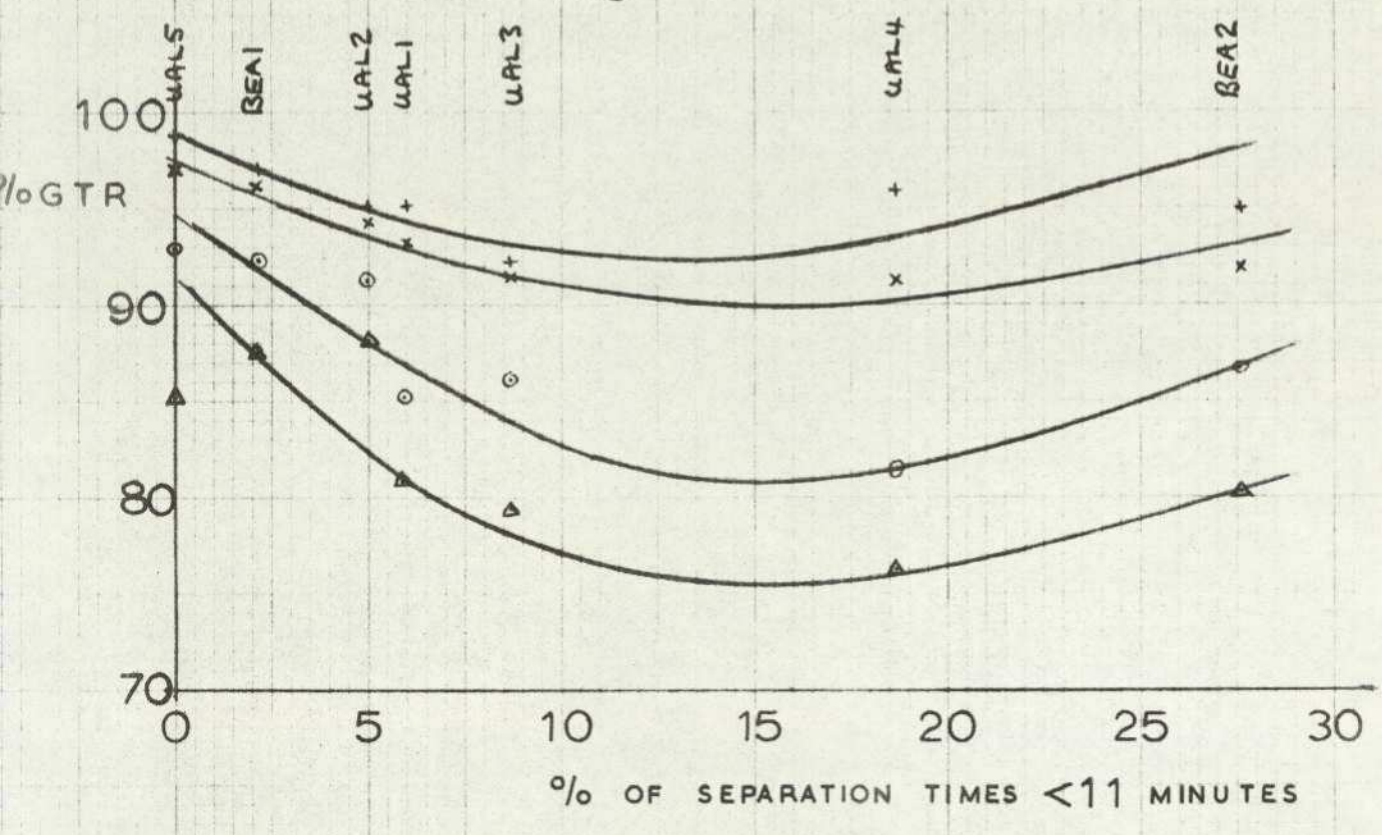


figure 8

VARIATION OF % GTR WITH % OF SEPARATION TIMES LESS THAN 11 MINUTES.

figure 9



VARIATION OF GATE HOLD FREQUENCY
WITH GATE PLAN MSST VALUES

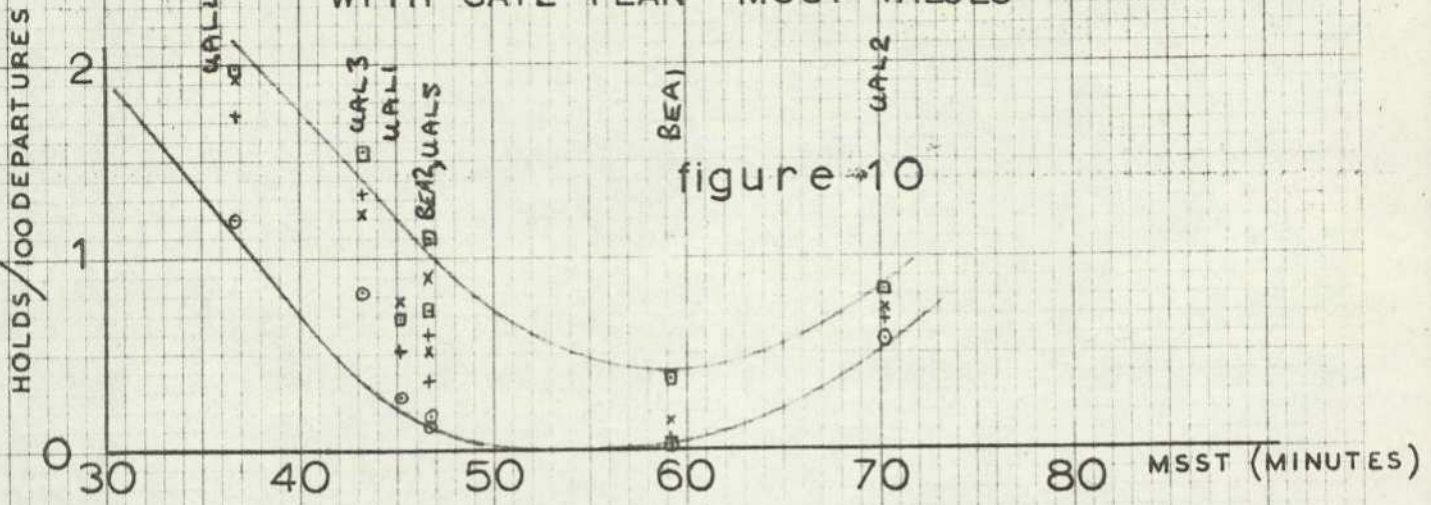


figure 10

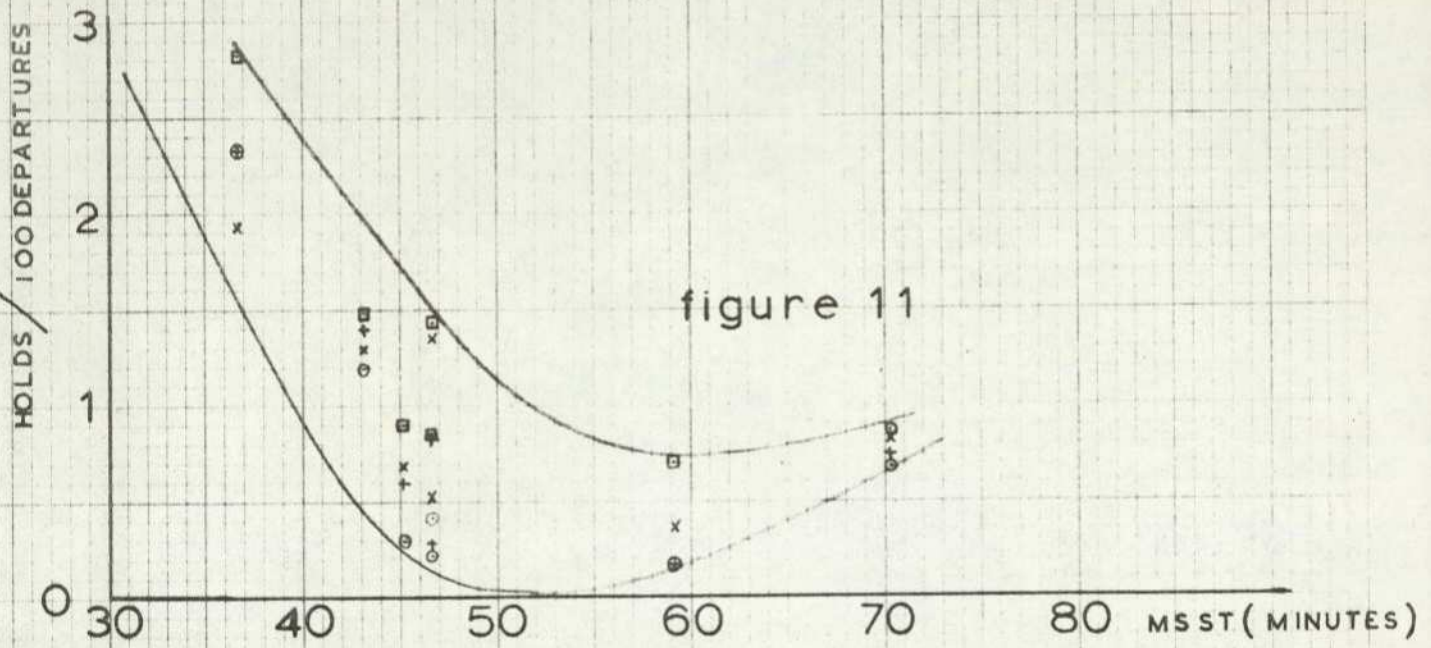


figure 11

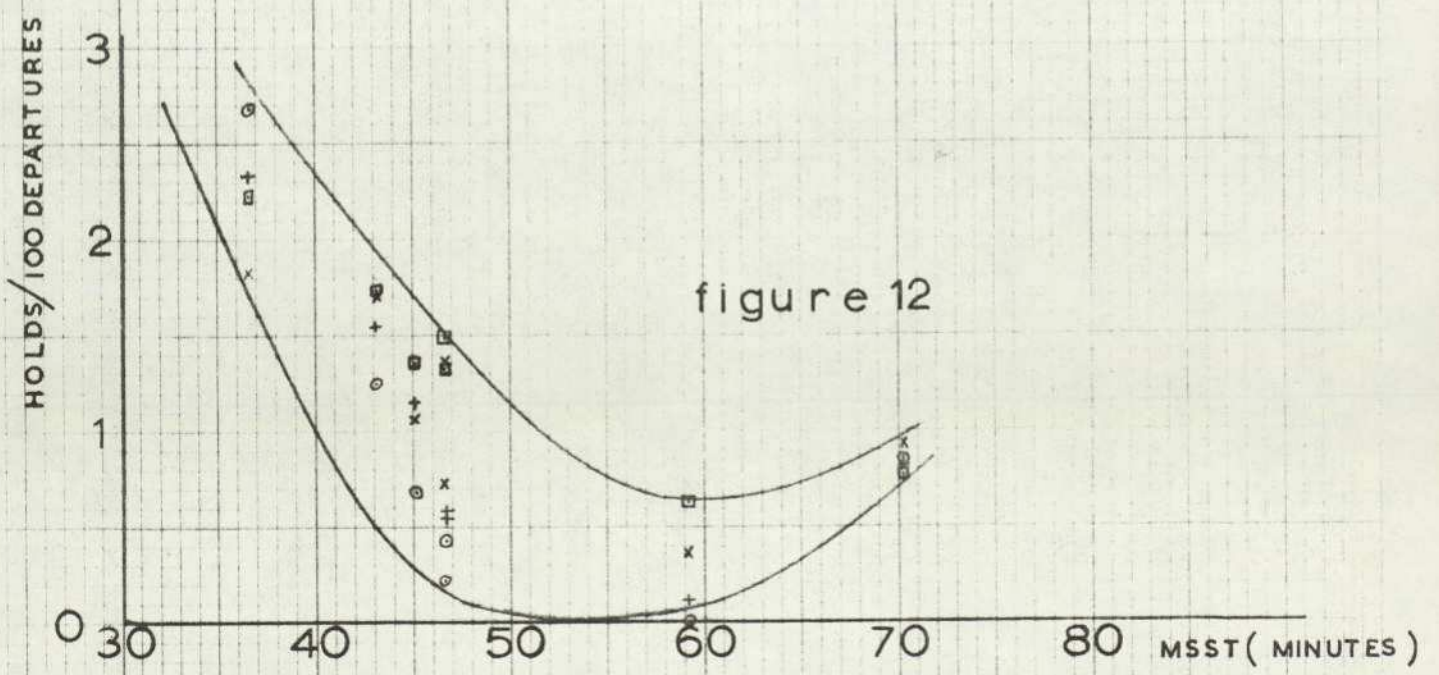


figure 12

VARIATION OF GATE HOLD FREQUENCY WITH RELATIVE DISPERSION OF SEPARATION TIMES.

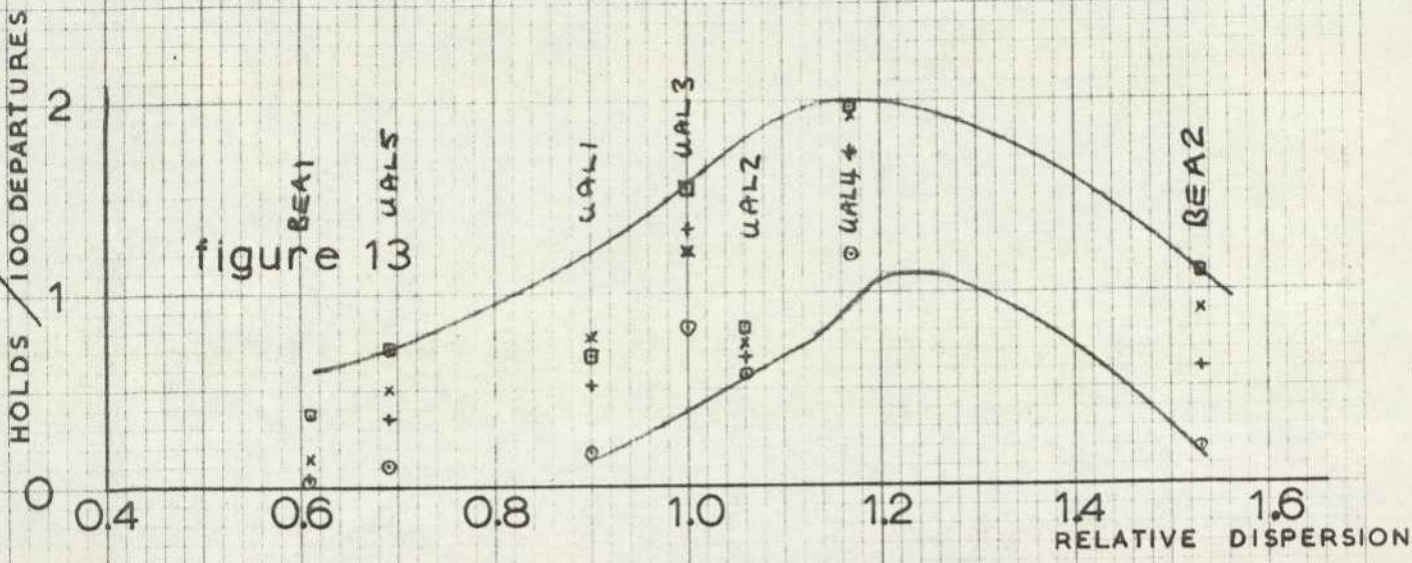


figure 13

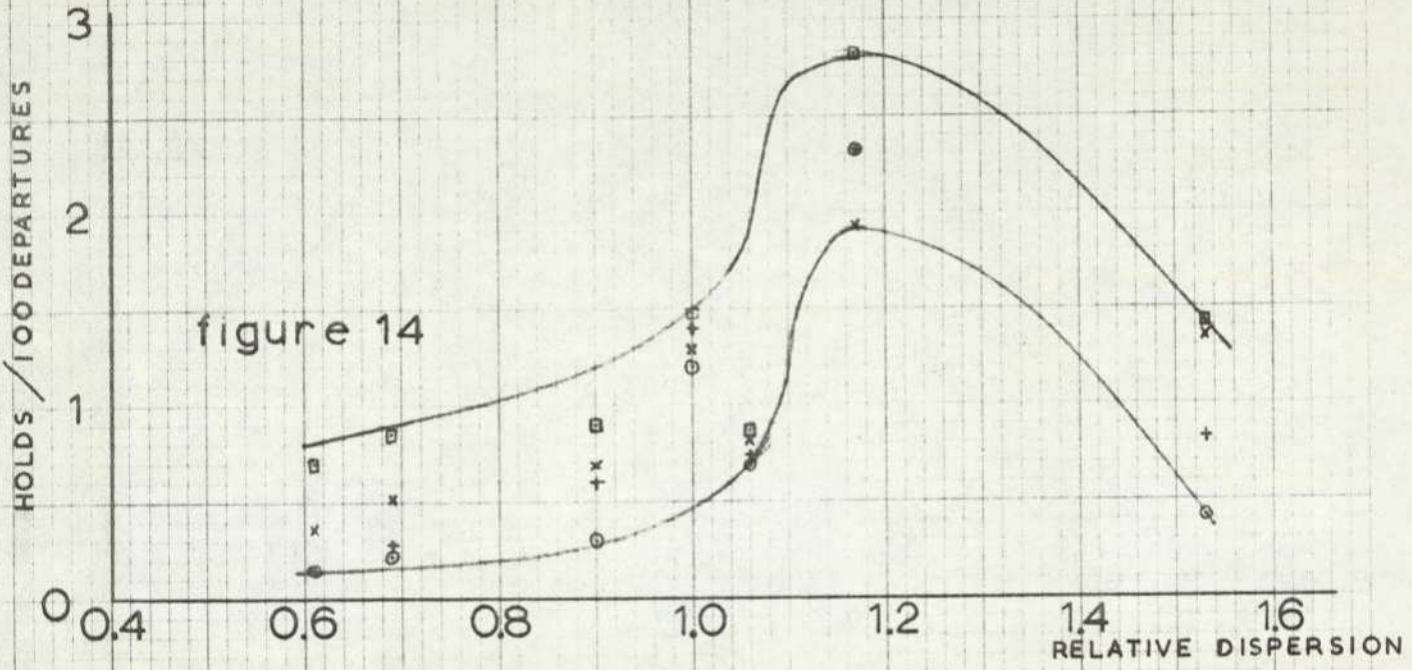


figure 14

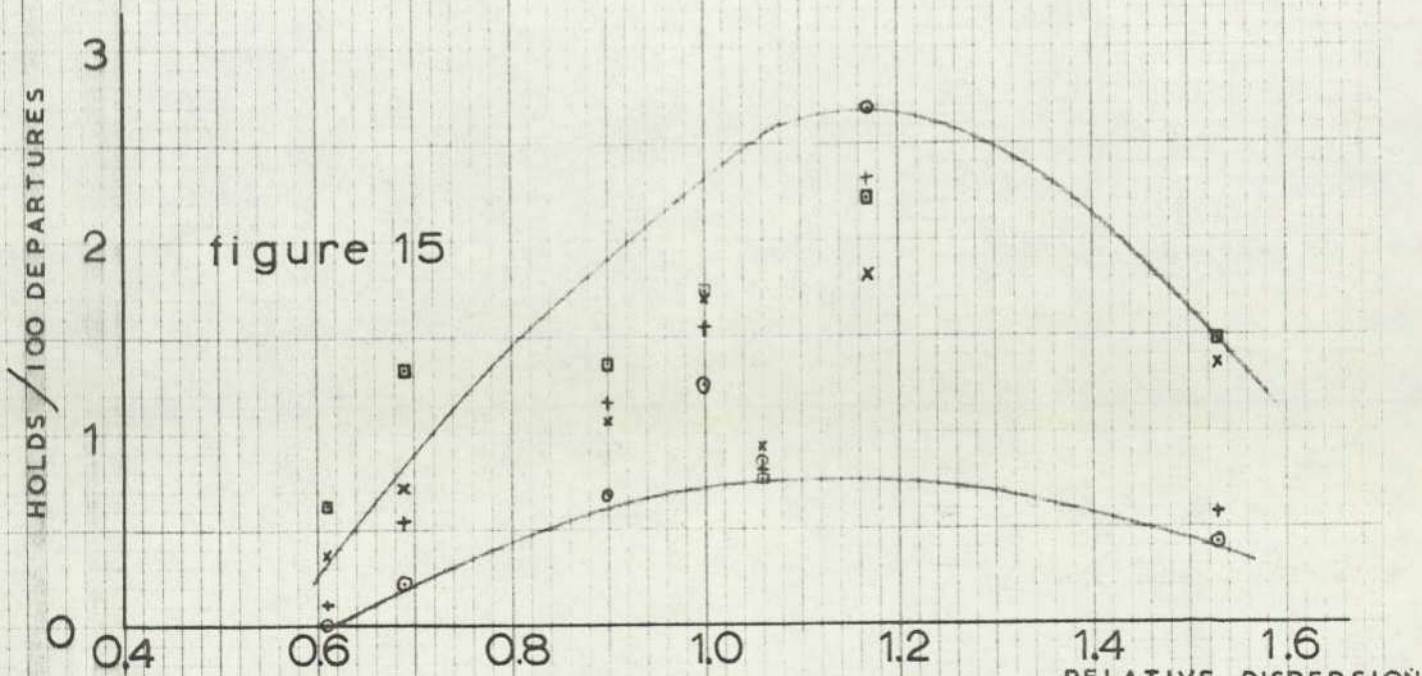


figure 15

VARIATION OF GATE HOLD FREQUENCY WITH
% OF SEPARATION TIMES LESS THAN 11 MINUTES.

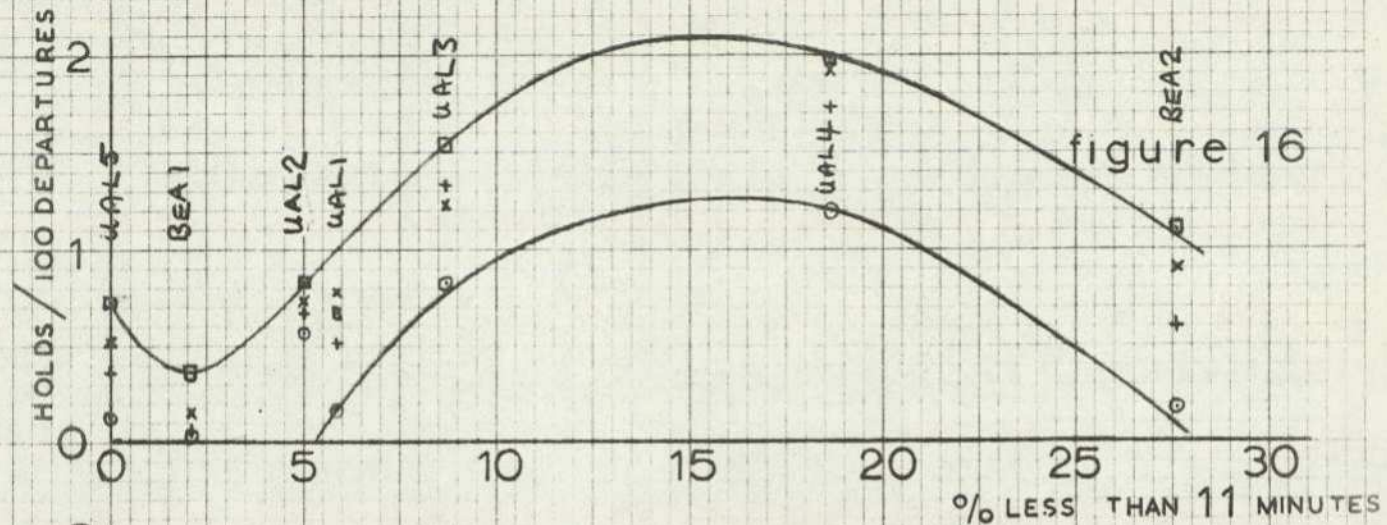


figure 16

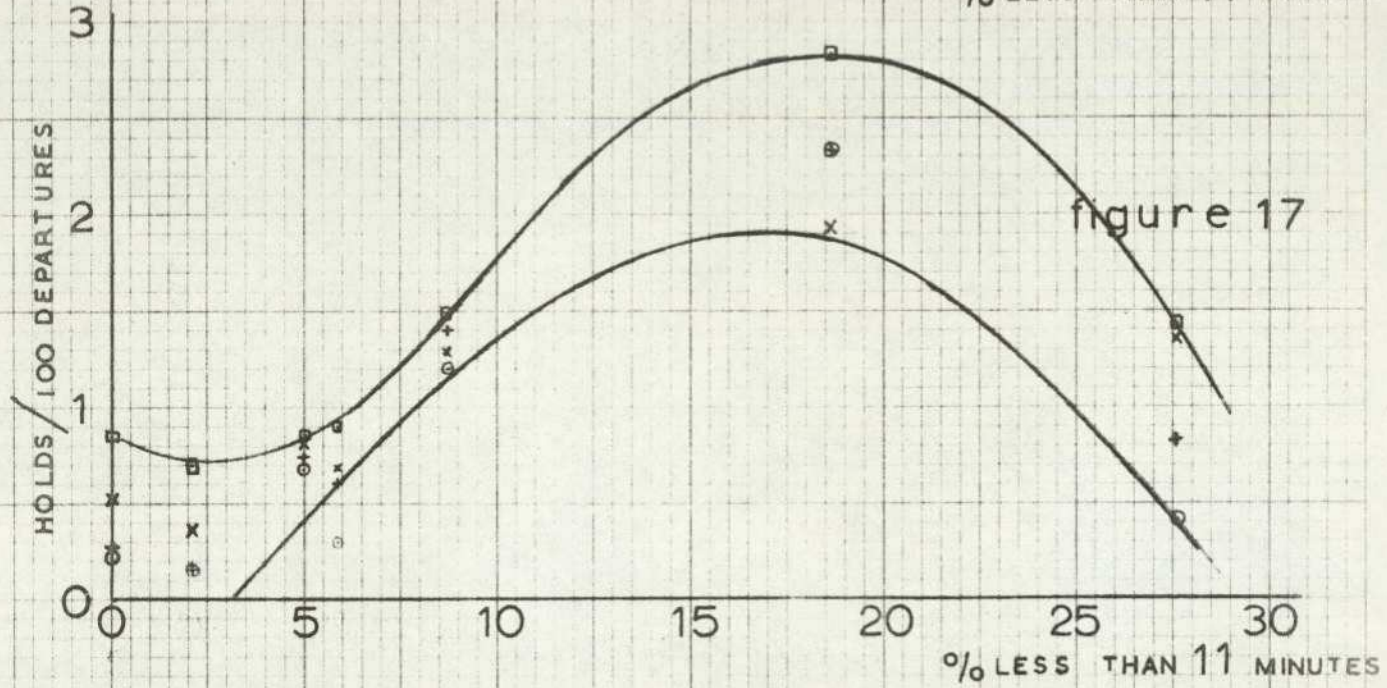


figure 17

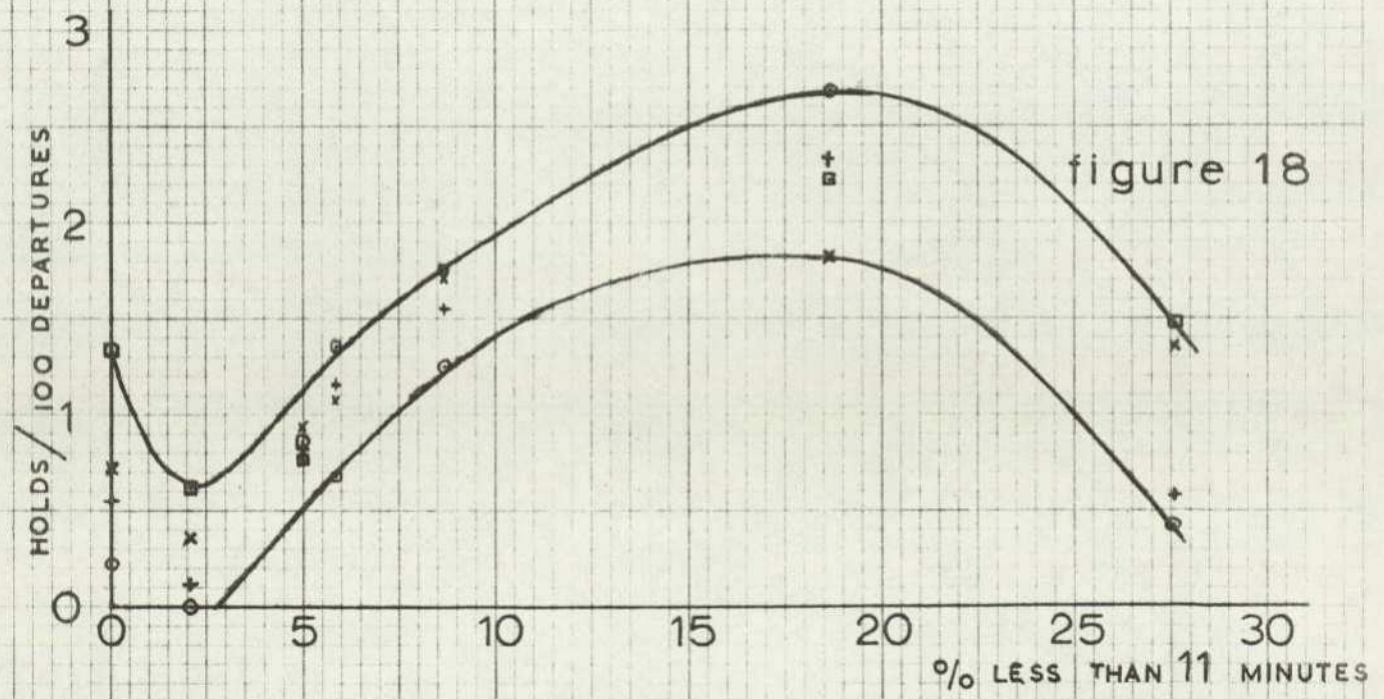


figure 18

VARIATION OF GATE HOLD FREQUENCY WITH DEPARTURE PUNCTUALITY.

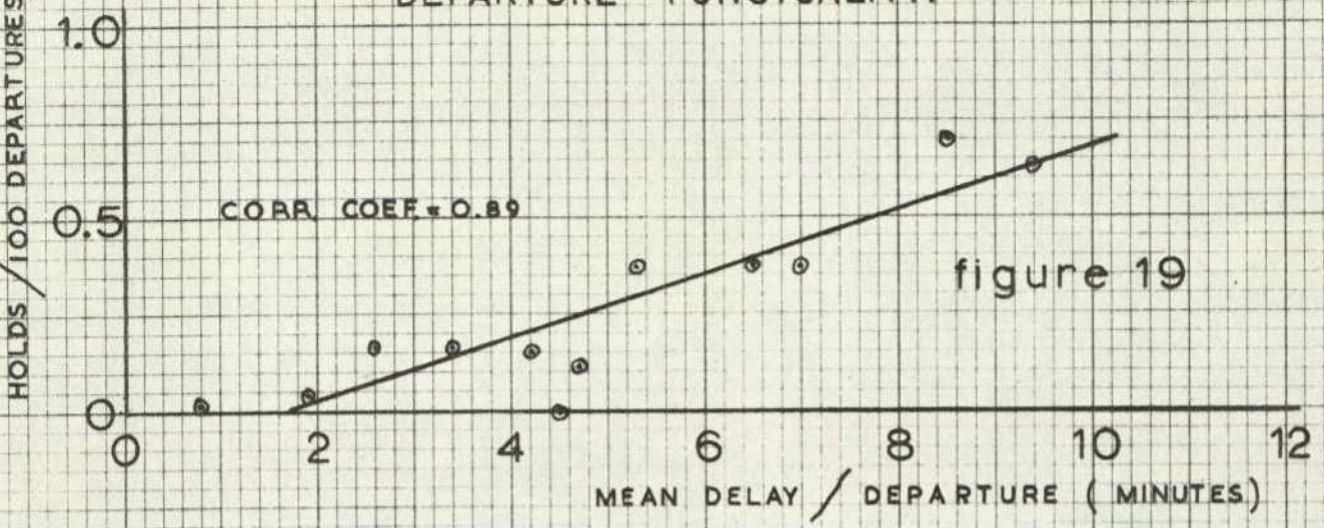


figure 19

VARIATION OF TOTAL TIME HELD WITH DEPARTURE PUNCTUALITY.

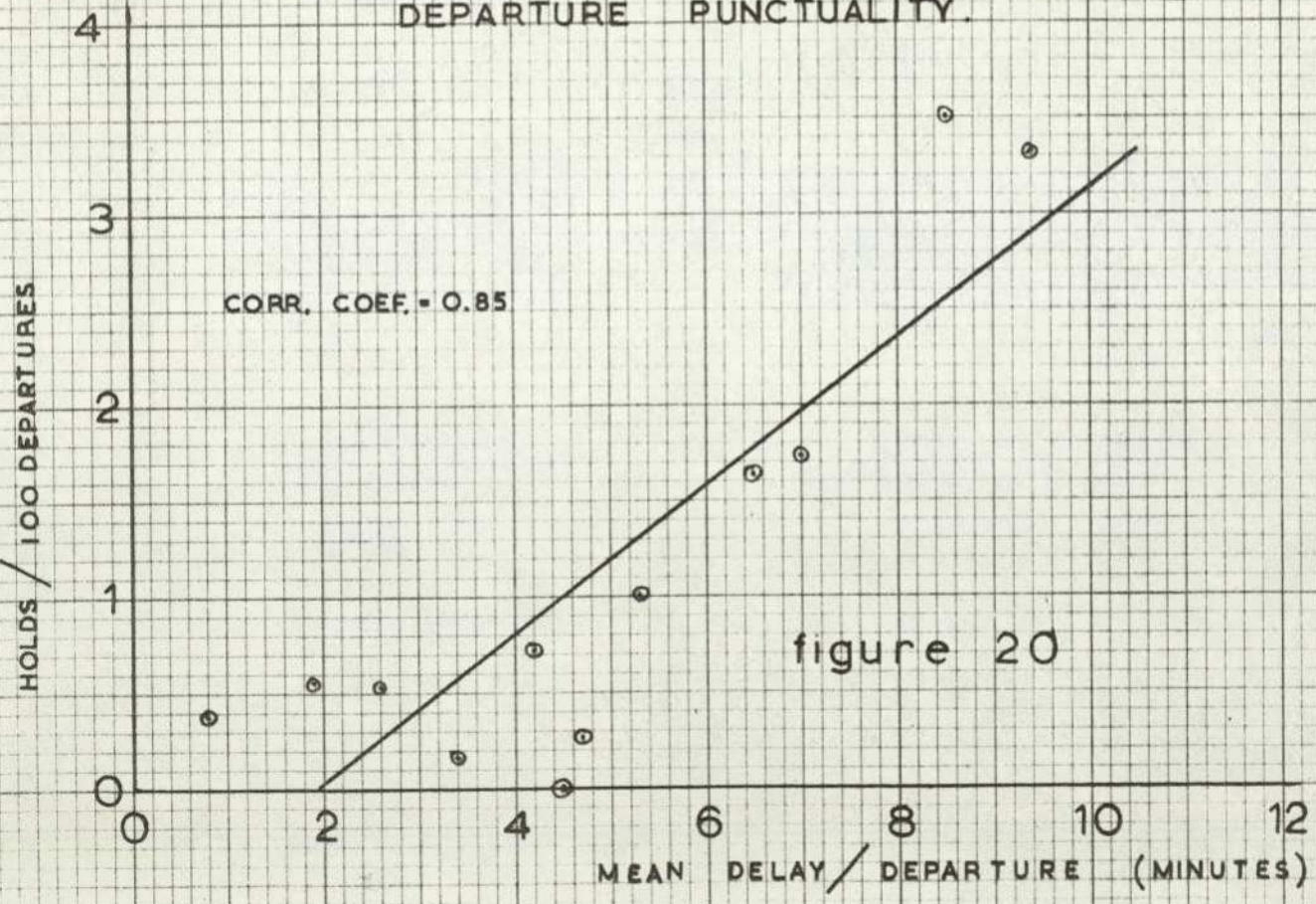


figure 20

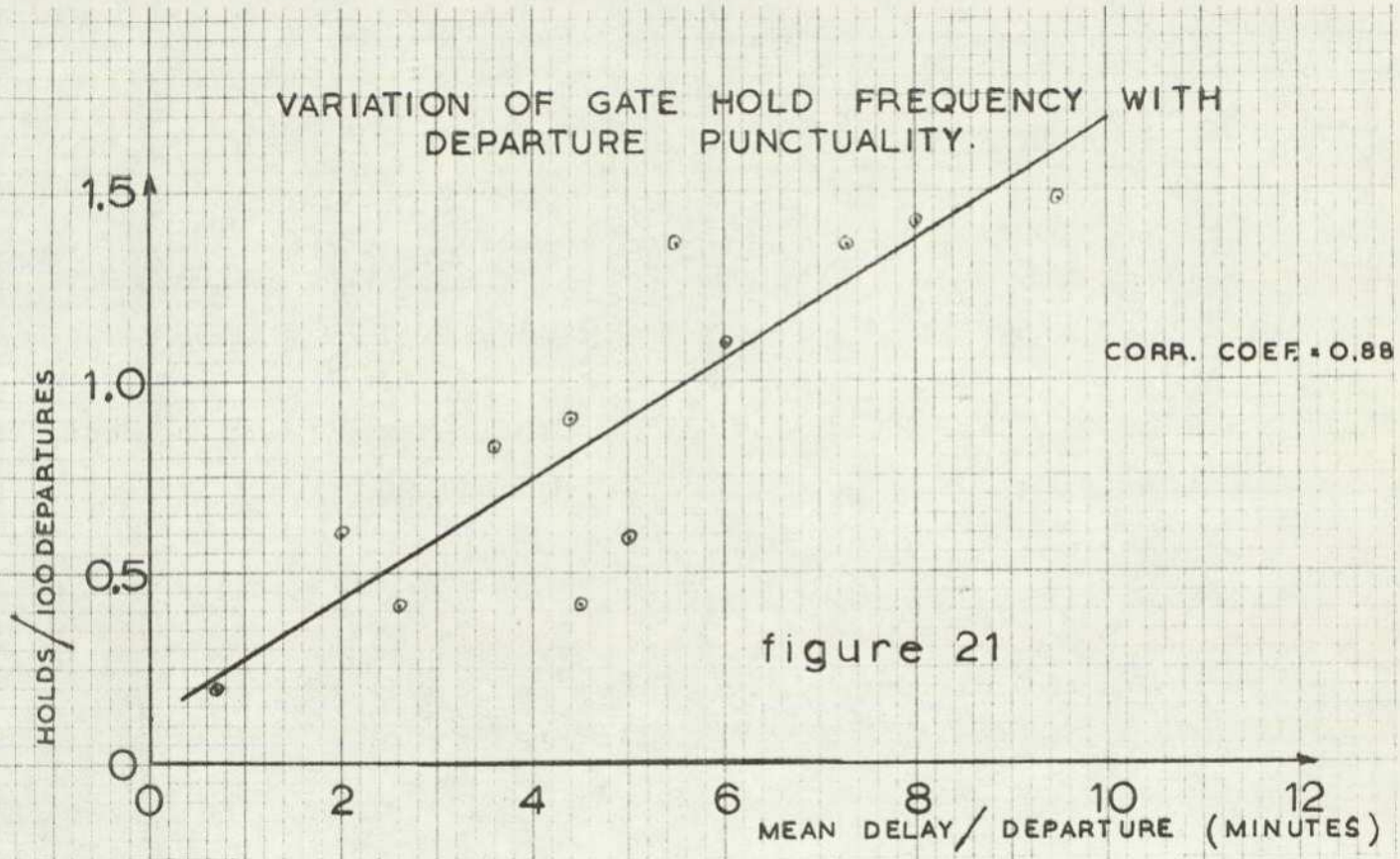


figure 21

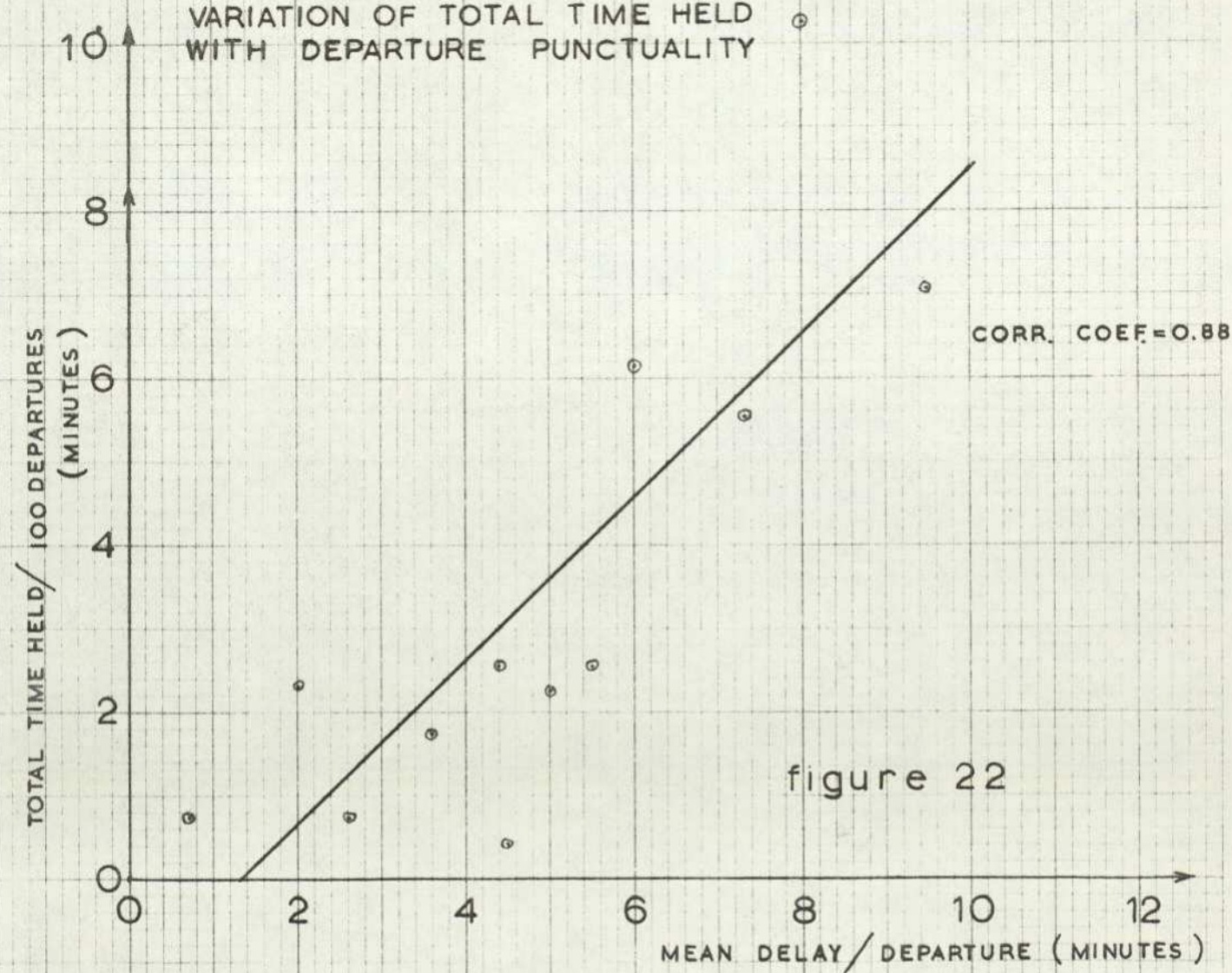


figure 22

VARIATION OF %GTR WITH DEPARTURE PUNCTUALITY WITHIN A GIVEN GATE TIMETABLE.

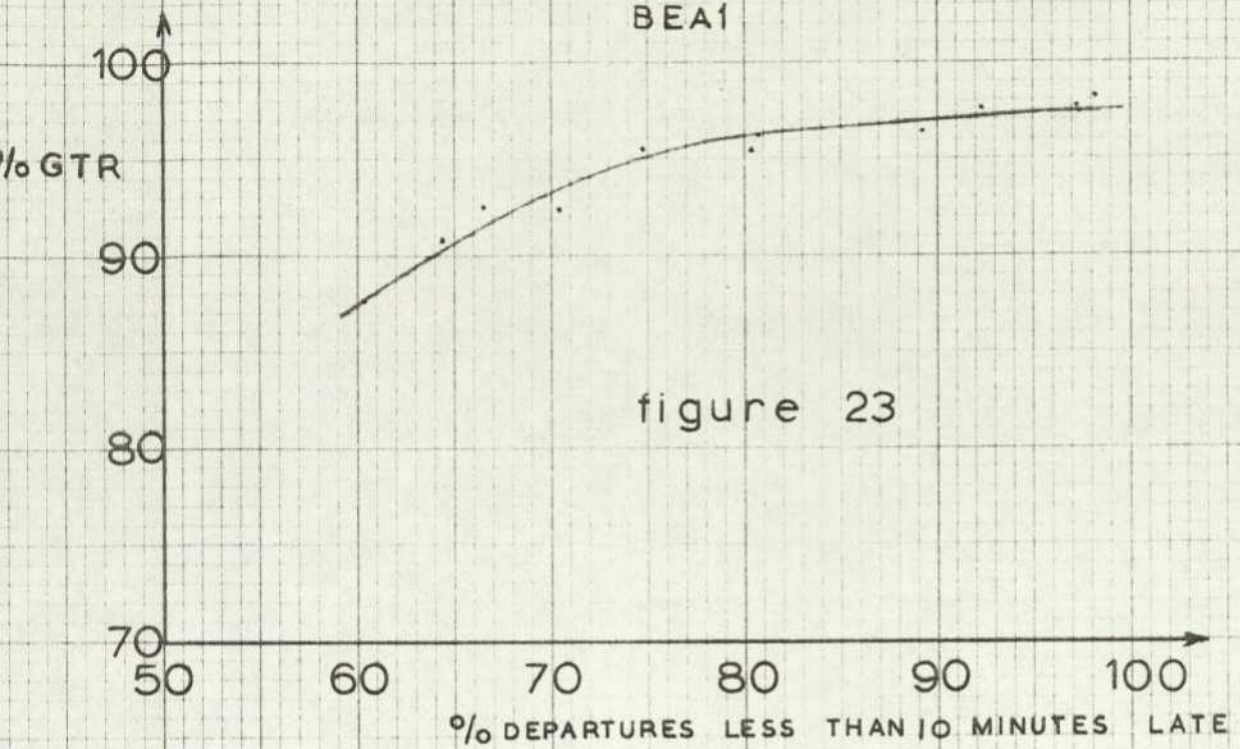


figure 23

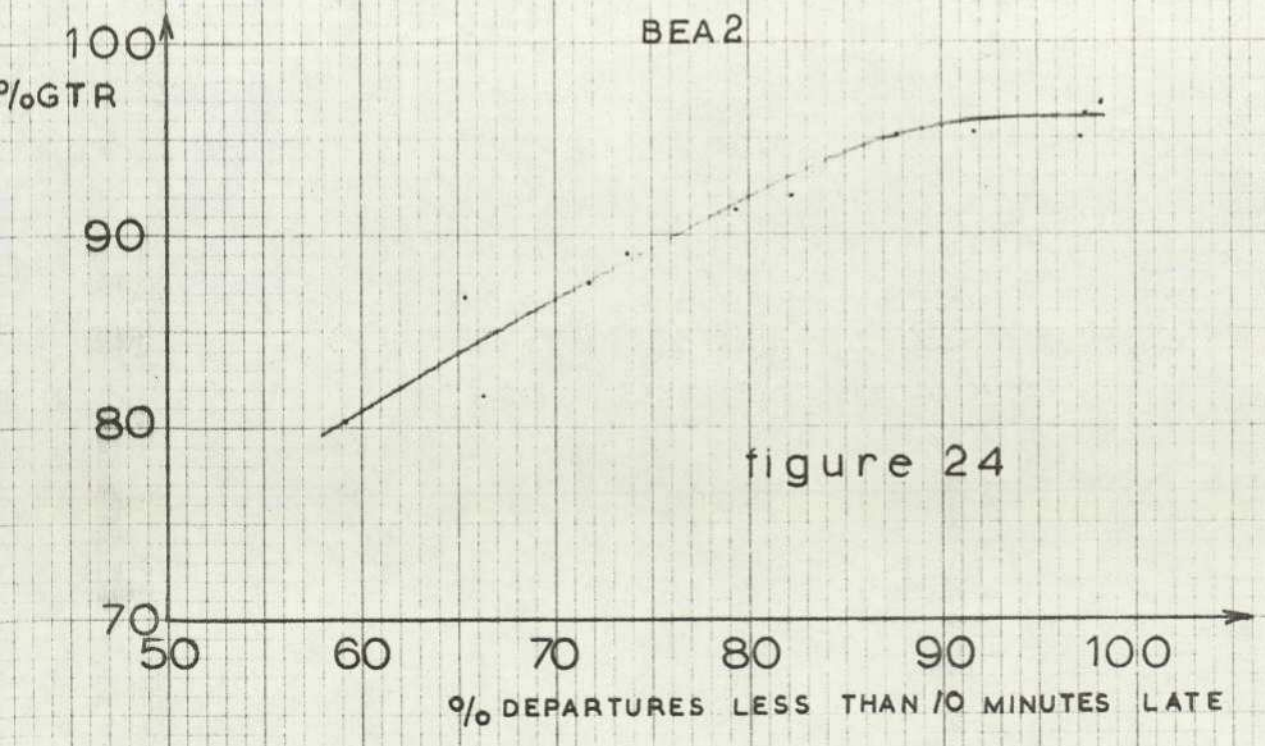


figure 24

SAMPLING ANALYSIS

Comparison of departure delay rates for gate plans
BEA1, 2, UAL 1-5

It is considered that it is sufficient to base the comparison on the mean delay per departure.

It is first assumed for a given input delay condition that the departure delay distribution from each gate plan belong to the same population.

Let this have mean $\bar{D}_p$ minutes delay per departure with $\hat{\sigma}_p$ the estimate of its standard deviation.

$\bar{D}_p$ was given the value of the mean delay for all the plans.
$\hat{\sigma}_p$ was calculated from the formula

$$= \frac{N}{N-1} \cdot \frac{\sum_1^K s^2}{K}$$ where

N = number of departures in each sample
S = standard deviation of each gate plan
K = number of gate plans

Let $\bar{D}_m$ = mean delay per departure of gate plan
$\sigma_{\bar{D}}$ = standard deviation of sample mean delay

The significance ratio $\frac{\bar{D}_p - \bar{D}_m}{\sigma_{\bar{D}}}$ provides an estimate of the deviation of the sample mean from the stated population mean.

Now $\sigma_{\bar{D}} = \frac{1}{\sqrt{N}} \hat{\sigma}_p$

Hence significance ratio (S.R) $= \sqrt{N} \frac{\bar{D}_p - \bar{D}_m}{\hat{\sigma}_p}$

By applying this ratio to the normal distribution it is possible to evaluate the probability (P) that such a deviation or larger can exist between sample mean from population mean. This is given below.

Input Distrib's		$\bar{D}_p$	$\hat{\sigma}_p$	BEA 1		BEA 2		UAL 1		UAL 2		UAL 3		UAL 4		UAL 5	
				S.R.	P	S.R.	P	S.R.	P	S.R.	P	S.R.	P	S.R.	P	S.R.	P
10	2	.65	2.80	2.98	.76	.080	.94	.099	.92	.099	.92	.099	.92	.099	.92	.099	.92
10	5	1.81	4.26	.118	.90	.199	.84	.013	.99	.144	.89	.144	.89	.097	.92	.013	.99
10	10	4.13	7.07	.046	.96	.076	.94	.024	.98	.102	.92	.102	.92	.013	.99	.024	.98
10	15	6.11	9.69	.139	.89	.063	.95	.051	.96	.051	.96	.063	.95	.045	.97	.006	.99
12	2.2	2.44	2.97	.186	.85	.240	.81	.031	.98	.262	.79	.075	.94	.042	.97	.262	.79
12	5.5	3.40	4.76	0	1.0	.188	.85	0	1.0	0	1.00	0	1.00	.066	.94	.117	.90
12	11.0	5.36	7.87	.026	.97	.078	.94	.193	.85	.032	.98	.144	.89	.016	.98	.084	.94
12	16.4	8.14	11.36	.110	.91	.035	.97	.013	.99	.016	.98	.016	.98	.049	.96	.073	.94
14	2.4	4.35	3.49	.149	.88	.149	.88	.063	.95	.192	.85	.064	.95	.045	.97	.050	.96
14	5.9	4.75	6.24	.028	.98	.139	.89	.012	.99	.032	.98	.107	.91	.076	.94	.027	.98
14	11.8	7.06	9.51	.022	.98	.087	.93	.063	.95	.063	.95	.106	.91	.013	.99	.014	.99
14	17.6	9.44	13.09	.011	.99	.019	.98	.098	.92	.064	.95	.095	.92	.039	.97	.018	.98

It can be seen that for each input distribution no significant differences are found between the sample means and the population mean.

Reference: Applied General Statistics
Croxton & Cowden

CHAPTER 11.

STABILITY OF THE SIMULATION.

11.1 Requirement of steady state.

11.2 Rate of achievement of stability.

11.3 Simulation of a number of inter-dependent days.

11.4 Run time of GATESIM.

11. STABILITY OF THE SIMULATION.

It has been shown that GATESIM was designed to evaluate certain features of a gate timetable under controlled delay conditions, over a period of one operating day, or cycle.

11.1 It is necessary to repeat these cycles in the simulation until a steady state result is obtained.

Thirty one cycles were performed initially using small input delays and stability was obtained after about ten. This was expected to increase with the delay rate.

Tables 1 to 7 show the cumulative results of N cycles for each of the seven simulated plans. Tables 8 to 14 show for each value of N, the 95% confidence limits on the cumulative mean.

It is seen that for a given number of cycles, those limits widen as the mean and the relative dispersion of the input distributions are increased. Because of a shortage of computer time, it was necessary to reduce the number of cycles in later runs. Unfortunately this corresponded to the higher delay rate conditions.

11.2 The rate of achievement of stability is also dependent on the timetable being simulated. UAL 1 and 5 appear to take longest, while UAL 4 seems to have stabilised quickly but with the widest limits.

11.3 It must be emphasised that N cycles of GATESIM are used to produce one value of % GTR under a given generated delay situation. This is not to be regarded as a simulation of N separate operating days each with their own simulated value of punctuality and timetable reliability.

Thirty one cycles are not equivalent to a month's airline operation. The latter, though possibly having the same punctuality summary as the stable result of simulating one day, will have suffered considerable variation in delay rates from day to day. The timetable reliability will show a corresponding degree of scatter.

It is therefore not theoretically correct to compare the mean % GTR obtained by observation over a period with that obtained from the simulation, after a similar number of cycles. Ideally, to compare 4 weeks performance with the simulation, it would be necessary to create 28 sets of delay distributions which could generate comparable punctuality rates for each day. After obtaining a stable value of GTR for each day, the actual or adjusted values, together with their scatter, could be compared to actuals.

11.4 The run time of GATESIM obviously depends on the number of cycles to be performed, together with the number of gate and aircraft changes generated.

11.4.1 The University of London Computer Centre, where GATESIM was run on a CDC 6600 machine, applies the following formula to estimate the machine usage of each program. It is an expression of the processor time, memory storage and peripheral equipment usage required for job execution.

$$\text{Usage Units} = \frac{1}{100}\left\{(c + \frac{p}{3})\,(1 + \frac{M}{16}) + \frac{1}{200}\,(R + L + 5B)\right\}$$

Where C = Central Processor Time in Seconds
P = Peripheral Time in Seconds
M = Memory in Units of 1000 words
R = Number of cards read
L = Number of lines printed
B = Number of cards punched.

11.4.2 Several input distributions were simulated during one program execution, so it is not possible to show the run time in Central Processor seconds for each delay and gate plan combination.

However the variation is seen in Table 11.1 below. The CP time, required to perform one pass through one day's operation is shown.

Gate Plan	Input Distribution		% GTR	CP Seconds per pass.
	Mean	S.D.		
UAL 5	14	17.6	85.4	33.4
UAL 5	10	2	99.1	24.6
UAL 4	14	17.6	76.2	44.6
UAL 4	10	2	97.6	23.5
UAL 3	10	2	95.1	25.0
UAL 2	10	2	97.1	27.6
UAL 1	10	2	96.8	29.4
BEA 1	10	2	98.1	14.7
BEA 2	10	15	92.4	25.1

TABLE 11.1

APPENDIX 11.

TABLE	1	Stability of % GTR values UAL 1.
	2	" " " " " UAL 2
	3	" " " " " UAL 3
	4	" " " " " UAL 4
	5	" " " " " UAL 5
	6	" " " " " BEA 1
	7	" " " " " BEA 2
	8	Confidence limits of % GTR values UAL 1
	9	" " " " " " UAL 2
	10	" " " " " " UAL 3
	11	" " " " " " UAL 4
	12	" " " " " " UAL 5
	13	" " " " " " BEA 1
	14	" " " " " " BEA 2

References 1. Applied General Statistics
Croxton and Cowden.

2. Introduction to Statistical Method
Ehrenfeld and Littauer.

3. Statistical Inference
Van Nostrand.

TABLE 1

STABILITY OF SIMULATION RESULTS OF % GTR.

GATE PLAN UAL 1.

Input Distrib.	Mean S.D.	10 2		10 5		10 10		10 15		12 2.19		12 5.48		12 10.95		12 16.35		14 2.36		14 5.91		14 11.8		14 17.6	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
% GTR after 5 days run		96.6	1.17	96.6	0.44	92.2	1.74	84.6	1.77	94.2	1.34	93.0	1.84	84.7	6.76	81.6	4.47	96.3	1.42	94.1	2.40	84.0	3.74	79.7	4.62
6		97.0	1.29	96.4	0.62	92.5	1.76	85.1	1.99	94.6	1.64	93.6	2.43	85.1	6.13	82.2	4.31	96.1	1.35	92.6	4.38	84.4	3.48	79.8	4.24
7		97.4	1.65	96.3	0.59	92.5	1.61	85.3	1.88	94.7	1.51	93.7	2.26	85.7	5.76	82.8	4.24	95.6	1.75	93.0	4.15	84.7	3.25	80.0	3.81
8		97.3	1.54	96.5	0.77	92.7	1.64	85.6	1.91	95.1	1.80	94.0	2.20	85.5	5.35	83.1	4.02	95.4	1.70	92.8	3.87	84.8	2.84	80.1	3.53
9		97.1	1.52	96.3	1.06	92.9	1.61	85.4	1.83	94.7	2.05	93.6	2.35	86.3	5.55	83.3	3.79	95.3	1.62	93.3	3.84	85.3	3.07	80.5	3.62
10		97.3	1.55	96.2	1.02	93.0	1.52	85.4	1.73	94.6	1.98	93.9	2.34	86.5	5.29	82.8	3.85	95.3	1.54	93.4	3.63	85.3	2.92	81.2	4.01
11		97.3	1.48	96.2	1.00	92.6	1.82	85.7	1.86	94.8	2.00	94.0	2.28	87.1	5.39	83.3	4.05							81.2	3.81
12		97.2	1.42	96.1	1.07	92.2	2.26	85.9	1.89	95.1	2.25	94.0	2.18	87.6	5.40	83.2	3.90							80.7	4.09
13		97.3	1.36	96.0	1.10	91.9	2.50	86.3	2.41	95.2	2.18	94.1	2.14	87.7	5.18	83.6	4.07							80.9	4.01
14		97.2	1.31	95.9	1.20	91.7	2.46	86.1	2.40	95.0	2.23	94.1	2.06	87.6	5.00	83.5	3.95							80.7	3.84
15		97.3	1.27	95.7	1.26	91.5	2.46	86.5	2.67	94.8	2.24	94.3	2.09	87.7	4.84									81.0	3.96
16		97.2	1.23	95.8	1.30	91.2	2.75	86.2	2.75	95.1	2.42	94.5	2.14	87.7	4.69										
17		97.1	1.37	96.0	1.41	91.3	2.70	85.9	2.91	94.9	2.54	94.6	2.19	88.0	4.68										
18		97.0	1.34	96.0	1.37	91.2	2.66	85.5	3.45	95.0	2.61	94.7	2.14	88.0	4.55										
19		97.0	1.31	96.0	1.33	91.2	2.59	85.2	3.50	95.0	2.55	94.7	2.10	87.6	4.62										
20		97.1	1.27	96.1	1.41	91.2	2.52	85.3	3.41	95.1	2.52	94.7	2.05	87.8	4.52										
21		97.0	1.24	96.0	1.43	91.3	2.49																		
22		96.9	1.30	96.0	1.42	90.9	2.98																		
23		97.0	1.29	96.0	1.42	91.0	2.99																		
24		97.0	1.24	96.0	1.40	91.0	2.95																		
25		96.9	1.24	96.0	1.38	91.3	3.26																		
26		97.0	1.26	96.1	1.40	91.4	3.23																		
27		97.0	1.29	96.2	1.42	91.6	3.34																		
28		97.1	1.28	96.2	1.41	91.6	3.29																		
29		96.9	1.48	96.3	1.39	91.6	3.23																		
30		97.0	1.46	96.2	1.44	91.7	3.20																		
31		96.8	1.65	96.2	1.42	91.8	3.24																		

M - Mean % GTR

SD - Standard deviation of % GTR distribution.

TABLE 2

Stability of simulation results of % GTR

GATE PLAN UAL 2.

Input Distrib.	Mean / SD	10 / 2		10 / 5		10 / 10		10 / 15		12 / 2.19		12 / 5.48		12 / 10.95		12 / 16.35		14 / 2.36		14 / 5.91		14 / 11.8		14 / 17.6	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
% GTR after 5 Days Run		97.0	0.85	96.3	1.36	93.2	1.28	91.9	2.87	95.9	1.23	95.5	1.43	92.2	1.79	89.3	2.44	95.6	2.78	94.8	2.67	92.1	0.90	87.4	2.70
	6	96.9	0.77	96.6	1.39	93.0	1.29	90.7	3.94	96.1	1.18	95.5	1.28	91.8	1.95	89.3	2.18	95.7	2.50	94.8	2.39	92.0	0.84	87.8	2.66
	7	97.0	0.71	96.7	1.32	93.1	1.23	91.3	3.93	95.9	1.15	95.4	1.17	91.9	1.80	88.8	2.46	96.0	2.43	94.5	2.29	91.5	1.60	88.2	2.63
	8	97.0	0.66	96.9	1.28	93.2	1.14	91.4	3.65	96.2	1.43	95.5	1.12	92.2	2.00	88.8	2.28	96.0	2.25	94.6	2.12	91.3	1.55	88.3	2.54
	9	96.9	0.68	96.9	1.20	93.5	1.36	91.2	3.47	96.4	1.46	95.4	1.11	92.2	1.84	89.6	3.27	95.6	2.51	94.4	2.02	91.6	1.76	88.2	2.50
	10	96.9	0.67	96.8	1.22	93.9	1.79	90.6	3.75	96.5	1.41	95.3	1.13	92.6	2.14	89.4	3.14	95.1	2.81	94.6	1.98	91.6	1.67	88.5	2.55
	11	97.0	0.66	96.7	1.17	93.9	1.73	90.9	3.69	96.4	1.40	95.4	1.10	92.5	2.05	89.2	3.06	95.2	2.69	94.6	1.88	91.2	1.88	88.3	2.53
	12	96.8	0.74	96.7	1.12	93.9	1.66	90.7	3.56	96.4	1.32	95.5	1.20	92.4	2.04	89.1	2.95	95.2	2.57	94.4	1.89	91.3	2.10	88.2	2.42
	13	96.7	0.95	96.8	1.08	93.9	1.60	90.9	3.45	96.4	1.27	95.7	1.33	92.3	2.00	89.0	2.83	95.2	2.46	94.4	1.81	91.3	2.03		
	14	96.8	0.97	96.8	1.05	93.8	1.58	91.0	3.34	96.3	1.23	95.7	1.28	92.4	1.91	88.9	2.74	95.4	2.48	95.4	1.85	91.3	1.96		
	15	96.9	0.99	96.9	1.16	93.7	1.63	91.0	3.22	96.4	1.21	95.7	1.24	92.5	1.86	89.3	3.03	95.4	2.39	94.7	1.83				
	16	96.9	1.00	97.1	1.19	93.6	1.63	90.8	3.21	96.4	1.18	95.8	1.39	92.7	1.96	89.3	2.93	95.3	2.41	94.5	1.85				
	17	97.0	1.00	97.0	1.15	93.6	1.58	90.7	3.18	96.3	1.14	96.0	1.44			89.5	2.90	95.1	2.40						
	18	97.0	1.00	96.8	1.42	93.6	1.55	90.8	3.18	96.4	1.17	96.0	1.41			89.6	2.85	95.1	2.33						
	19	97.1	1.12	96.8	1.38	93.8	1.66	91.0	3.15	96.4	1.14	95.9	1.47			89.3	3.01	95.2	2.27						
	20	97.1	1.10	96.8	1.36	93.8	1.63	90.9	3.09	96.5	1.15	95.9	1.45			89.3	2.94	95.2	2.22						
	21	97.1	1.08	96.8	1.34	93.9	1.61	91.0	3.02	96.4	1.18	95.9	1.42												
	22	97.1	1.09	96.8	1.33	93.9	1.59	91.1	3.05	96.5	1.17	95.8	1.48												
	23	97.1	1.07	96.8	1.30	93.9	1.56	91.1	2.98	96.5	1.22	95.8	1.46												
	24	97.2	1.12	96.7	1.54	93.9	1.54	91.3	2.98	96.4	1.54	95.9	1.49												
	25	97.3	1.23	96.7	1.55	93.9	1.56	91.3	2.93	96.4	1.52	95.8	1.48												
	26	97.3	1.20	96.7	1.54	94.0	1.70	91.2	2.90	96.5	1.52														
	27	97.3	1.23	96.7	1.51	94.0	1.67	91.3	2.85	96.5	1.51														
	28	97.3	1.20	96.7	1.49	94.0	1.64	91.3	2.80	96.5	1.50														
	29	97.2	1.31	96.7	1.46	94.0	1.62	91.4	2.79	96.3	1.57														
	30	97.1	1.33	96.7	1.45	93.8	1.73	91.4	2.75	96.4	1.55														
	31	97.1	1.30	96.7	1.46	93.9	1.70			96.3	1.52														

TABLE 3

Stability of simulation results of % GTR

GATE PLAN UAL 3

Input mean / Distrib. SD	10 / 2		10 / 5		10 / 10		10 / 15		12 / 2.19		12 / 5.48		12 / 10.95		12 / 16.35		14 / 2.36		14 / 5.91		14 / 11.8		14 / 17.6	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
% GTR after 5 days run	94.4	1.09	93.8	0.43	87.8	4.24	86.8	0.95	93.8	2.04	91.4	1.78	90.4	2.72	84.0	3.25	92.5	1.63	91.6	3.31	86.2	2.55	80.7	2.13
6	94.8	1.31	93.6	0.61	88.9	4.58	86.0	2.11	93.8	1.83	91.8	1.80	90.2	2.52	84.3	2.99	92.7	1.53	91.3	3.07	85.8	2.51	80.5	1.96
7	95.0	1.35	93.8	0.80	88.1	4.68	85.9	1.95	93.9	1.75	91.8	1.67	90.2	2.30	83.8	2.93	92.9	1.52	91.5	2.84	85.7	2.30	80.4	1.82
8	94.6	1.57	93.9	0.77	88.1	4.33	86.3	2.09	93.6	1.92	91.6	1.60	89.7	2.53	83.6	2.80	92.5	1.79	91.6	2.64	85.6	2.64	80.0	2.07
9	94.3	1.78	93.4	1.44	88.3	4.09	85.9	2.26	93.5	1.80	91.5	1.56	89.4	2.54	83.6	2.62	92.3	1.82	91.5	2.47	85.5	2.03	79.5	2.42
10	94.6	1.93	93.5	1.39	88.7	4.12	85.2	3.03	93.6	1.73	91.5	1.47	89.7	2.57	82.9	3.40	92.0	1.91	91.8	2.43	85.0	2.50	79.2	2.46
11	94.5	1.86	93.6	1.33	88.9	3.95	85.2	2.87	93.6	1.64	91.2	1.67	89.4	2.68	82.9	3.23	92.1	1.85	91.7	2.33	85.4	2.81	79.5	2.49
12	94.7	1.89	93.8	1.41	89.2	3.92	85.5	2.90	93.4	1.74	91.6	2.16	88.8	3.17	83.4	3.49	92.3	1.87	91.7	2.22	85.3	2.73		
13	94.7	1.81	93.7	1.37	88.8	4.01	85.0	3.25	93.4	1.67	91.5	2.11	88.8	3.03	83.4	3.34	92.3	1.79	91.7	2.13	85.5	2.68		
14	94.9	1.88	93.8	1.37	89.0	3.89	85.2	3.16	93.6	1.77	91.7	2.20	88.6	3.04	83.3	3.23	92.3	1.72	91.9	2.14	85.8	2.94		
15	94.9	1.81	93.9	1.45	89.2	3.83	85.1	3.83	93.7	1.79	91.9	2.31	88.2	3.27	83.0	3.70	92.4	1.73	91.8	2.08	86.2	3.16		
16	94.9	1.75	94.0	1.41	89.2	3.70	85.1	2.94	93.8	1.82	91.7	2.43	88.1	3.18	83.0	3.19	92.4	1.68	91.7	2.05				
17	95.1	1.85	94.0	1.38	88.9	3.68	85.4	3.01	93.8	1.78	91.9	2.48	88.0	3.10	83.3	3.22	92.5	1.68	91.7	1.99				
18	95.3	1.91	94.1	1.34	89.0	3.59	85.4	2.94	93.9	1.80	92.1	2.60	87.8	3.18	83.3	3.13	92.4	1.76	91.6	1.95				
19	95.2	1.89	94.2	1.39	88.9	3.56	85.5	2.86	94.0	1.85	92.0	2.57	87.8	3.09	83.2	3.07	92.4	1.72	91.5	1.92				
20	95.2	1.85	94.3	1.49	88.9	3.46	85.9	3.38	94.0	1.80	92.2	2.66			83.1	3.03	92.5	1.72	91.7	2.02				
21	95.2	1.81	94.4	1.54	89.0	3.44	85.9	3.30	94.0	1.76	92.2	2.59												
22	95.1	1.84	94.4	1.51	89.0	3.37	85.8	3.23	94.0	1.72	92.2	2.53												
23	95.3	1.97	94.3	1.53	89.0	3.29	85.6	3.27	94.0	1.69	92.4	2.55												
24	95.1	2.02	94.2	1.59	89.0	3.23	85.8	3.31	93.9	1.68	92.5	2.62												
25	95.1	1.99	94.2	1.57	89.0	3.19	85.9	3.28	94.0	1.65	92.5	2.57												
26	95.1	1.95	94.2	1.54	88.9	3.18	85.9	3.22	94.0	1.62	92.5	2.53												
27	95.3	2.05	94.2	1.51	89 0	3.16	85.9	3.17	93.9	1.60	92.7	2.60												
28	95.1	2.20	94.2	1.48	89.2	3.17	86.0	3.15	93.9	1.60	92.5	2.79												
29	95.0	2.19	94.3	1.46	89.2	3.11	86.0	3.11	93.8	1.59	92.5	2.74												
30	95.1	2.16	94.3	1.50	89.2	3.06	86.1	3.07	93.9	1.65	92.6	2.72												
31	95.1	2.13	94.3	1.48	89.2	3.01	86.0	3.06	93.9	1.62	92.5	2.68												

TABLE 4

Stability of simulation results of % GTR.

GATE PLAN UAL 4.

Input mean / Distrib. SD	10 / 2		10 / 5		10 / 10		10 / 15		12 / 2.19		12 / 5.48		12 / 10.95		12 / 16.35		14 / 2.36		14 / 5.91		14 / 11.8		14 / 17.6	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
% GTR after 5 days run	98.2	1.23	96.9	1.78	88.5	2.94	83.1	3.55	94.7	2.22	93.8	2.33	87.0	3.66	78.6	4.09	95.9	1.58	93.1	2.94	81.4	3.05	75.9	2.99
6	98.4	1.15	96.7	1.66	88.9	2.78	82.2	3.89	95.4	2.54	93.8	2.08	86.5	3.54	78.4	3.68	96.0	1.42	92.5	2.99	81.9	2.94	76.3	2.85
7	97.9	1.60	96.9	1.58	89.0	2.57	82.1	3.58	95.8	2.60	93.6	2.01	86.0	3.46	78.5	3.36	96.2	1.44	91.9	3.10	81.1	3.39	76.8	2.89
8	97.8	1.56	97.0	1.48	88.8	2.48	82.7	3.71	96.1	2.52	94.0	2.22	86.1	3.21	79.1	3.55	95.9	1.54	91.9	2.88	81.4	3.27	76.3	3.03
9	97.6	1.57	96.9	1.38	88.6	2.36	82.2	3.77	96.2	2.37	94.1	2.11	86.4	3.16	79.3	3.36	95.7	1.59	91.8	2.72	81.3	3.07	76.9	3.39
10	97.8	1.61	96.5	1.94	88.5	2.26	82.5	3.67	96.1	2.25	93.6	2.53	86.7	3.17	79.8	3.54	96.0	1.83	91.3	2.96	81.5	2.94	76.2	3.78
11	97.5	1.80	96.6	1.86			83.0	3.86							79.6	3.39								
12	97.4	1.72	96.2	2.13			83.2	3.81							79.9	3.36								
13	97.5	1.68	96.2	2.04			82.9	3.83																
14	97.4	1.62	96.3	1.99			83.1	3.73																
15	97.6	1.65	96.2	1.93			83.0	3.60																
16	97.7	1.63	96.2	1.87			83.2	3.56																
17	97.6	1.60	96.3	1.83																				
18	97.7	1.57																						
19	97.7	1.56																						
20	97.7	1.51																						
21	97.8	1.50																						
22	97.7	1.50																						
23	97.7	1.46																						
24	97.7	1.43																						
25	97.6	1.44																						
26	97.6	1.44																						
27	97.6	1.42																						
28	97.6	1.40																						
29	97.6	1.38																						
30	97.6	1.37																						
31	97.7	1.37																						

TABLE 5

Stability of simulation results of % GTR

GATE PLAN DAL 5

Input mean / Distrib. SD	10 / 2		10 / 5		10 / 10		10 / 15		12 / 2.19		12 / 5.48		12 / 10.95		12 / 16.35		14 / 2.36		14 / 5.91		14 / 11.8		14 / 17.6	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
% GTR after 5 days run	98.4	2.03	99.0	0.74	96.0	1.92	93.3	0.61	99.2	0.91	98.5	0.74	91.5	2.10	89.0	2.64	98.3	1.62	97.5	2.51	94.1	1.14	86.1	3.63
6	98.6	1.93	99.2	0.78	96.2	1.74	93.6	1.03	99.3	0.88	98.2	0.93	90.9	2.38	89.9	3.14	98.6	1.60	97.6	2.26	93.6	1.77	84.8	4.48
7	98.7	1.77	99.1	0.72	96.4	1.74	93.7	0.94	99.1	0.94	98.3	0.90	91.5	2.65	90.4	3.22	98.6	1.47	97.7	2.07	92.7	2.80	85.7	4.75
8	98.9	1.69	99.2	0.68	96.6	1.69	94.0	1.20	99.2	0.93	98.1	0.99	91.8	2.66	90.2	3.06	98.6	1.36	97.5	1.96	93.4	3.29	86.5	4.96
9	99.0	1.63	98.8	1.21	96.2	2.05	93.3	2.19	99.2	0.87	98.3	1.11	92.4	2.97	89.9	3.03	98.8	1.36	97.7	1.90	93.2	3.13	85.5	4.64
10	99.0	1.54	98.7	1.17	96.1	1.96	93.2	2.09	99.2	0.82	98.4	1.07	92.7	2.99	89.7	2.89	98.9	1.34	97.7	1.79	93.1	2.98	86.3	4.44
11	99.0	1.46	98.8	1.12	96.0	1.86	93.1	2.05	99.1	0.86	98.6	1.12	92.9	2.99	90.0	2.91	99.0	1.31	97.1	2.62	93.0	2.83	85.9	4.43
12	99.0	1.39	98.9	1.12	96.4	2.12	92.9	2.01	99.2	0.86	98.6	1.08	93.1	2.85	89.8	2.89	98.9	1.33					85.8	4.24
13	99.1	1.36	98.8	1.10	96.2	2.10	92.9	1.93	99.1	0.88	98.5	1.05	93.6	3.20									85.6	4.11
14	99.0	1.34	98.8	1.06	96.3	2.04	93.1	1.91	99.1	0.85	98.6	1.08	93.9	3.40									85.6	3.95
15	99.0	1.31	98.9	1.07	96.4	2.05	93.3	2.03	99.1	0.85	98.7	1.10	93.8	3.33									85.6	3.81
16	99.1	1.29	99.0	1.07	96.5	1.99	93.5	2.21	99.2	0.85	98.9	1.11	93.9	3.26									85.4	3.76
17	99.2	1.27	99.0	1.06	96.5	1.93	93.4	2.17	99.2	0.85	98.9	1.11	93.9	3.17										
18	99.2	1.24	99.1	1.06	96.5	1.87	93.3	2.21	99.3	0.84	98.9	1.11												
19	99.2	1.21	99.1	1.04	96.5	1.82	93.3	2.14	99.3	0.82	99.0	1.11												
20	99.2	1.18	99.1	1.01	96.5	1.80	93.2	2.15	99.2	0.80	99.0	1.08												
21	99.2	1.15	99.1	0.98	96.5	1.76	93.3	2.15	99.3	0.80	99.0	1.05												
22	99.2	1.13	99.1	1.00	96.5	1.75	93.4	2.15	99.3	0.80	99.0	1.05												
23	99.2	1.11	99.1	0.96	96.6	1.82	93.4	2.10	99.3	0.78	99.0	1.02												
24	99.2	1.12	99.1	0.94	96.6	1.79	93.5	2.11	99.2	0.86	99.0	1.00												
25	99.2	1.11	99.1	0.93	96.7	1.79	93.6	2.21	99.3	0.85	99.0	0.98												
26	99.1	1.09	99.1	0.92	96.7	1.76	93.6	2.16	99.2	0.84	99.0	0.96												
27	99.1	1.09	99.1	0.96	96.8	1.74	93.8	2.25	99.2	0.82	99.0	0.94												
28	99.1	1.12	98.9	1.18	96.9	1.82	93.7	2.26	99.2	0.85	99.1	0.94												
29	99.1	1.10	98.9	1.17	96.8	1.85	93.8	2.29	99.2	0.84	99.1	0.92												
30	99.1	1.10	98.9	1.17	96.8	1.82	93.7	2.29	99.2	0.84	99.1	0.91												
31	99.1	1.09	98.9	1.16	96.9	1.80	93.6	2.37	99.3	0.84	99.1	0.89												

TABLE 6

Stability of simulation results of % GTR

GATE PLAN BEA 1

Input mean / Distrib. SD	10 / 2		10 / 5		10 / 10		10 / 15		12 / 2.19		12 / 5.48		12 / 10.95		12 / 16.35		14 / 2.36		14 / 5.91		14 / 11.8		14 / 17.6	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
% GTR after 5 days run	99.1	0.86	98.7	0.92	96.0	2.58	92.7	2.87	96.2	0.71	97.5	2.73	96.8	2.76	90.0	1.61	98.2	1.23	97.3	1.08	91.5	2.35	86.6	3.00
6	98.9	0.87	98.6	0.86	95.4	2.75	92.1	2.95	96.9	1.66	97.5	2.44	96.1	2.96	90.5	1.86	97.6	1.81	97.0	1.24	92.1	2.58	86.9	2.76
7	98.7	0.98	98.4	0.91	95.2	2.53	92.2	2.72	97.1	1.67	96.9	2.68	95.9	2.80	90.1	2.04	97.8	1.70	96.6	1.48	92.4	2.44	87.3	2.79
8	98.6	1.02	98.3	0.91	95.5	2.46	92.7	2.85	97.2	1.54	97.0	2.49	95.5	2.76	90.5	2.31	97.9	1.61	96.7	1.39	92.3	2.26	87.2	2.60
9	98.3	1.12	98.1	1.03	95.2	2.51	92.2	3.02	97.1	1.45	96.9	2.33	95.9	2.79	91.1	2.70	97.8	1.51	96.3	1.87	92.2	2.13	87.5	2.57
10	98.4	1.10	98.2	0.98	95.3	2.42	92.2	2.85	97.4	1.64	96.6	2.43	95.9	2.63	91.2	2.60	97.7	1.48	96.3	1.77	92.3	2.01	87.6	2.44
11	98.3	1.09	98.1	0.97	95.3	2.31	92.3	2.72	97.6	1.75	96.5	2.32	95.9	2.50	91.1	2.50	97.5	1.50	96.1	1.79	92.3	1.91	87.4	2.41
12	98.0	1.48	97.9	1.10	94.8	2.73	92.4	2.63	97.8	1.80	96.4	2.24	95.5	2.69	90.9	2.50	97.4	1.49	96.1	1.70	92.5	1.92	87.7	2.57
13	97.9	1.46	97.8	1.11	94.8	2.62																		
14	97.8	1.41	97.6	1.32	95.0	2.56																		
15	98.0	1.47	97.6	1.27	94.9	2.47																		
16	97.9	1.46	97.6	1.23	95.1	2.51																		
17	97.8	1.44	97.6	1.19	95.1	2.43																		
18	98.0	1.49	97.5	1.22	95.2	2.42																		
19	97.8	1.62	97.6	1.22	95.2	2.38																		
20	97.8	1.57	97.5	1.19	95.3	2.37																		
21	97.9	1.61	97.5	1.21	95.4	2.36																		
22	97.9	1.58	97.4	1.19																				
23	97.9	1.54	97.4	1.20																				
24	98.0	1.52	97.5	1.29																				
25	98.1	1.54	97.6	1.35																				
26	98.1	1.55	97.7	1.34																				
27	98.0	1.64	97.6	1.41																				
28	98.0	1.61	97.6	1.40																				
29	98.1	1.59	97.6	1.38																				
30	98.1	1.60	97.7	1.37																				
31	98.1	1.57	97.6	1.36																				

TABLE 7

Stability of simulation results of % CTR

GATE PLAN BEA 2.

Input mean / Distrib. SD	10 2		10 5		10 10		10 15		12 2.19		12 5.48		12 10.95		12 16.35		14 2.36		14 5.91		14 11.8		14 17.6	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
% CTR after 5 days run	96.8	1.54	95.1	2.25	90.8	2.89	84.2	4.20	96.8	0.97	94.4	3.01	88.3	2.32	85.2	5.77	95.6	2.03	90.3	2.39	85.9	4.65	80.3	4.43
6	97.0	1.45	95.2	2.04	90.8	2.59	85.4	4.69	97.1	1.18	94.7	2.76	89.2	3.02	85.3	5.17	95.3	1.96	90.5	2.18	86.2	4.22	80.0	4.05
7	97.2	1.48	94.9	2.04	90.5	2.49	86.1	4.66	96.8	1.35	94.5	2.54	89.2	2.76	83.8	6.19	95.4	1.80	91.2	2.75	85.7	4.05	80.2	3.75
8	97.0	1.56	94.9	1.84	90.5	2.32	86.6	4.54	96.8	1.27	94.5	2.35	89.0	2.59	83.5	5.79	95.5	1.70	91.8	3.02	86.0	3.82	80.8	3.90
9	96.7	1.64	95.3	2.03	90.2	2.33	85.7	5.10	96.7	1.27	94.4	2.21	88.7	2.55	82.1	6.82	95.3	1.71	91.8	2.83	86.6	4.01	80.4	3.83
10	96.6	1.60	95.1	1.97	90.2	2.20	86.0	4.92	96.4	1.45	94.8	2.37	88.5	2.54	81.4	6.88	95.4	1.65	92.1	2.77	86.8	3.84	80.5	3.61
11	96.5	1.53	95.6	2.38	90.0	2.17	86.2	4.69	96.4	1.37	95.0	2.30	88.8	2.68	81.4	6.53	95.2	1.70	92.0	2.63	87.0	3.69	80.6	3.45
12	96.5	1.46	95.5	2.27	90.0	2.08	86.2	4.48	96.4	1.33	94.6	2.47	88.2	3.41	81.7	6.29	95.0	1.69	92.0	2.52	86.8	3.61	79.9	4.12
13	96.6	1.47	95.5	2.18	90.2	2.06	86.7	4.57	96.1	1.63	94.7	2.37	88.5	3.48									79.8	3.96
14	96.9	1.67	95.6	2.19	90.1	1.98	86.8	4.42	96.2	1.59	94.6	2.29	88.7	3.43									80.1	4.05
15	96.8	1.62	95.5	2.16	89.9	2.05	86.8	4.26	96.2	1.54	94.7	2.26	88.8	3.32									80.1	3.90
16	96.9	1.59	95.5	2.09	90.2	2.29	87.2	4.41	96.3	1.55	94.8	2.24	88.6	3.29									80.2	3.77
17	96.9	1.54	95.1	2.74	90.4	2.30	87.3	4.29	96.4	1.55	95.0	2.29	88.9	3.36									80.2	3.65
18	96.9	1.49	95.1	2.67	90.1	2.55	87.5	4.21	96.5	1.55	95.0	2.23	89.0	3.30										
19	96.8	1.47	95.0	2.59	90.1	2.46	87.6	4.11	96.5	1.52	95.0	2.18	89.0	3.21										
20	96.9	1.49	95.2	2.61	90.1	2.40	87.7	4.06	96.3	1.71	95.1	2.14												
21					90.3	2.54	87.7	3.97																
22					90.5	2.67	87.6	3.88																
23					90.6	2.66	87.5	3.81																
24					90.6	2.60	87.3	3.91																
25					90.8	2.73	87.2	3.84																
26					91.1	2.89	87.3	3.80																
27					91.2	2.99	87.3	3.75																
28					91.2	2.94	87.3	3.68																
29					91.3	2.91	87.4	3.65																
30							87.4	3.60																
31							87.5	3.56																

TABLE 8

Stability of simulation results for % GTR

GATE PLAN UAL1

95% Confidence Limits on Mean = $\pm$ X

Input Distrib.	mean SD	10 2	10 5	10 10	10 15	12 2.19	12 5.48	12 10.95	12 16.35	14 2.36	14 5.91	14 11.8	14 17.6
After 5 days run		1.6	0.6	2.4	2.5	1.9	2.6	9.4	6.2	2.0	3.3	5.2	6.4
6		1.5	0.7	2.0	2.3	1.9	2.8	7.0	5.0	1.6	5.0	4.0	4.8
7		1.7	0.6	1.6	1.9	1.5	2.3	5.8	4.2	1.8	4.2	3.3	3.8
8		1.4	0.7	1.5	1.7	1.6	2.0	4.8	3.6	1.5	3.5	2.5	3.2
9		1.2	0.9	1.3	1.5	1.7	1.9	4.5	3.1	1.3	3.1	2.5	3.0
10		1.2	0.8	1.1	1.3	1.5	1.8	4.0	2.9	1.2	2.7	2.2	3.0
11		1.0	0.7	1.3	1.3	1.4	1.6	3.8	2.9				2.7
12		0.9	0.7	1.5	1.3	1.5	1.4	3.6	2.6				2.7
13		0.9	0.7	1.6	1.5	1.4	1.3	3.3	2.6				2.5
14		0.8	0.7	1.5	1.4	1.3	1.2	3.0	2.4				2.4
15		0.7	0.7	1.4	1.5	1.3	1.2	2.8					2.3
16		0.7	0.7	1.5	1.5	1.3	1.2	2.6					
17		0.7	0.7	1.4	1.5	1.3	1.2	2.5					
18		0.7	0.7	1.4	1.8	1.3	1.1	2.3					
19		0.6	0.7	1.3	1.7	1.3	1.0	2.3					
20		0.6	0.7	1.2	1.6	1.2	1.0	2.2					
21		0.6	0.7	1.2									
22		0.6	0.6	1.4									
23		0.6	0.6	1.3									
24		0.5	0.6	1.3									
25		0.5	0.6	1.4									
26		0.5	0.6	1.3									
27		0.5	0.6	1.3									
28		0.5	0.6	1.3									
29		0.6	0.5	1.3									
30		0.6	0.5	1.2									
31		0.6	0.5	1.2									

X- VALUES

$X = t\hat{\sigma}$ WHERE $\hat{\sigma} = \frac{S}{\sqrt{N-1}}$

S = Sample standard deviation

N = Sample size

TABLE 9

Stability of Simulation Results for % GTR

GATE PLAN UAL 2.

95% Confidence Limits on Mean = $\pm$ X

Input mean	10	10	10	10	12	12	12	12	14	14	14	14
Distrib. SD	2	5	10	15	2.19	5.48	10.95	16.35	2.36	5.91	11.8	17.6
After 5 days run	1.2	1.9	1.8	4.0	1.7	2.0	2.5	3.4	3.9	3.7	1.2	3.7
6	0.9	1.6	1.5	4.5	1.4	1.5	2.2	2.5	2.9	2.7	1.0	3.1
7	0.7	1.3	1.2	3.9	1.2	1.8	2.5	2.5	2.4	2.3	1.6	2.6
8	0.6	1.1	1.0	3.3	1.3	1.0	1.8	2.0	2.0	1.9	1.4	2.3
9	0.6	1.0	1.1	2.8	1.2	0.9	1.5	2.7	2.0	1.6	1.4	2.0
10	0.5	0.9	1.3	2.8	1.1	0.9	1.6	2.4	2.1	1.5	1.3	1.9
11	0.5	0.8	1.2	2.6	1.0	0.8	1.4	2.2	1.9	1.3	1.5	1.8
12	0.5	0.7	1.1	2.4	0.9	0.8	1.4	2.0	1.7	1.3	1.4	1.6
13	0.6	0.7	1.0	2.2	0.8	0.9	1.3	1.8	1.5	1.1	1.3	
14	0.6	0.6	0.9	2.0	0.7	0.8	1.1	1.6	1.5	1.1	1.2	
15	0.6	0.7	0.9	1.8	0.7	0.7	1.1	1.7	1.4	1.0		
16	0.6	0.7	0.9	1.8	0.6	0.8	1.1	1.6	1.3	1.0		
17	0.5	0.6	0.8	1.7	0.6	0.8		1.5	1.3			
18	0.5	0.7	0.8	1.6	0.6	0.7		1.5	1.2			
19	0.6	0.7	0.8	1.6	0.6	0.7		1.5	1.1			
20	0.5	0.7	0.8	1.5	0.6	0.7		1.4	1.1			
21	0.5	0.6	0.8	1.4	0.5	0.7						
22	0.5	0.6	0.7	1.4	0.5	0.7						
23	0.5	0.6	0.7	1.3	0.5	0.6						
24	0.5	0.7	0.7	1.3	0.7	0.6						
25	0.5	0.7	0.7	1.2	0.6	0.6						
26	0.5	0.6	0.7	1.2	0.6							
27	0.5	0.6	0.7	1.1	0.6							
28	0.5	0.6	0.6	1.1	0.6							
29	0.5	0.6	0.6	1.1	0.6							
30	0.5	0.6	0.7	1.0	0.6							
31	0.5	0.5	0.6		0.6							

X - VALUES

$X = t\hat{\sigma}$ WHERE $\hat{\sigma} = \frac{S}{\sqrt{N-1}}$

S = Sample standard deviation

N = Sample size

TABLE 10

Stability of Simulation Results for % GTR

GATE PLAN UAL 3

95% Confidence Limits on Mean = $\pm$ X

Input	mean	10	10	10	10	12	12	12	12	14	14	14	14
Distrib.	SD	2	5	10	15	2.19	5.48	10.95	16.35	2.36	5.91	11.8	17.6
After 5 days run		1.5	0.6	5.9	1.3	2.8	2.5	3.8	4.5	2.3	4.6	3.5	3.0
6		1.5	0.7	5.3	2.4	2.1	2.1	2.9	3.4	1.8	3.5	2.9	2.3
7		1.4	0.8	4.7	2.0	1.8	1.7	2.3	2.9	1.5	1.8	2.3	1.8
8		1.4	0.7	3.9	1.9	1.7	1.4	2.3	2.5	1.6	2.4	1.9	1.9
9		1.5	1.2	3.3	1.8	1.5	1.3	2.1	2.1	1.5	2.0	1.7	2.0
10		1.5	1.0	3.1	2.3	1.3	1.1	1.9	2.6	1.4	1.8	1.9	1.9
11		1.3	0.9	2.8	2.0	1.2	1.2	1.9	2.3	1.3	1.6	2.0	1.8
12		1.3	0.9	2.6	1.9	1.2	1.4	2.1	2.3	1.2	1.5	1.8	
13		1.1	0.9	2.5	2.0	1.1	1.3	1.9	2.1	1.1	1.3	1.7	
14		1.1	0.8	2.3	1.9	1.1	1.3	1.8	1.9	1.0	1.3	1.8	
15		1.0	0.8	2.2	1.7	1.0	1.3	1.9	1.9	1.0	1.2	1.8	
16		1.0	0.8	2.0	1.6	1.0	1.3	1.7	1.8	0.9	1.1		
17		1.0	0.7	2.0	1.6	0.9	1.3	1.6	1.7	0.9	1.1		
18		1.0	0.7	1.8	1.5	0.9	1.3	1.6	1.6	0.9	1.0		
19		0.9	0.7	1.8	1.4	0.9	1.3	1.5	1.5	0.9	1.0		
20		0.9	0.7	1.7	1.6	0.9	1.3		1.5	0.8	1.0		
21		0.8	0.7	1.6	1.5	0.8	1.2						
22		0.8	0.7	1.5	1.5	0.8	1.1						
23		0.9	0.7	1.5	1.4	0,7	1.1						
24		0.9	0.7	1.4	1.4	0.7	1.1						
25		0.8	0.7	1.3	1.4	0.7	1.1						
26		0.8	0.6	1.3	1.3	0.7	1.0						
27		0.8	0.6	1.3	1.3	0.6	1.0						
28		0.9	0.6	1.3	1.2	0.6	1.1						
29		0.8	0.6	1.2	1.2	0.6	1.1						
30		0.8	0.6	1.2	1.2	0.6	1.0						
31		0.8	0.6	1.1	1.1	0.6	1.0						

X-VALUES

$X = \pm \hat{\sigma}$ WHERE $\hat{\sigma} = \frac{S}{\sqrt{N-1}}$

S = Sample standard deviation

N = Sample size

TABLE 11

Stability of Simulation Results for % GTR

GATE PLAN UAL 4

95% Confidence Limits on Mean = $\pm$ X

Input mean	10	10	10	10	12	12	12	12	14	14	14	14
Distrib. SD	2	5	10	15	2.19	5.48	10.95	16.35	2.36	5.91	11.8	17.6
After 5 days run	1.7	2.5	4.1	4.9	3.1	3.2	5.1	5.7	2.2	4.1	4.2	4.2
6	1.3	1.9	3.2	4.5	2.9	2.4	4.1	4.2	1.6	3.4	3.4	3.3
7	1.6	1.6	2.6	3.6	2.6	2.0	3.5	3.4	1.4	3.1	3.4	2.9
8	1.4	1.3	2.2	3.3	2.3	2.0	2.9	3.2	1.4	2.6	2.9	2.7
9	1.3	1.1	1.9	3.1	1.9	1.7	2.6	2.7	1.3	2.2	2.5	2.8
10	1.2	1.5	1.7	2.8	1.7	1.9	2.4	2.7	1.4	2.2	2.2	2.9
11	1.3	1.3		2.7				2.4				
12	1.1	1.4		2.5				2.2				
13	1.1	1.3		2.4								
14	1.0	1.2		2.2								
15	0.9	1.1		2.1								
16	0.9	1.0		2.0								
17	0.8	1.0										
18	0.8											
19	0.8											
20	0.7											
21	0.7											
22	0.7											
23	0.6											
24	0.6											
25	0.6											
26	0.6											
27	0.6											
28	0.6											
29	0.5											
30	0.5											
31	0.5											

X - VALUES

$X = t\hat{\sigma}$ WHERE $\hat{\sigma} = \frac{S}{\sqrt{N-1}}$

S = . Sample standard deviation

N = Sample size

TABLE 12

Stability of Simulation Results for % GTR

GATE PLAN UAL 5

95% Confidence Limits on Mean = $\pm$ X

Input Distrib.	mean SD	10 2	10 5	10 10	10 15	12 2.19	12 5.48	12 10.95	12 16.35	14 2.36	14 5.91	14 11.8	14 17.6
After 5 days run		2.8	1.0	2.7	0.8	1.3	1.0	2.9	3.7	2.2	3.5	1.6	5.0
6		2.2	0.9	2.0	1.2	1.0	1.1	2.7	3.6	1.8	2.6	2.0	5.2
7		1.8	0.7	1.7	0.9	0.9	0.9	2.7	3.2	1.5	2.1	2.8	4.8
8		1.5	0.6	1.5	1.1	0.8	0.9	2.4	2.7	1.2	1.8	2.9	4.4
9		1.3	1.0	1.7	1.8	0.7	0.9	2.4	2.5	1.1	1.5	2.6	3.8
10		1.2	0.9	1.5	1.6	0.6	0.8	2.3	2.2	1.0	1.3	2.2	3.3
11		1.0	0.8	1.3	1.4	0.6	0.8	2.1	2.1	0.9	1.8	2.0	3.1
12		0.9	0.7	1.4	1.3	0.6	0.7	1.9	1.9	0.9			2.8
13		0.9	0.7	1.3	1.2	0.6	0.7	2.0					2.6
14		0.8	0.6	1.2	1.1	0.5	0.6	2.0					2.4
15		0.8	0.6	1.2	1.2	0.5	0.6	1.9					2.2
16		0.7	0.6	1.1	1.2	0.5	0.6	1.8					2.1
17		0.7	0.6	1.0	1.2	0.5	0.6	1.7					
18		0.6	0.5	1.0	1.1	0.4	0.6						
19		0.6	0.5	0.9	1.1	0.4	0.5						
20		0.6	0.5	0.9	1.0	0.4	0.5						
21		0.5	0.5	0.8	1.0	0.4	0.5						
22		0.5	0.5	0.8	1.0	0.4	0.5						
23		0.5	0.4	0.8	0.9	0.3	0.5						
24		0.5	0.4	0.8	0.9	0.4	0.4						
25		0.5	0.4	0.8	0.9	0.4	0.4						
26		0.4	0.4	0.7	0.9	0.3	0.4						
27		0.4	0.4	0.7	0.9	0.3	0.4						
28		0.4	0.5	0.7	0.9	0.3	0.4						
29		0.4	0.5	0.7	0.9	0.3	0.4						
30		0.4	0.4	0.7	0.9	0.3	0.3						
31		0.4	0.4	0.7	0.9	0.3	0.3						

X-VALUES

$X = t\hat{\sigma}$ WHERE $\hat{\sigma} = \frac{S}{\sqrt{N-1}}$

S = Sample standard deviation

N = Sample size

TABLE 13

Stability of Simulation Results for % GTR

GATE PLAN BEA 1

95% Confidence Limits on Mean = $\pm$ X

Input mean	10	10	10	10	12	12	12	12	14	14	14	14
Distrib. SD	2	5	10	15	2.19	5.48	10.95	16.35	2.36	5.91	11.8	17.6
After 5 days run	1.2	1.3	3.6	4.0	1.0	3.8	3.8	2.2	1.7	1.5	3.3	4.2
6	1.0	1.0	3.2	3.4	1.9	2.8	3.4	2.1	2.1	1.4	3.0	3.2
7	1.0	1.0	2.5	2.7	1.7	2.7	2.8	2.0	1.7	1.5	2.4	2.8
8	0.9	0.8	2.2	2.5	1.4	2.2	2.5	2.1	1.4	1.2	2.0	2.3
9	0.9	0.8	2.0	2.5	1.2	1.9	2.3	2.2	1.2	1.5	1.7	2.1
10	0.8	0.7	1.8	2.1	1.2	1.8	2.0	2.0	1.1	1.3	1.5	1.8
11	0.8	0.7	1.6	1.9	1.2	1.6	1.8	1.8	1.1	1.3	1.3	1.7
12	1.0	0.7	1.8	1.7	1.2	1.5	1.8	1.7	1.0	1.1	1.3	1.7
13	0.9	0.7	1.6									
14	0.8	0.8	1.5									
15	0.8	0.7	1.4									
16	0.8	0.7	1.4									
17	0.8	0.6	1.3									
18	0.8	0.6	1.2									
19	0.8	0.6	1.2									
20	0.8	0.6	1.1									
21	0.8	0.6	1.1									
22	0.7	0.5										
23	0.7	0.5										
24	0.7	0.6										
25	0.6	0.6										
26	0.6	0.6										
27	0.7	0.6										
28	0.6	0.6										
29	0.6	0.5										
30	0.6	0.5										
31	0.6	0.5										

X-VALUES

$X = t\hat{\sigma}$ WHERE $\hat{\sigma} = \frac{S}{\sqrt{N-1}}$

S = Sample standard deviation

N = Sample size

TABLE 14.

Stability of Simulation Results for % GTR

GATE PLAN REA 2

95% Confidence Limits on Mean = $\pm$ X

Input mean	10	10	10	10	12	12	12	12	14	14	14	14
Distrib. SD	2	5	10	15	2.19	5.48	10.95	16.35	2.36	5.91	11.8	17.6
After 5 days run	2.1	3.1	4.0	5.8	1.3	4.2	3.2	8.0	2.8	3.3	6.5	6.1
6	1.7	2.3	3.0	5.4	1.4	3.2	3.5	5.9	2.3	2.5	4.9	4.7
7	1.5	2.0	2.5	4.7	1.4	2.5	2.8	6.2	1.8	2.8	4.1	3.8
8	1.4	1.6	2.1	4.1	1.1	2.1	2.3	5.2	1.5	2.7	3.4	3.5
9	1.3	1.7	1.9	4.2	1.0	1.8	2.1	5.6	1.4	2.3	3.3	3.1
10	1.2	1.5	1.7	3.7	1.1	1.8	1.9	5.2	1.2	2.1	2.9	2.7
11	1.1	1.7	1.5	3.3	1.0	1.6	1.9	4.6	1.2	1.9	2.6	2.4
12	1.0	1.5	1.4	3.0	0.9	1.6	2.3	4.2	1.1	1.7	2.4	2.7
13	0.9	1.4	1.3	2.9	1.0	1.5	2.2					2.5
14	1.0	1.3	1.2	2.6	1.0	1.4	2.1					2.4
15	0.9	1.2	1.2	2.4	0.9	1.3	1.9					2.2
16	0.9	1.1	1.3	2.4	0.9	1.2	1.8					2.1
17	0.8	1.5	1.2	2.3	0.8	1.2	1.8					1.9
18	0.8	1.4	1.3	2.2	0.8	1.1	1.7					
19	0.7	1.3	1.2	2.0	0.8	1.1	1.6					
20	0.7	1.3	1.2	1.9	0.8	1.0						
21			1.2	1.9								
22			1.2	1.8								
23			1.2	1.7								
24			1.1	1.7								
25			1.1	1.6								
26			1.2	1.6								
27			1.2	1.5								
28			1.2	1.5								
29			1.1	1.4								
30				1.4								
31				1.3								

X - VALUES

$X = t\hat{\sigma}$ WHERE $\hat{\sigma} = \frac{S}{\sqrt{N-1}}$

S = Sample standard deviation

N = Sample size

CHAPTER 12.

UNITED AIRLINES, CHICAGO O'HARE AIRPORT.

12.1 Introduction

12.2 % GTR as recorded at O'Hare.

12.3 Effect on % GTR of United's extra flights.

12.4 Effect of aircraft unserviceability.

12.5 Other effects.

12.6 Range of acceptable simulated values for GTR.

12.7 Comparison of punctuality, simulated-actual.

12.8 Realism of the simulated value of GTR.

12 UNITED AIRLINES, CHIGAGO O'HARE AIRPORT.

12.1 During the summer of 1969, the author spent six weeks at O'Hare Airport studying United's operational methods and compiling data describing their performance. The latter is discussed in this chapter and is compared with the results obtained from simulating their schedule of summer '69 under gate plan UAL1. The organisation and methods used by United are not discussed until chapter 13 when those of American, Western and Delta are also presented.

12.2 The basic plan used by United was represented by UAL1, but minor planned alterations were required due to the scheduling of extra flights. This of course was not done in the simulation. Gate timetable reliability as defined in this project was not normally calculated by UAL, but interest was expressed in the concept. A monitor was instigated and the results of thirty days operation are shown in figure 1 of appendix 12. The mean % GTR is seen to be 73% with a standard deviation of 8.6. Although it has been emphasised throughout this work that it is the relative simulated performance of different gate timetables which is of prime importance, a check on the reliability of UAL1 compared to that of the actual plan is worthwhile.

12.3 Effect on % GTR of United's extra flights.

The frequency of planned extra flights per day and the % GTR were recorded over the same time period. On average, four extras were operated per day and were planned such that a gate was available preferably involving no change to the original gate allocations. Obviously the distribution of separation and occupancy times were slightly affected, but this was not recorded.

During the day's operation, the number of departure gate changes which were caused either as a direct result of such occupancies, or as a reactionary effect due to they themselves experiencing a gate change, was recorded. Some occupancies resulted in up to five departure gate changes while others were absorbed into the plan with no side effects whatsoever. The mean was one gate change per extra occupancy. Assuming four extras per day, and two hundred departures per day, their absence should have increased the % GTR by approximately 2 percentage points.

12.4 Effect of Aircraft Unserviceability.

This was discussed in chapter 8, and it was shown that the aircraft unserviceability results in unscheduled turnrounds and associated gate changes. There was insufficient time to obtain accurate data concerning this, but a reasonable estimate is that the elimination of unserviceability induced aircraft changes could increase the % GTR by 5-10% provided the punctuality rates remained unchanged.

12.5 The simulation of UAL1 took neither of the above two conditions into account. Provided all other factors are adequately reproduced in GATESIM, and comparable delay rates apply, a difference of 7-12% should exist between the recorded and simulated values. Unfortunately, the other factors cannot be claimed as being simulated exactly, and their effect on GTR cannot be quantified. The following are listed as examples.

i) The gates at O'Hare are not fully interchangeable as assumed by GATESIM. During congested gate occupancy periods this may force gate holds and increase the value of GTR even though the opposite may be desired.

ii) The state of congestion in the taxiways may produce large variations in the time between touch down and positioned at the gate. This could lead the ramp controller into creating gate changes which, under more stable conditions, would have been avoided. This was not programmed.

iii) An unusually large number of connecting passengers between specific flights may be best processed by positioning the operating aircraft as closely together as possible.

iv) The schedule may be such that the desired gate for a given occupancy is not available on a planned basis because of a higher priority flight requiring it. However, when flight delays are such that the gate can accommodate both occupancies, a gate change may be preferable to the planned departure from the less desireable position.

12.6 From the above it is apparent that even under comparable delay rate conditions, it is not possible to statistically calculate, at a stated confidence level, a range of % GTR which must be achieved by the simulation before the hypothesis that the simulation is realistic can be accepted. It is however submitted that the largest deviation from reality is the omission of unserviceability data.

12.7 Comparison of punctuality performance.

Table 1 in appendix 12 shows the actual departure punctuality as recorded during May, 1969 together with the results obtained from the simulation. The twelve input distributions which were used to generate each set of delays are also shown.

The Kolmogorov-Smirnoff test was used to ascertain if any of the simulated delay rates could belong to the same population as the observed ones. This hypothesis was rejected in each case even at the 0.001 significance level. It is therefore invalid to claim that the simulation reproduced United's punctuality performance.

It is seen from table 2 of appendix 12 that the maximum deviation of the cumulative relative frequency has its smallest values under the two most severe input delay conditions. This deviation is caused in the main by the simulation generating too many delays in the range 10-20 minutes at the expense of those over one hour. It is clear that either the distributions themselves could not generate the observed delay rates, or else the simulation succeeded in performing aircraft changes which reduced the effect of the estimated long delays.

12.7.1 It is clearly possible to identify input distributions which react with GATESIM'S logic and limitations in such a way as to produce departure punctuality figures which statistically compare well with observed results, for any airline's operation. This is desireable provided no attempt is made to use delay distributions to overcome limitations of the simulation design purely in the interest of realistic punctuality. It is more acceptable to have discrepancies in the punctuality figures and to be able to compensate for them, than to assume that realistic ones are the product of an equally realistic total simulation. The reasons for the difference must be identified and explained.

12.7.1 If too much emphasis is placed on punctuality alone, the input distributions, whether theoretical or empirical, may result in the simulation reflecting at least part of the individual airline's operating procedures. The decision tables may then be presented with weighted data in a manner inconsistent with their design conditions. Comparison of different airlines becomes even more difficult for two main reasons.

If the input distributions are tailored to suit one carrier's operation, it is not reasonable to assume that the same data will generate equal realism with another carrier even though the flight schedules may be comparable. Conversely, if a second set of data is designed, comparison is still dubious because the originating disruptions to the flight schedule differ.

The constancy of initial disturbances is important to GATESIM, since it is the relative response of different gate timetables to them, that is being investigated.

12.7.2 Although statistical tests indicate that the actual and the simulated departure delay distributions are highly unlikely to originate from the same population, reference is again made to table 2.

Under the most severe delay conditions, when the input distribution had a mean of 14 minutes and a standard deviation of 17.6 the delay rates up to 30 minutes are seen to be at least comparable. An insufficient number of longer delays are generated.

If all arrivals operated on time, and no aircraft changes were performed, the above input distribution is expected to produce a departure punctuality of the order of that shown in table 3. In the same table is shown the estimated effect of including the arrival delay pattern, without aircraft changes.

It is seen that aircraft changes have resulted in the following:

i) The simulation performed 91.7% of departures within 30 minutes of STD compared with the estimated 85%.

12.7.2 ii) Only 8.3% of departures had delays in the range 30-59 minutes compared with the estimated 14%.

iii) No delays over one hour were recorded, whereas about 1% could be expected to be of this magnitude.

It is evident that although the above input distribution could not generate delays of the magnitude experienced by United, its expected maximum delays did not occur because of the alleviating role of aircraft changes.

This effect will become more pronounced as the size of the initial disturbances is increased. The problems outlined in 12.7.1 may well be encountered under such conditions. These apart, it is not considered prudent to generate long delays because of the manner in which they occur in practice, as outlined below.

12.7.3 The simulation assumes all departures have the same priority and performs aircraft changes to achieve the best total punctuality performance for the Station. This includes involving a departure of a through flight in an aircraft change possibly before the arrival with the same flight number has been performed.

In practice, the decision to change aircraft like this or to accept a delayed departure is dependent on many factors, including:

i) new passengers boarding the flight
ii) later connecting flights to ultimate destination.
iii) passengers boarding the flight at later transit stations.

This data is not available to the simulation, so it was decided to request aircraft changes whenever the estimated delay warranted.

Thus large departure delays to through flights, which in some cases are accepted by the airline, will be reduced by the simulation's implementation of an aircraft change.

In addition the availability and scheduling of flight and cabin crew may require that an inbound crew operate a specific departure. Their late arrival will cause a delayed departure which GATESIM again would attempt to reduce.

12.7.3 The ideal situation would be to generate these longer delays but to make only some of them reduceable by aircraft changes. However this is not possible under the adopted program structure. Alternatively it would be necessary to make the input distribution skew to allow for the built-in alleviating effect. This suffers from two main drawbacks.

Firstly, the large delays eventually accepted by the simulation would be the end result of a change sequence, probably of type INDIRECT or NSINDIRECT, involving a considerable number of aircraft. In reality, they tend not to be the result of aircraft changes but the alternative to them.

Secondly, it would be highly unlikely in an aircraft change of type INDIRECT, that only one large delay is caused. It is more probable that other small additional delays will be caused. The effect of these on the gate timetable reliability, together with the extra unscheduled turnrounds cannot be quantified.

It is considered more reasonable to accept the simulation as capable of reproducing small delays well, and to regard the results in this context. An allowance can be estimated for the effect of long delays caused by very late arrivals or aircraft unserviceability which the airline, in its wisdom, decides to accept by retaining the original aircraft allocation.

This is considered below.

12.7.4 Effect of long delayed turnrounds on % GTR.

Such turnrounds have merely been displaced in time, since the forecasted departure delay is caused either by a very late arrival or unserviceability. In the latter case, under a gate timetable controlled situation, the aircraft would be positioned on a gate area only after defect rectification, unless its presence through the maintenance process did not seriously affect the gate plan.

Since a delay is involved, it is reasonable to assume that all efforts will be made to perform a minimum gate occupancy. Assume this to be 30 minutes, with a five minute additional separation time.

12.7.5 The use of the Erlang Loss Formula for the estimation of the required number of gates is discussed in reference 1 from which figure 2 was taken. The non dimensional number, the Erlang is calculated as follows:-

$$\text{Erlang number} = \frac{\text{rate of arrival of aircraft}}{\text{rate of service of aircraft}}$$

where rate of arrival = average number of aircraft arriving per hour.

rate of service = reciprocal of gate occupancy time in hours.

The reference shows that the formula is best used when the rate of arrival is calculated over a period of eight hours. The conventional use of this method is to calculate the Erlang number for a given operation, and to read from figure 2 or equivalent, the required number of gates.

The application in this work is the reverse.

12.7.6 Table 4 shows rate of arrival which can be serviced at the 99% confidence level, by a stated number of gates, e.g. ten gates would be required to satisfy an average arrival rate of 7.4 aircraft per hour, assuming a service time of 35 minutes.

Figure 3 shows, in bandwidths of five minutes, the number of gates in UAL1 which are free for at least thirty five minutes. i.e. In each band the number of time displaced occupancies which can commence simultaneously and which can be absorbed into the timetable as originally planned, is shown.

Figure 3 is analysed below.

No. of 5 minute bands with $\geq$ X gates available.

	X=0	X=1	X=2	X=3	X=4	X=5	X=6	X=7	X=8	X=9	X=10
0700-1500	96	94	60	32	21	19	16	13	11	3	1
1500-2300	96	93	72	48	26	25	20	14	11	7	3

12.7.7 If the displaced occupancy have an arrival rate equivalent to a steady state of 0.9 aircraft per hour, from table 2, it is seen that only 3 gates are required. However, the probability that 3 gates will be available without gate changes is obtained from table 12.1 above.

in period 0700-1500 $= \frac{32}{96} = 0.33$

in period 1500-2300 $= \frac{48}{96} = 0.5$

Thus during the first period 33% of the displaced occupancy should find a gate available on arrival, assuming that the other occupancies are all on schedule. However, if the plan contains twenty gates, evenly utilised, there is only a 5% chance that the displaced occupancies will be accommodated on their originally planned gate. Hence only about 2% of them will not effect the value of GTR. 31% of them will have one wrong departure gate per arrival. If it is assumed that any gate changes will be of type DIRECT SWOP, 67% of the arrivals will incur two wrong departure gates.

12.7.8 If for example, the rate of 0.9 arrivals per hour were maintained for 16 hours, approximately 14 occupancies are involved. From the above,

2% will not affect GTR = .28 aircraft = 0
31% will incur one wrong gate each = 5 wrong gates
67% will incur two wrong gates each = 18 wrong gates.

Thus approximately 23 wrong gate departures would be caused by these 14 displaced occupancies. This would decrease the value of %GTR by about 10 points.

Obviously this is a very general approach and has the merit of being simple but is suffers from the following shortcomings:-

i) The arrival rates is likely to be small, though significant peaks may occur. These are liable to be large compared to those shown as acceptable in the reference.

ii) The co-incidence of these peaks with the peaks or troughs in gate availability shown in figure 3 is not taken into account.

iii) The histogram of gate availability assumed on-schedule movements of all other occupancies.

12.7.8 iv) Accuracy of Erlang method decreases with reducing value of Erlang number.

12.7.9 These disadvantages can be circumvented in specific cases as follows. As an example, assume that an arrival rate of 1.7 pertained to the time period 0900-1200 hours only.

The number of arrivals = 5

P_r ($\geq$ 3 gates available) = $\frac{12}{36}$ (from figure3)

31% will incur one wrong gate $\Rightarrow$ 2 wrong gate departures
67% will incur two wrong gates $\Rightarrow$ 6 wrong gate departures.

This will reduce the %GTR by about 2.8 points.

12.7.10 It is considered highly unlikely that:-

i) The arrival rate of such displaced occupancies will ever exceed 1.7 aircraft per hour consistent with the remainder of the simulations limitations being satisfied.

ii) This arrival rate will be maintained for more than three hours at one time.

iii) The incidence of such three hour bands will ever exceed two.

12.7.11 It is concluded that the effect of excluding these long delay turnrounds from the simulation was to falsely increase the estimated value of % GTR by up to 5 points.

12.8 The accuracy of the simulated value of % GTR is seen to vary according to the realism of the punctuality performance.

Excluding the effect of through flights, the following estimates are considered reasonable:-

i) When no corrections for displaced occupancy are necessary to provide delay rate comparability with the operation being simulated, GATESIM is expected to produce a value for % GTR which 7-12 points toohigh.

ii) When such corrections are required, the difference can be expected to rise to up to 17 points.

APPENDIX 12.

TABLE 1	Departure punctuality UAL 1.
2	Departure punctuality UAL 1, in cumulative form.
3	Effect of station delays, with 100% arrival punctuality.
4	Gate requirement using Erlang number.

FIGURE 1	% GTR as recorded at O'Hare.
2	Erlang numbers.
3	Availability of gates in UAL 1.

Reference 1. Use of the Erlang Loss Formula for calculation of required number of operational stands.

A.E. Knowler,
Ministry of Aviation.

TABLE 1

DEPARTURE PUNCTUALITY AS RECORDED AT O'HARE COMPARED TO SIMULATION PUNCTUALITY FOR UAL 1

		% < 10 late	% < 20 late	% < 30 late	% < 60 late	% < 90 late	% < 120 late	% < 180 late	% GTR
ACTUAL		66.7	79.3	88.5	92.5	97.7	99.1	99.6	73.0
SIMULATION: Input Distrib.									
mean	S.D.								
10	2	99.0	99.7	100	100	100	100	100	96.8
10	5	93.5	99.4	99.9	100	100	100	100	96.1
10	10	80.6	96.7	98.4	100	100	100	100	91.8
10	15	72.0	88.9	96.3	100	100	100	100	85.3
12	2.2	98.2	99.3	99.9	100	100	100	100	95.1
12	5.5	89.7	99.4	99.8	100	100	100	100	94.7
12	11.0	72.6	93.4	99.5	100	100	100	100	87.8
12	16.4	66.2	84.4	94.2	99.5	100	100	100	83.5
14	2.4	98.5	99.7	99.9	100	100	100	100	95.3
14	5.9	83.2	97.9	99.8	100	100	100	100	93.4
14	11.8	65.3	88.5	97.4	100	100	100	100	85.3
14	17.6	61.3	80.3	91.7	100	100	100	100	81.0

TABLE 2

COMPARISON OF DEPARTURE PUNCTUALITY BETWEEN THE SIMULATION AND ACTUAL PERFORMANCE USING UAL 1

Mean	S.D	<10 late	<20 late	<30 late	<60 late	<90 late	<120 late	<180 late
10	2	32.3	20.4	11.5	7.5	2.3	0.9	0.4
10	5	26.8	20.1	11.4	7.5	2.3	0.9	0.4
10	10	13.9	17.4	9.9	7.5	2.3	0.9	0.4
10	15	5.3	27.0	7.8	7.5	2.3	0.9	0.4
12	2.2	31.5	20.0	11.4	7.5	2.3	0.9	0.4
12	5.5	23.0	20.1	11.3	7.5	2.3	0.9	0.4
12	11.0	5.9	14.1	11.0	7.5	2.3	0.9	0.4
12	16.4	- 0.5	19.2	5.7	7.0	2.3	0.9	0.4
14	2.4	31.8	20.4	11.4	7.5	2.3	0.9	0.4
14	5.9	16.5	18.6	11.3	7.5	2.3	0.9	0.4
14	11.8	- 1.4	9.2	8.9	7.5	2.3	0.9	0.4
14	17.6	- 5.4	1.0	3.2	7.5	2.3	0.9	0.4

Punctuality limits are expressed in minutes , the difference in cumulative % is shown.

A positive value indicates that the simulation has generated insufficient delays in the range shown.

TABLE 3

Departure punctuality assuming no aircraft changes.

% of total departures

Delay size	No arrival delays	with arrival delays of mean = 3, s,d = 13.08
≤ 10 minutes	63.3	55.6
≤ 20 minutes	81.8	72.2
≤30 minutes	93.1	85.3
≤60 minutes	99.9	99.2
≤120 minutes	100	99.9

Estimates based on station delays belonging to distribution with mean = 14 minutes standard deviation = 17.6, and in flight delays having a mean of 3 minutes and a standard deviation of 13.08.

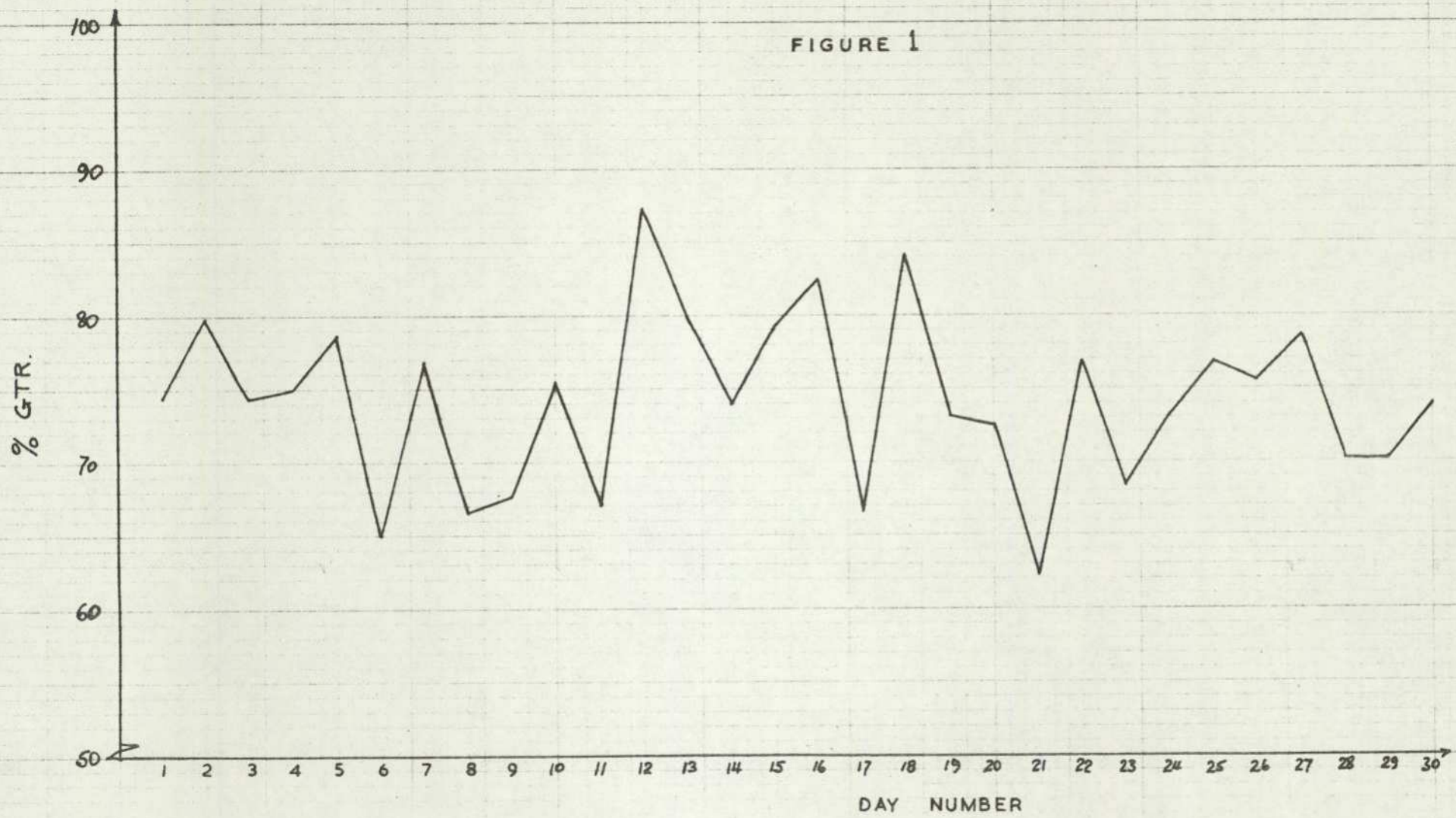
TABLE 4

No. of Gates	Maximum Supportable Erlang Number	Maximum Average Arrival rate
2	0.1	0.2
3	0.5	0.9
4	1.0	1.7
5	1.5	2.7
6	2.0	3.4
7	2.5	4.3
8	3.1	5.3
9	3.7	6.3
10	4.3	7.4

UNITED AIRLINES - O'HARE

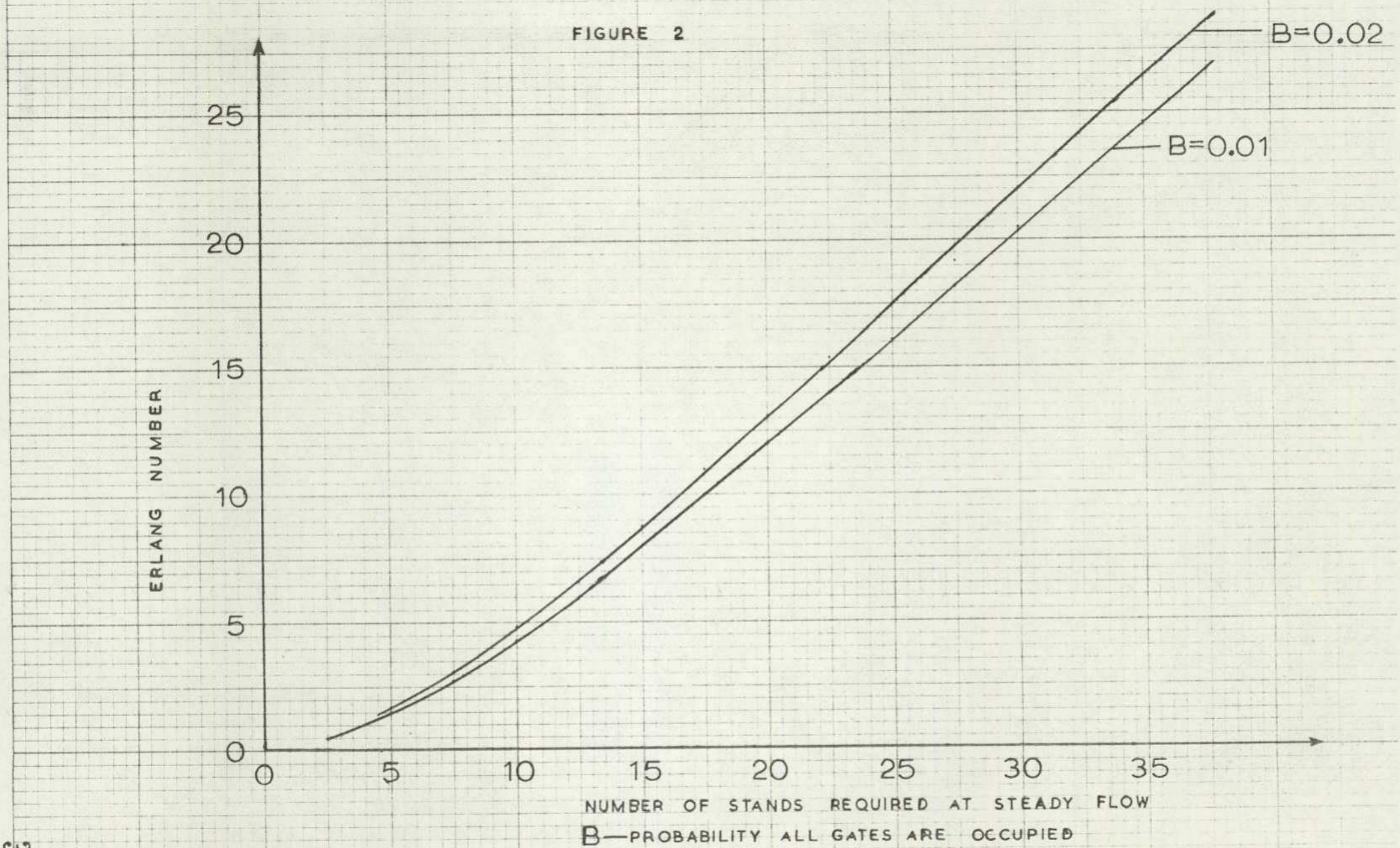
ACHIEVED VALUES OF %GTR

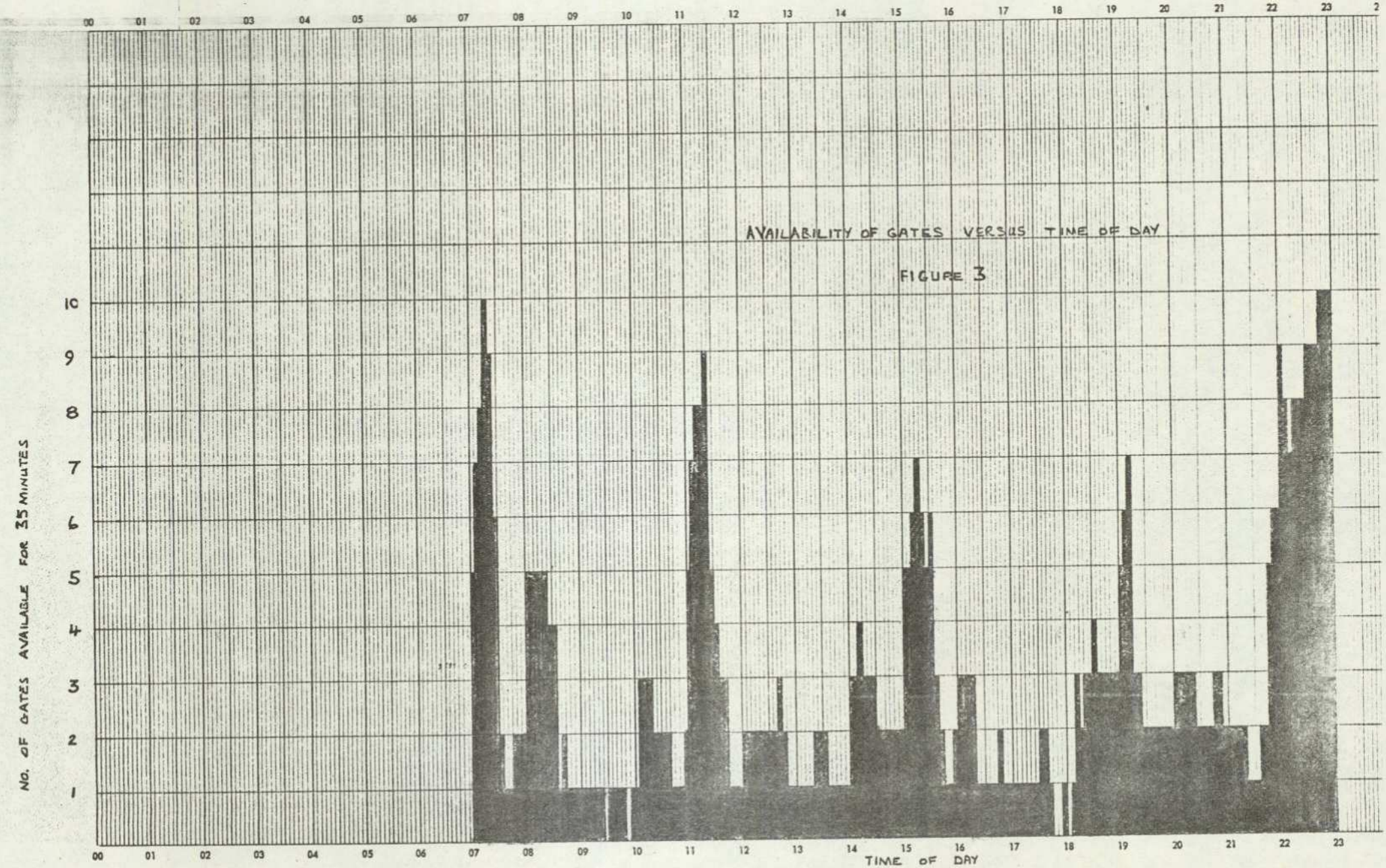
FIGURE 1



GATE REQUIREMENT.

FIGURE 2




AVAILABILITY OF GATES VERSUS TIME OF DAY
FIGURE 3
NO. OF GATES AVAILABLE FOR 35 MINUTES
TIME OF DAY
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23
1 2 3 4 5 6 7 8 9 10

CHAPTER 13

STUDY OF FOUR MAJOR AIRLINES IN THE UNITED STATES.

13.1 American Airlines
13.2 United Airlines
13.3 Delta Airlines
13.4 Western Airlines

13. STUDY OF FOUR MAJOR AIRLINES IN THE UNITED STATES.

The study tour was financed by the Robert Blackburn Memorial Scholarship and was undertaken during the spring and summer of 1969. The main aims were to ascertain the practical feasibility of a gate timetable, to record performance data and to identify operating procedures which are significantly different from those used at Heathrow and which were generated, at least in part, by the adoption of a gate plan.

Each airline is described in turn.

13.1 American Airlines.

13.1.1 American Airlines is a domestic carrier with its head office in New York and Maintenance Base in Tulsa, Oklahoma. It operates from all three New York airports, namely John F. Kennedy, La Guardia and Newark, but only La Guardia was studied in detail. It was chosen because only short and medium haul flights with B727 and BAC 1-11 aircraft served it at the time. This resulted in La Guardia being the closest approximation in American Airlines to the hub of a "hub and spoke" type operation.

13.1.2 La Guardia Airport.

La Guardia is owned by the New York Port Authority from whom the airlines lease terminal areas. The concourse, holding lounges, and gate areas are under the complete control of the tenant airline which is free to develop the area to suit its own requirements. Similarly, it is free to determine an acceptable utilisation figure for its gates and to use this as a constraint on its schedule construction. Obviously an exceptionally low figure will cause the Authority to review the allocation especially if another airline is seeking extra facilities. This situation has not arisen due to high rentals, and any temporary spare capacity is usually sub-let to another carrier without the Authority's intervention.

13.1.2 The American facility, sketched overleaf in figure 13.1, consists of one main concourse having ten gates and an eleventh gate at the base of the neighbouring concourse, leased from United in the manner described above.

It can be seen that the manoeuvering area between the two concourses is very limited and interference can occur between aircraft of competing airlines and indeed between American aircraft. Aircraft at all gates are parked using their own power but require a tug on departure. This is especially critical on gates 10 and 11 since the aircraft must be positioned opposite gates 8/9 before the engines can be started, in order to avoid possible jet blast damage to the terminal building. Movements to or from gates 8-11 are thus impossible while such an operation is in progress.

The movement of aircraft in the alleyway formed by the two concourses is not controlled by the Airport Ground Controller. His responsibilities only apply to operational taxiways, and gates such as 2, 3 and 4 where a push-out could interfere with taxying aircraft. Consequently it is the airlines' responsibility to ensure that their occupancies are planned to produce the minimum chance of interference between positioning aircraft.

However, this has not been extended to include, in this case, United's movements, and a race type situation was often apparent. Minor aircraft collisions have occurred, emphasising the need for a co-ordinated control system.

Gate restrictions do exist in that the B727-100 cannot use gates 4 or 11 while the larger B727-200 cannot use gates 4, 8, 9, 10 or 11.

13.1.3 La Guardia as a constraint on schedule construction.

When constructing a new flight schedule, the limited number of gates at La Guardia provides a positive constraint in that no more than eleven occupancies are scheduled at any one time. It is attempted to have a minimum gate separation time of fifteen minutes, assuming 100% punctuality. The availability of an off-line parking area permits more than eleven aircraft to be accepted but this facility is normally utilised at the

LA GUARDIA AIRPORT

AMERICAN AIRLINES FACILITY.

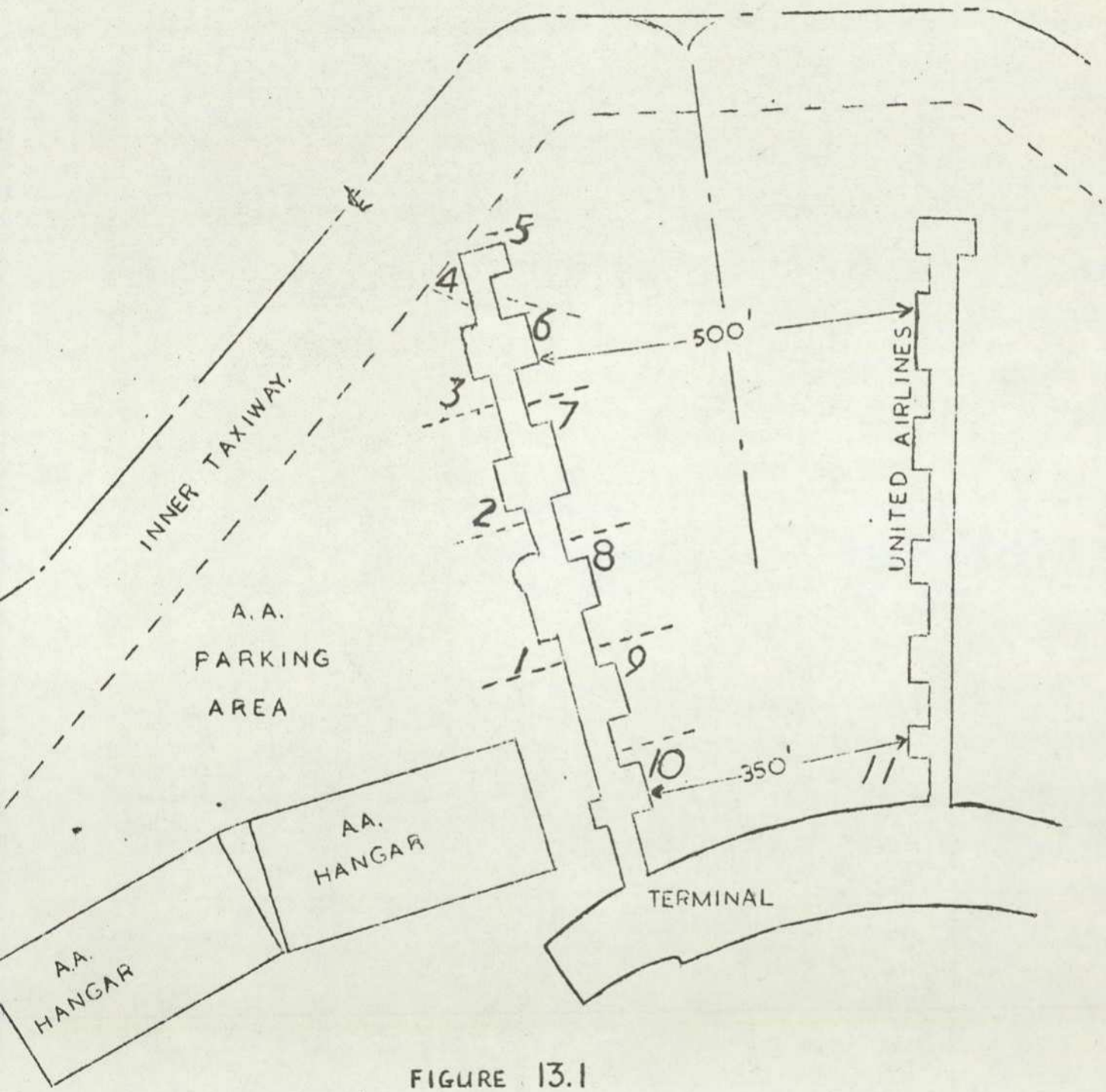


FIGURE 13.1

13.1.3 schedule construction stage only when an overnight or a maintenance turnround is being considered. No attempt is made by the schedulers to provide an operational gate plan.

Before a schedule is agreed, the station management must be satisfied that the total resources can satisfy the demand. This includes manpower as well as gate areas. To achieve this, the station forms its gate timetable by applying the following restrictions which were not necessarily imposed in total by the schedule department. These are:-

1. Gate restrictions in terms of aircraft type must be adhered to.
2. Originating departures must be positioned on their gates at least thirty minutes before STD.
3. A minimum of forty five minutes should elapse between successive departures on the same gate. This allows the holding lounge to be available for passenger processing, without the aircraft being in position.
4. Twenty five minutes must exist between the arrival of a terminating aircraft and the arrival of the following turnround on the same gate. Since the minimum turnround time was twenty minutes for a through flight, this condition permitted a terminating flight to be scheduled between two departures which had the minimum separation period stated in 3 above. This would be planned only in exceptional situations.
5. No minimum separation time between departing and arriving flights was stipulated.
6. Long turnrounds may be removed to the parking areas provided they are not through flights and provided conditions 2 and 3 above can be satisfied.
7. Congestion in the alleyway is reduced as much as possible.
8. The Chicago bound "Commuter Jets" are scheduled from the same gate wherever possible.

The plan is formulated manually in bar chart form and then transposed to the "LGA Ramp Control Log" which is the working document for station staff, and shown in figure 13.2 overleaf.

FIGURE 13.2

LGA RAMP CONTROL LOG

MID: _____ AM: _____ PM: _____ OFF: _____ DATE: _____

FREQ.	FROM....	FLT	SHIP	SKD ARVL	ETA	ACT. ARVL.	GATE	T W R	R M P
DAL-LGA XS	LAX 1735 DAL2250 MEM 0040 BNA 0200 IAD 0455 100	620		0543			5		
	LAX 1950 PHX 2125 TUS 2225 ELP 0050 100 90	90		0631			2		
XS	BUF 0610 ROC 0700 400	456		0757			5		
XS	BUF 0700 TO DCA 100	524		0802			10		
XS	BOS 0730 TOLAX 200	125		0822			6		
XJS	DCA 0730 TO DTW 100	492		0827			8		
J B	DCA 0730 400	492		0829			8		
XS	SYR 0745 400	418		0836			9		
XS	CLE 0730 200	360		0840			2		
XJS	BOS 0800 TO DCA 400	585		0852			10		
XS	YYZ 0750 TO BOS 200	374		0901			7		
XS	BOS 0830 200	381		0922			6		
XJS	DCA 0830 TO SYR	494		0932			11		
XJS	ROC 400	442		0934			4		
XJS	ORD 0700 TO BOS 200	260		0948			7		
	BUF 0850 200 (100 J B)	330		0954			2		

SOURCE	FLT	SHIP	SKD DPTR	PLND PRBL.	GATE	TO....	FREQ. MEAL	TIMES PRE.	TIMES ACT.	DELAY
0	409		0700		8	ROC 400	XJS V			
0	691		0700		1	ORD 100	XJS B			
0	495		0700		3	DCA TYS MEM LIT 100	XS V			
0	329		0700		6	BUF 200 (100 J B)	XS V			
0	505		0705		9	ALB ORD 100				
0	539		0715		11	SYR 400	V			
0	429		0730		10	DCA 100	XJS V			
620	401		0730		5	YYZ 100	XJS V			
0	518		0730		7	BOS 200 (400 S B)	V			
0	617		0755		4	BUF 400	XJS V			
0	357		0755		9	CLE DAY DAL TUS 100	XJ B			
0	141		0755		8	DTW 100	XS B			
0	OZ 907		0800		3	IAD DSM SUX FSD	XS			
0	231		0800		1	ORD 200	XS B			
0	247		0800		6	SDF MEM DAL LAX 200	B			
0	612		0830		7	BOS 200	XS V			
524	524		0830		10	DCA FROM BUF 100	XS V			
90	143		0830		2	PIT HOU SAT SFO 100	B			
0	241		0840		3	CVG 100	XS V			
458	413		0845		5	ROC 400	V			
125	125		0850		6	FROM BOS STL TUL OKC LAX 200	XS V			

13.1.4 Gate Timetable, April, 1969.

The operational timetable is shown in figure 1 and its analysis is given in table 1, both in appendix 13. The mean station separation time is seen to be 35.4 minutes with a relative dispersion of 0.81. Both these values are lower than any of the plans simulated. This is caused in part by the ban on night flights, resulting in a first departure at 0700 hours, an no long separation times early in the morning. Although not a FOFI plan, the gates, excepting number four, appear to be reasonably evenly utilised. The number of occupancies per gate varies only from eleven to thirteen while the percentage time occupied ranges from 50.5 to 69.4.

13.1.5 Passenger Handling.

Each gate has an adjoining passenger lounge where all passenger check-in is done. "Skycaps", i.e. baggage agents, check in the bags of confirmed space passengers at the terminal building kerbside but no boarding passes are issued there. Standby passengers must carry their bags to the forward lounge.

Gate information is displayed on manually operated boards behind the reservation desks in the main building. Although announcements of the imminent departure of a flight are made over the public address system, the opening of a gate area for check-in is not. Departing passengers proceed to the gate shown on the departure board, allowing processing to commence before the arrival of their aircraft.

This eliminates the mad rush to a gate, all too often observed and experienced, at airports where the display of the gate number is witheld until the last moment and is accompanied by a loudspeaker announcement. Early publication does of course imply the planned occupancy sequence provided by a gate timetable.

Unfortunately, a late gate change does involve the transfer of processed passengers to the new lounge, but no occurrence of this was recorded during my three week study.

13.1.6 Ramp Control Tower.

Ramp Control is responsible for monitoring the progress of inbound flights, the allocation of gates, the co-ordination of ramp activities, and for informing downline stations of a La Guardia departure.

The Control is exercised from a tower positioned between gates 6 and 7 on the roof of the concourse from which an excellent view of the American gates is available. Four staff are accommodated there comprising:-

i) Ramp Manager, responsible for co-ordinating the complete activity of the station.

ii) An arrival agent responsible for preparing estimates of arriving flights and recording their delays, etc.

iii) A departure agent responsible for informing downline stations of flight details, including initial arrival estimates. He also records departure punctuality.

iv) A ramp planner, who, acting on arrival and departure estimates from his two colleagues, confirms or amends the planned gate allocation.

Incoming Flights.

All airports serving La Guardia directly, have a telephone link to the ramp tower and use it to inform the arrival agent of flight departure times and initial arrival estimates. These are confirmed by a teletype message providing more information including the flight control points en route. As each of these control points is passed, revised arrival estimates are made until the flight is within 40-60 miles of La Guardia when it is picked up on a monitor of the FAA approach frequency. The accuracy of arrival estimates made before radio contact is +5 to -10 minutes at the gate. No conversation is conducted between the arrival agent and the aircraft.

These estimates permit the ramp planner to judge whether the planned gate will be available or not. If a change is not envisaged, no further action is required by him. The station staff are aware of the gate from the pre-printed schedule, as is the air traffic controller. Only the occurrence of a

13.1.6 gate change prompts him to inform all departments. Where possible this is done at least one hour before the next scheduled departure of the aircraft or before the flight arrival, whichever is earlier. Maximum advance warning is essential since American rely on air traffic controllers to inform the aircraft. Their workload and that of the air crew do not permit a constant monitoring of the gate situation and they cannot guarantee an immediate response to a gate change signal. Thus changes are sometimes incurred, which could have been avoided if the aircraft were allocated its gate by American personnel after arrival.

Departing Flights.

The ramp tower is not concerned with flight plans, crew briefings, etc., its sole object being to clear the gate on schedule in preparation for the next arrival. The ramp manager has direct links to personnel of all departments and by this means identifies potential delay areas and co-ordinates their activities.

The departure agent informs the downline station of departure time and estimated arrival time.

13.1.7 Flight Dispatch Centre.

American's system wide operation is controlled and monitored by three dispatch centres, each with regional responsibilities. These are located at New York (JFK), Chicago (ORD), and Los Angeles (LAX). Their responsibilities include:-

i) Production and verification of all flight plans.
ii) Production of weather information for flight crew.
iii) Aircraft cycle changes and type changes.
iv) Cancellation of services.

13.1.7.1 Flight plans are formulated by an IBM system (FLIPLN) using raw meterological data supplied by the Federal Weather Bureau. Print outs include:-

fuel used at specified points of the flight
total fuel burn off
total fuel bill
altitude recommendation
time of climb, cruise and descent.

13.1.7.1 Three such plans are produced for each flight from which the captain makes his selection, unless none are acceptable in which case further alternatives may be produced. The flight plan must be signed by a dispatch officer before any flight is released.

13.1.7.2 The dispatch centre deals directly with flight crew at JKF, ORD and LAX but are also responsible for distributing weather information to all stations in their area.

13.1.7.3 Aircraft and type changes may only be made on the authority of the relevant dispatch centre personnel. They alone are in possession of all parts relating to crew availability, passenger load factors, runway limitations, etc. They do not, however, control the maintenance function. Thus having chosen the best operational change sequence, they must have this confirmed by MOC (see below).

13.1.8 Maintenance Operations Centre (M.O.C.)

M.O.C. is situated at the maintenance base in Tulsa, Oklahoma. It is responsible for the planning and recording of all aircraft maintenance, Consequently, it controls the aircraft routings or cycles, but does not have operational responsibilities towards reducing delays by initiating aircraft changes.

M.O.C. has three sections described as follows:-

13.1.8.1 Long term planning section, advance programmes.

i) Maintenance workload generated by the next schedule change is estimated.

ii) System and aircraft reliability is monitored.

iii) Maintenance performance at each station is monitored.

iv) Maintenance targets are set for stations.

13.1.8.2 Medium term planning section.

i) Maintenance is planned on monthly and weekly time scales, using aircraft registrations.

13.1.8.2 ii) Aircraft hours are updated once per week and aircraft whose flying must be restricted to a given number of hours per week until their next schedule check, are identified.

iii) Special checks and component changes are scheduled, again on a weekly and monthly basis.

13.1.8.3 Immediate operational requirements section.

i) Records are maintained of all aircraft unserviceability.

ii) Outstanding defects on each aircraft are monitored.

iii) Aircraft are allocated to cycles such that they will be positioned at a maintenance station for a planned check.

iv) Individual aircraft cumulative flying hours and landings are updated once per day on the completion of their cycle.

v) The following days flying hours are estimated.

vi) Each maintenance station is informed daily of its overnight workload and the target time for the maintenance aircraft's serviceability the following day.

vii) Constant liaison with the medium term group is essential.

From the above it is apparent that MOC must have the authority to accept or reject a request for a specific aircraft change. Having accepted one, MOC permit the aircraft to remain on their new cycles, thus retaining turnround reliability.

13.1.9 Aircraft Changes.

The two major causes of aircraft changes, viz. unserviceability and late arrivals, are treated in a similar way.

13.1.9.1 Unserviceability.

i) Station foreman informs ramp manager and estimates time of aircraft serviceability.

ii) Ramp manager discusses position with Dispatch Centre who decide whether to accept delay,

13.1.9.1 ii) cancel the service, or request an aircraft change.

iii) Irrespective of Dispatch's decision, MOC is informed of unserviceability.

iv) If a change is preferred, MOC are asked to confirm it.

v) The decision is referred back to the ramp manager who co-ordinates any necessary station action.

It is important to note that the foreman is not involved in the aircraft change decision. His duty is to report the unserviceability and to make a technical assessment of its probable duration. Dependant on this and on whether a change is confirmed, the ramp manager will instruct him either to complete the rectification while positioned at the gate or to have the aircraft removed to an off-line area.

13.1.9.2 Late arrival.

The procedure is very similar to the above with the following exceptions:

i) Neither the station foremen nor MOC are involved unless an aircraft change is decided upon.

ii) Either the ramp manager or dispatch may originate the discussion between them regarding cancellation, change, etc.

13.2 United Airlines.

13.2.1 United Airlines is the largest domestic operator in the United States, with its headquarters near Chicago and its maintenance base in San Francisco. On 27th April, 1969 it had 337 passenger or quick change aircraft in service.

It was studied mainly because of its size. Six weeks were spent at O'Hare Airport, Chicago, while one week was spent at Los Angeles.

O'Hare was chosen purely on account of the size of United's operation there, and the Los Angeles study was intended to ascertain if the same procedures and controls were used at a smaller, but still important station.

13.2.2 O'Hare Airport.

All three airports at Chicago are run by the Chicago City Council, and O'Hare was converted from a military airfield with money raised by the US Domestic airlines themselves. As a result of this the airport authority operates with the absolute minimum of interference with the airlines, preferring to let them get on with the job of carrying passengers and freight whilst they, for their part, maintain and develop the facilities to ensure smooth running of the airport.

The airport authority is not responsible for air traffic control, approach control or ground movement control which is in the hands of the FAA and operated essentially from the Control Tower.

They are responsible for the maintenance and upkeep of runways, taxiways, roads, buildings and joint user installations such as the hydrant refuelling system.

The airlines rent concourses and tarmac areas from the authority, and are completely responsible for any alterations or additions they may make in their area, and for the control of all activities in that area.

This means in practice that ATC Ground Movements Control will direct an incoming aircraft to a company's tarmac area and then hand over to the company's ramp controller who will direct the pilot to the gate position which has been pre-planned for this service.

The airport authority is not concerned how long an aircraft is at a gate position, nor how many aircraft a company can get on to any one gate or group of gates (for example, Ozark airlines were getting 4 aircraft on to two gate positions by double parking).

The authority is responsible for cleaning, lighting, building maintenance, runway and tarmac cleaning and maintenance (tarmac cleaning is done <u>for</u> the airlines who are free to do it themselves or get someone else to do it), snow removal, policing and general administrations.

The United facility consists of a Y shaped concourse with 21 gate positions, and is sketched overleaf in figures 13.3 and 13.4.

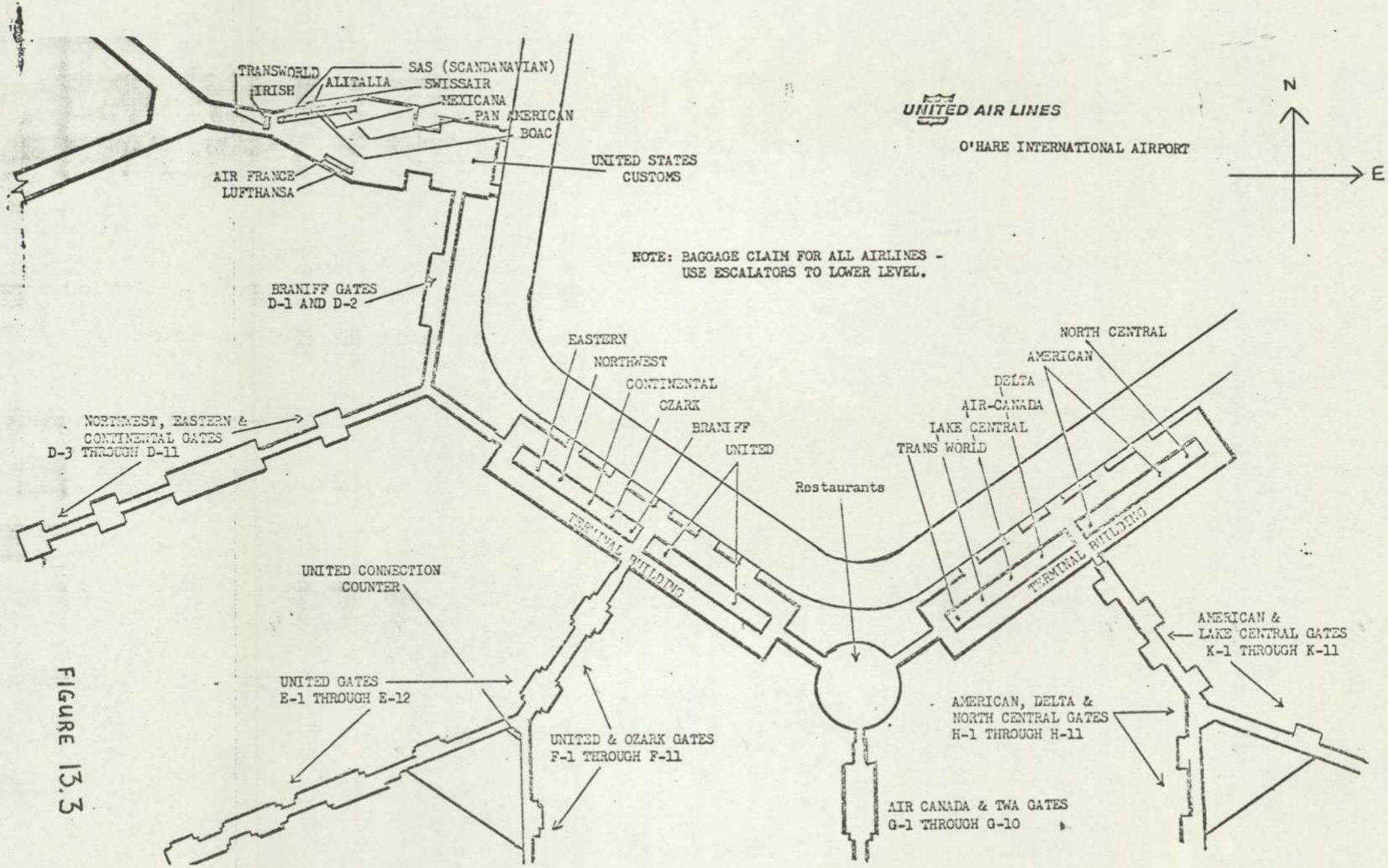

UNITED AIR LINES
O'HARE INTERNATIONAL AIRPORT
N
E
TRANSWORLD
IRISH
ALITALIA
SAS (SCANDANAVIAN)
SWISSAIR
MEXICANA
PAN AMERICAN
BOAC
AIR FRANCE
LUFTHANSA
UNITED STATES CUSTOMS
NOTE: BAGGAGE CLAIM FOR ALL AIRLINES - USE ESCALATORS TO LOWER LEVEL.
BRANIFF GATES D-1 AND D-2
NORTHWEST, EASTERN & CONTINENTAL GATES D-3 THROUGH D-11
EASTERN
NORTHWEST
CONTINENTAL
OZARK
BRANIFF
UNITED
NORTH CENTRAL
AMERICAN
DELTA
AIR-CANADA
LAKE CENTRAL
TRANS WORLD
Restaurants
TERMINAL BUILDING
UNITED CONNECTION COUNTER
UNITED GATES E-1 THROUGH E-12
UNITED & OZARK GATES F-1 THROUGH F-11
AMERICAN & LAKE CENTRAL GATES K-1 THROUGH K-11
AMERICAN, DELTA & NORTH CENTRAL GATES H-1 THROUGH H-11
AIR CANADA & TWA GATES G-1 THROUGH G-10

FIGURE 13.3

UNITED'S FACILITY
O'HARE

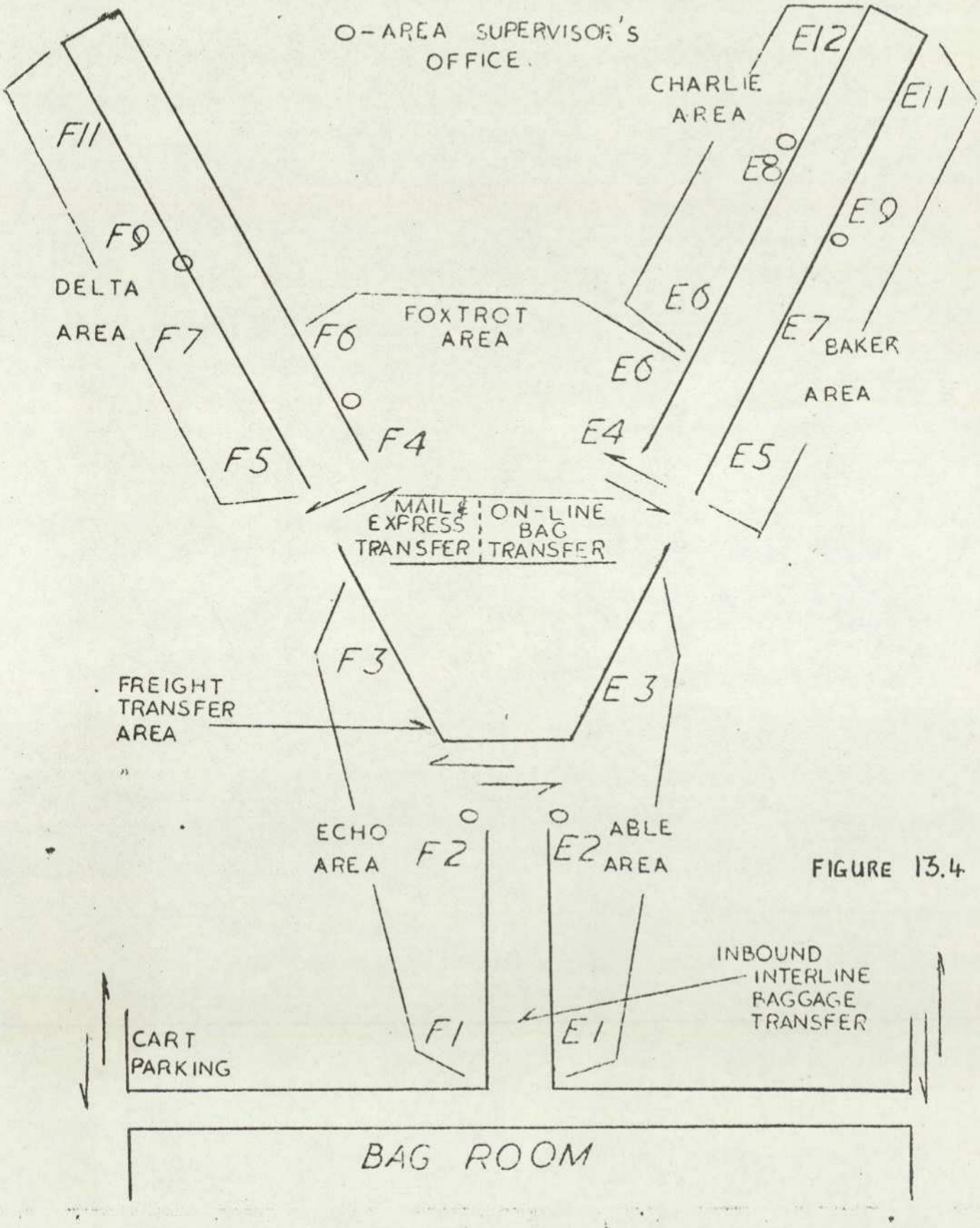


FIGURE 13.4

13.2.3 Los Angeles Airport.

The airport is run by Los Angeles City Authority on a basis very similar to that at O'Hare. The airlines lease gate and terminal areas from the authority, and the above comments in 13.2.2 apply equally well to Los Angeles.

The United facility consists of one satellite complex with nine gates and one concourse with four gates. Each gate is equipped with air jetties. The layout is sketched overleaf in figure 13.5.

13.2.4 Airport gate capacity as a constraint on schedule construction.

When constructing a new schedule, the availability of gates is a positive constraint, as was seen to be the case with American.

Although twenty one gates are available at O'Hare, the schedule planners ensure that a projected schedule requires only eighteen of them together with a minimum separation time of fifteen minutes. The other three gates are designed to be an allowance for extra flights and flight delays.

At the planning stage, no reduction in gate capacity at Los Angeles was assumed, though a minimum separation time of fifteen minutes was adhered to.

The only reason offered by UAL staff for this difference between the two stations was one of experience. It had been found that the scale of operation at O'Hare demanded this special approach which was not warranted at L.A.

It should be noted that United did not stipulate a minimum time between departures as did American.

A minimum gate occupancy time for originating departures and for terminating arrivals did exist, depending on aircraft type.

Gate restrictions in terms of aircraft type were present at both airports and were considered at schedule construction stage, not as individual gates, but as a total resource limitation.

LOS ANGELES AIRPORT

DOMESTIC TERMINALS

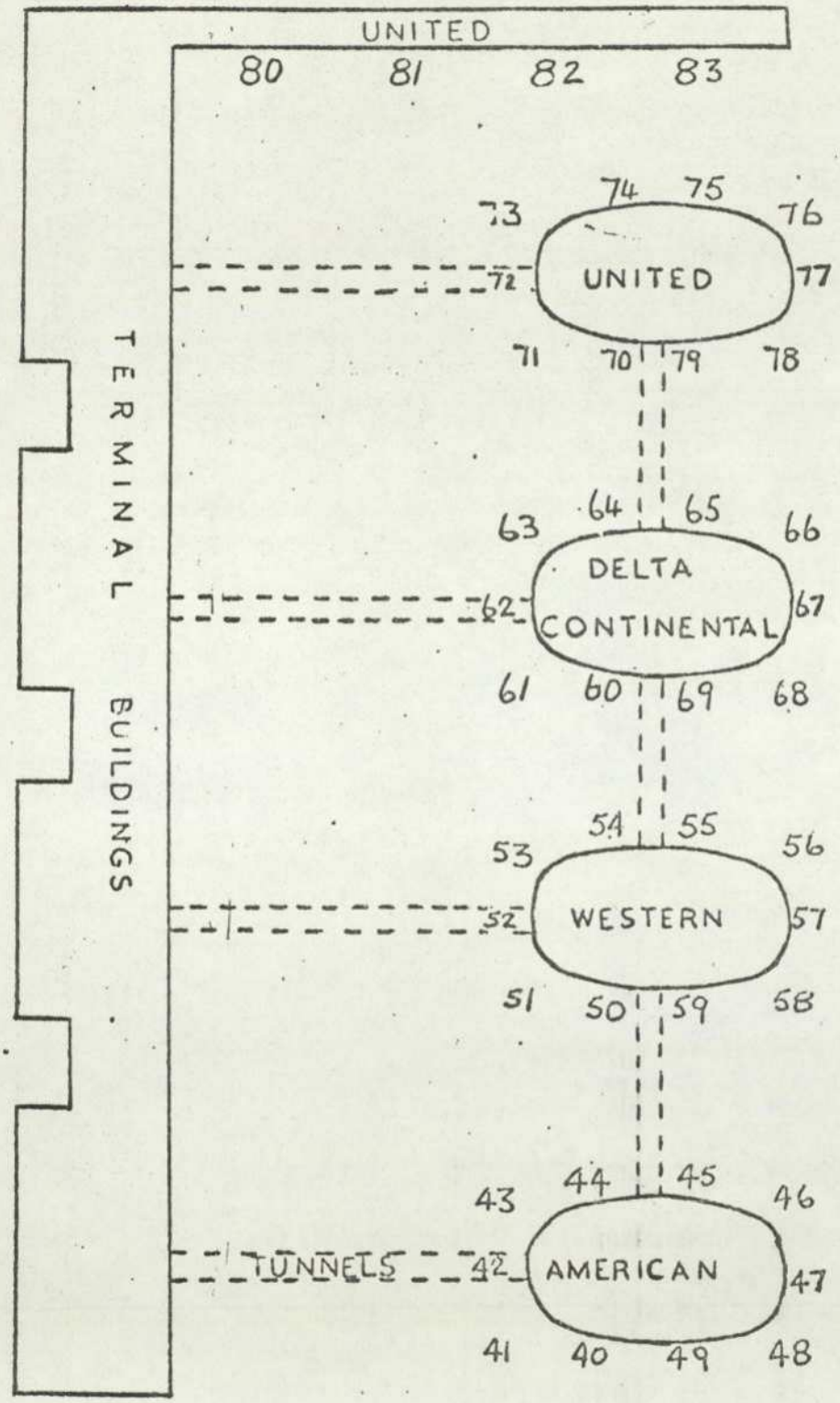


FIGURE 13.5

NOT TO SCALE

13.2.5 Formulation of the operational gate timetable.

This is the responsibility of station staff and in particular the ramp planner, whose duties are more fully explained in section 13.2.8.2.

UAL operate an annual fixed shift pattern, with staff allocated to one of three eight hour shifts. Since each one handles the same flights every day it is in their interest to ensure that the gate timetable for their duty tour is planned in accordance with the way in which they feel best suited to implement. Consequently, the gate plan is created in three sections by the ramp planner on each shift. The gate allocation of occupancies close to the shift change point are agreed between the two planners.

The gate utilisation is therefore planned by the operational staff whose success is measured, in part, by that of their own plan. In this context it was felt unnecessary to provide detailed guidelines for its construction.

Minimum occupancy times are of course provided together with any policy decision such as the desire to have all Honolulu flights (say) departing from a specific gate.

Los Angeles and O'Hare both operate in this manner.

13.2.6 Gate Timetables.

The operational plan at O'Hare is UAL1, discussed in previous chapters. 218 scheduled departures were operated from 21 gates in summer 1969.

The Los Angeles timetable is shown in figure 2 of Appendix 13 and analysed in table 2. The mean station separation time is seen to be 37.4 minutes, with a relative dispersion of 0.88 . The number of occupancies per gate using the variable time span figures, ranges from seven to thirteen.

126 scheduled departures were operated from 13 gates during summer 1969.

13.2.7 Passenger handling, both airports.

This is similar to American at La Guardia in that all passenger check-in is done at the gate. A "Skycap" service is operated but supplemented by baggage check-in facilities in the terminal building itself.

13.2.7 Flight and gate information is displayed on an electronic board in the main terminals, and on TV monitors situated throughout the concourses and satellite building in the case of Los Angeles.

13.2.8 Operations Planning Centre, both stations.

The Operations Planning Centre is responsible for the co-ordination of all turnround activities. In charge is the "Co-ordinator", whose main duties are supervisory and as an arbitrator when a conflict of departmental interests jeopordises a turnround.

Neither stations have Planning Centres which command a view of the United gates.

The information displayed in the Planning Centres takes two forms.

Down one wall of the rooms is a board showing the up to date planned allocation of gates to flight numbers. Each gate is represented by one line and the movements by magnetic plaques. A plumb line connected to a linear clock moves along the board from 0400 hours on the left to 0359 on the right.

Three closed circuit TV screens display the information shown on the electronic board in the terminal building. This board is itself updated from the Planning Centre.

Flight and control information is received by teleprinter, radio and telephone. The FAA approach and ground control frequencies are monitored. Arrival estimates are provided by the Flight Dispatch Centres via the telewriter based on data received from the departing station and the aircraft. These are updated when the flight is identified on the FAA monitor.

Information is broadcast from the Planning Centre using telewriters, radio and telephone, supplemented by strategically placed TV monitors of the passenger flight information board.

The duties of staff in the Planning Centre are given below.

13.2.8.1 Maintenance Planner.

Answerable through the General Foreman to the Shift Line Maintenance Operations Manager, the Maintenance Planner is the Maintenance representative in the Planning Centre, and is responsible for providing information on aircraft serviceability, and for advising on the best action to be taken to minimise the effect of delays for engineering reasons on the operation out of O'Hare.

Through flights - He is not concerned with any aircraft which are due to arrive without any prior indication of technical trouble and which turn round and continue their flight with the same flight number. He does not know and is not interested in the aircraft registration. He knows the aircraft type and is concerned that any change in gate position should be such that the turnround can still be performed from the Maintenance aspect. In practice the ramp planner knows this. The planner would inform the Ramp Foreman of any gate change and this would be repeated over the closed circuit television.

Originating and terminating flights - The Planner is concerned with all originating and terminating flights and he is given a list of aircraft registrations about 8 hours beforehand, and this information is continuously updated. These are normally the aircraft which are used to make changes to cover services for aircraft which are delayed for technical reasons. They also include aircraft which are due for scheduled minor maintenance at the Line Maintenance Hangar.

Moving aircraft - Whenever aircraft have to be moved from the ramp to the hangar or back again the Maintenance Planner is responsible for arranging the taxying crew.

13.2.8.1 Advance warning of flight snags - When it is known that an aircraft will arrive with an uncleared flight snag the Planner makes this known to the Foreman and obtains a provisional estimate of any delay to the turnround. The effect of this on the Station Operation is then discussed by the Centre as a whole and plans made to switch aircraft if required. Only when the effect on the whole operation has been discussed will Maintenance deliberately plan to do work which will result in a delay. It may be decided to do only part of the work or try to put off the work until the next Station.

Estimates of serviceability - No maintenance work beyond the normal turnround tasks is carried out without an estimated time serviceable being given. Occasionally, when the ramp engineers have not had time to investigate, there will be a 30 or 40 minute confirmation period at the end of which they will give their estimate.

These are under constant review by the Planner since he is using them to inform the Centre of aircraft availability. The impression obtained is that these estimates are very accurate because they know that they are being used to plan the whole operation.

Fuel state - The Maintenance Planner also keeps a record of the fuel state of OFF SERVICE aircraft to avoid, as far as possible, the need to off-load fuel when it goes back into service.

13.2.8.2 Ramp Planner.

Together with a clerk (or two clerks at busy periods) he is responsible for allocating gates to incoming aircraft. To do this he is in touch with the Flight Dispatcher by Telewrite for incoming flight times, and has to keep his finger on the pulse of the turnround to anticipate a late departure.

13.2.8.2 His contact on the apron is one of five ramp supervisors each of whom control one of the areas marked in figure 13.4. Radio and telephone links are used.

The clerk is in radio contact with the pilot to give him the gate number as he is taxying in.

Together, they are responsible for alterations to the display board. As soon as the moving clock has passed a flight and it has departed from the gate the board is altered to revert back to the original gate plan in readiness for the following day's operation.

As with all other facets of the Planning Centre, information about gates is issued by the ramp planner on an "exception report" basis. When flights are being allocated their correct gates, the information display in the terminal is updated by a Planning Centre clerk without instruction from the planners.

The clerk includes in the display, the latest flight arrival estimates which are received by telewriter from the Dispatch Centre.

Only in the case of a gate change is the ramp planner required to broadcast his decision.

13.2.8.3 Passenger Planner.

The passenger planner is the link man in the Planning Centre between the Planning Centre and on-site supervisors responsible for non-technical aircraft preparation, passenger check in and boarding. He is contacted only when a hitch occurs during a turnround. Otherwise the Co-ordinator expects an on time departure.

The passenger planner has the latest listing of passenger loads on all flights. Details of connecting passengers are also maintained. Consequently when a cancellation, type substitution or even a late gate change is being considered,

13.2.8.3 the passenger planner plays an important role in the decision making.

13.2.8.4 The Co-ordinator.

The Co-ordinator is responsible to the Station Manager for the smooth operation of all flights handled by the Planning Centre.

He is the final decision maker on all operational aspects of a turnround. This obviously excludes aircraft technical decisions and the Captains flight responsibility.

When activities are proceeding to plan, the Co-ordinator's main function is the silent supervision generated merely by the presence of his authority. However, when disruptions occur he is the inter-departmental arbitrator.

The responsibility for a delay or cancellation is allocated by him.

Apart from immobilised aircraft, the decision to rectify an unserviceable aircraft on a gate is his, having considered the estimated duration of work and the availability of gates.

Aircraft changes are initiated by him. The subsequent procedure is very similar to American in that a "Routing Centre", performing the same function as M.O.C., exists at United's Head Office complex. The Co-ordinator suggests the change sequence to the Centre and expects it to be accepted unless an aircraft maintenance input limitation exists. This was found to apply in only about 5% of requests.

13.2.9 Routing Centre.

This is situated in the United Head Office complex, some few miles from O'Hare field. The Centre performs a function similar to MOC in American but has additional responsibilities which, in American, are shouldered by the three Flight Dispatch Centres.

The primary function of the Routing Centre is to control and co-ordinate the entire UAL network. The activities of Flight Crews, Traffic staff and Maintenance personnel are integrated to ensure that the optimum deployment of the aircraft fleet is obtained.

The secondary function is the co-ordination of maintenance work such that its distribution amongst the stations results in the best utilisation of maintenance staff consistent with traffic demands and aircraft limitations.

For flights over 1000 miles, the Centre also provides a flight planning service. The station of flight origin prepares the plan for take off and climb phases, but the cruise, descent and landing stages are planned by the Routing Centre.

The above three responsibilities emphasise the system-wide approach which is adopted by all Routing Centre personnel.

13.2.9.1 Organisation of the Routing Centre.

The Centre is divided into groups, each responsible for one aircraft fleet, part of a fleet, or two fleets, dependent on their size.

In charge of each group is the Assistant Planner whose staff comprises:

i) Route Planner
ii) Equipment Planner
iii) Flight Crew Planner.

Each Assistant Planner reports to the Routing Centre Planner who has the overall administrative and control responsibility.

An additional group is controlled by the Line Maintenance Planner and provides technical guidance to the fleet Assistant Planners as required.

13.2.9.2 Responsibilities of personnel.

1. Planner.

He is responsible to the Vice President Operations for the entire UAL network. He is concerned only when things go wrong and cannot be corrected within the sphere of an Assistant Planner. Aircraft type changes for example require his authority, as do cancellations.

2. Assistant Planner.

He is responsible to the planner for the entire UAL operation of his aircraft fleet(s). He co-ordinates the activities of the following three people.

2.1 Route Planner.

He is responsible for allocating aircraft to cycles which are consistent with the limitations imposed by scheduled and un-scheduled maintenance. Aircraft changes are not normally originated by him. It is normally the station co-ordinators who request a specific change and seek his approval.

Information on scheduled work is passed to him from the San Francisco Base at least 100 flight hours before it is required.

2.2 Equipment Planner.

He is responsible for ensuring that the correct aircraft configuration is available for a planned service. This may involve configuration changes on the ramp. He ensures that staff are available to carry out the changeover and that the station concerned is advised.

2.3 Flight Crew Planner.

He is responsible for ensuring the availability of flight crew. As with the Route and Equipment Planner, most of the routine work

2.3 is done by the stations themselves, according to his initial plan, changes to which require his approval.

3. Line Maintenance Planner.

He is responsible to the Senior Vice President Line Maintenance for monitoring all technical defects and for providing specialist advice to stations with limited or no Maintenance personnel.

He works closely with the Assistant Planners to ensure that aircraft with defects are routed, where necessary, to stations with rectification capabilities.

13.3 Delta Airlines.

13.3.1 Delta Airlines has its Head Office and Maintenance Base in Atlanta, Georgia. During June, 1969, it operated 129 jet and 3 piston engined aircraft. The jet equipment included D8s, Super DC8s, DC9s and Super DC9s. The jet fleet had increased to 163 by March, 1974.

13.3.2 Atlanta Airport.

Delta leases two concourses from the Airport Authority and, like United and American, has complete control over their gate areas.

The terminal buildings are sketched in figure 13.6 overleaf. Each concourse has three gates along each side and a rotunda at its end providing a further six boarding positions. Each gate area has its own lounge and check-in desks.

Delta leases one additional gate on the neighbouring concourse but uses it as little as possible.

All aircraft are parked nose-in and require a tractor push-out.

13.3.3 Airport gate capacity as a constraint on schedule construction.

Atlanta is the busiest station on Delta's network and is used as a transit point by 60-70% of passengers passing through it. As a result of this, Delta schedule their flights into a number of limited periods, or "pushes" as they are called.

This reduces the connecting time for passengers but does lead to a very irregular demand on facilities and staff.

DELTA AIRLINES.

ATLANTA AIRPORT.

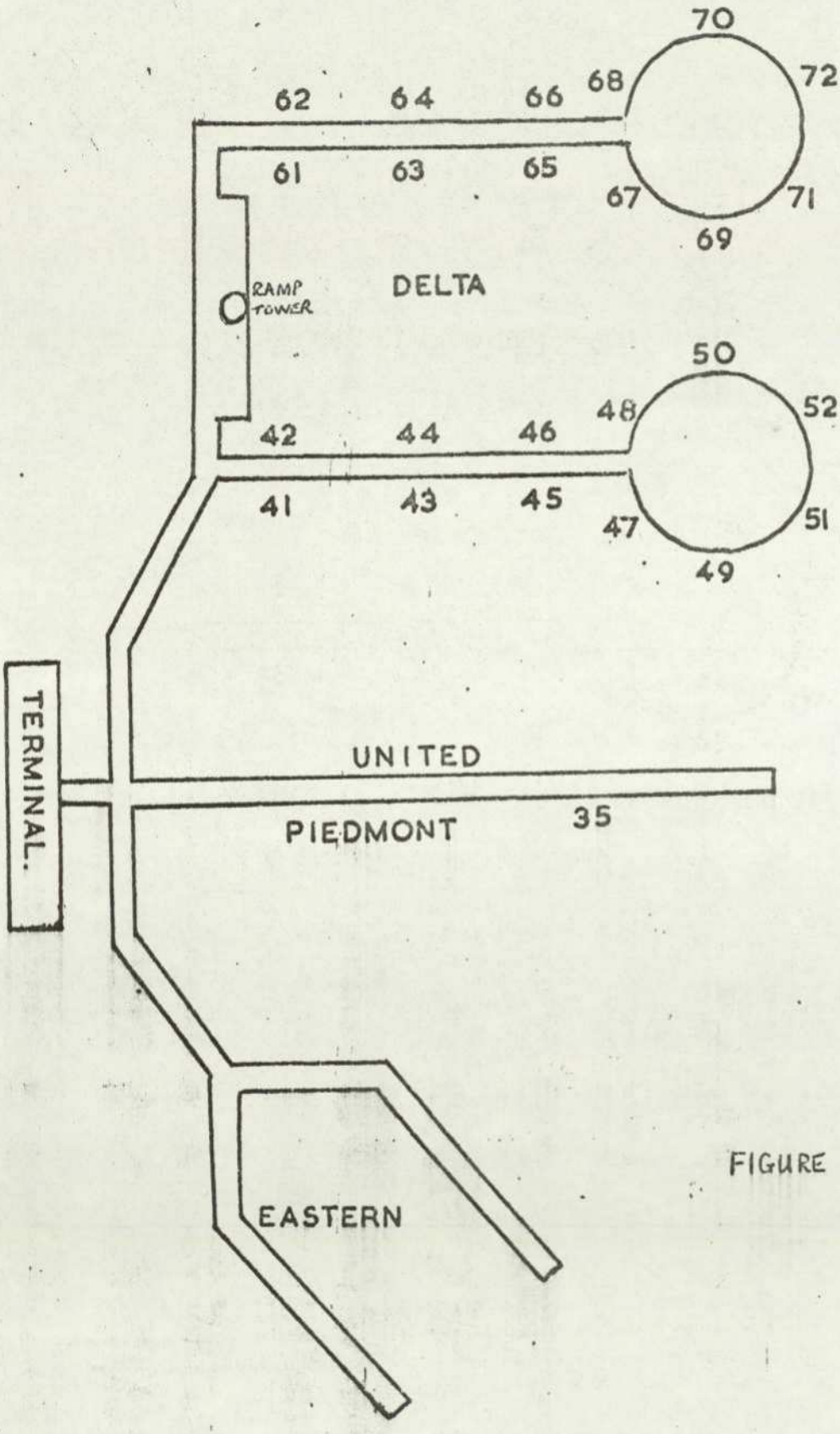


FIGURE 13.6

13.3.3 The operation during June, 1969 was divided into four major and three minor pushes as follows:

Major Pushes		Minor Pushes	
Time Span	No.of Departures	Time Span	No. of Departures
0615-0655	24		
1014-1055	26		
		1125-1245	24
1550-1630	23		
		1715-1808	19
		2015-2110	23
2347-0015	17		

Out of a total of 185 scheduled departures, 156 were planned to occur in these seven time spans.

The main gate limitation at Atlanta is therefore the total number of gates required during these pushes. The minimum separation time has no application because of the periods of relative inactivity which occur between the peaks.

During schedule construction, there is no need to generate a possible gate plan, like United, since it is sufficient to ensure that the peak occupancy demands can be met.

The operational gate timetable is formulated by station staff, initially in bar chart form. Gate restrictions do exist but within these, the main consideration is to reduce the distance between aircraft which are known to have a large number of transferring passengers. The pattern of connecting passengers has been built up from historical information.

The final plan is transcribed into diagrammatic form shown in figure 13.7 overleaf. This is the reference document of the Ramp Planner.

13.3.4 Gate Timetable, June, 1969.

The operational plan for June, 1969 is shown in figure 3 of appendix 13 and its analysis in table 3. The mean station separation time is seen to be 93.6 minutes with a relative dispersion of 0.75. The mean occupancy time is 47.3 minutes.

Effective April 27, 1969

0001- 1330

TIME	FLT. NO.	GATE	FLT. NO.	TIME		TIME	FLT. NO.	GATE	FLT. NO.	TIME
ORIG-0006	174		276	ORIG-0004		2316-0008	164		155	ORIG-0009
0529-TERM	65		278	0546-0618		0530-TERM	154		728	0113-TERM
ORIG-0625	339		324	0926-1015		ORIG-0629	552		670	ORIG-0615
0935-1020	351	72 71	512	1142-1216		ORIG-0816	386		609/647	0901-TERM
1120-1201	632					0925-1018	741	52 51	322	ORIG-1034
						1109-1141	355		334	1109-1145
					35					
ORIG-0001	51		176	ORIG-0002	507	0536-0634	64		159	0525-0631
ORIG-0625	50		537	ORIG-0617	0903-	0820-0846	527		5	0935-1025
0925-TERM	552	70 69	634	0931-1020	TERM	0937-1019	747	50 49	547	1106-TERM
ORIG-1028	505		729	1105-1209	542	1139-1220	733		598	ORIG-1211
1108-1212	529				ORIG-					
					1055					
0545-0615	172		724	ORIG-0635		OLR 0046-TERM	371		635	2300-0005
ORIG-0745	656		536	ORIG-0820		0540-0621	153		128	0533-----
0931-1023	580		725	0943-1014		0901-0925	702/614		770	ORIG-0620
1101-1149	717	68 67	368	1110-1140					737	0855-0931
						0932-1027	919	48 47	710	0944-1017
						1109-TERM	337		742	1105-1155
						ORIG-1201	732			
						1306-TERM	719			
ORIG-0400	189		940	2306-0003		2335-0007	287		126	0521-TERM
0535-0619	199		818	0320-TERM OLR		0538-0626	182		128	---- 0616
ORIG-0740	823		98	0534----		0935-1017	825	46 45	20	0938-1015
0944-1033	904	66 65	852	0724-TERM		1104-1142	980		943	ORIG-1217
ORIG-1210	897		829	ORIG-0816						
			973	0940-1031						
			819	1046-1143						
ORIG-0050	123		288	2320-0005		0124-0205	896		283	0538-0626
0530-0622	124		98	---- 0630		0545-0623	184		880	0938-1036
ORIG-1029	25		22	0944-1032		0937-TERM	816	44 43	845	1143-1221
1110-TERM	381	64 63	108	1105-TERM		ORIG-1245	839			
ORIG-1214	650		9	ORIG-1215						
2326-0010	129		281	0531-0624		ORIG-0636	709/41		431	ORIG-0636
			436	0908-TERM OLR					406	0901-TERM OLR
R 0037-TERM	36		803	0938-1026					303	0943-TERM
0545-0628	121					OLR 0905-TERM	422	42 41	391	ORIG-1055
0938-1030	27/885	62 61				0940-10X	331			
1130-1215	35					ORIG-1050	449		433	ORIG-1224
						1107-1149	428			

FIGURE 13.7

13.3.4 There are nevertheless 17 separation times of less than 15 minutes, and a small degree of disruption to the gate plan can be expected on their account. However, 10 of these are either commenced or terminated by a tow-on or tow-off respectively. These operations are less likely to create a gate hold or change situation than a flight movement.

The reliability of the Delta plan should be high and is indeed essential for the smooth operation of the pushes. The level of activity preceding and during them is so intense that even a small number of gate changes upsets the momentum of station staff.

In fact, Delta's plan can be compared with one created under the LOFI policy. Both exhibit long separation times which are not intended to provide extra capacity for an increase in scheduled flights. In the case of LOFI, they are designed to accommodate occupancies which are displaced from highly utilised gates. In Delta's case, the long occupancies ensure that gates are available for the pushes. Their use by extra flights would undoubtedly result in a lack of capacity during the peaks.

13.3.5 Passenger handling.

This is similar to American and United. Reservation desks and baggage check-in facilities are positioned in the terminal building, while all passenger check-in is performed at the departure gate. 'Skycaps' are also in attendance at the terminal entrances.

Flight information is provided throughout the terminal building and concourses by closed circuit TV displays.

13.3.6 Ramp Control Tower.

The ramp tower is situated between the two concourses and, like that at La Guardia, affords an excellent view of all but two gates.

13.3.6.1 Only one person, the ramp agent, is positioned in the tower. His duties are:-

i) monitoring of FAA frequencies in order to alert station personnel to the imminent arrival of a flight

13.3.6.1 ii) allocating aircraft to gates and informing the flight crew of his decision.

iii) recording arrival and departure punctuality

iv) recording certain flight time parameters supplied by incoming air crew.

13.3.6.2 The communication systems available to the planner are simple but most effective. These are:

i) Radio monitors of final approach and ground control frequencies.

ii) A transmitter/receiver tuned to the Delta frequency.

iii) An open line telephone system.

iv) A microphone connected to a loudspeaker system which covers Delta's total outside ramp area.

v) A receiving and transmitting point for 'electrowriter' messages.

13.3.6.3 The ramp agent receives estimates of flight arrival times from the Flight Dispatch Centre and checks the availability of the planned gate. If a gate change is required, he broadcasts the new gate on the electrowriter and also over the loudspeakers.

When a Delta flight is picked up on the final approach frequency, a call "flight XYZ in range" is made over the loudspeakers and again on the electrowriter. Gate numbers are not quoted since the planned gates are shown on station working documents.

Having landed, the flight crew call up the ramp agent on the Delta radio frequency, and are allocated a gate. When stationary, they recall the agent and give arrival punctuality together with engine hours and block time of the flight.

It is apparent that the ramp agent has a very high workload prior to and during the major pushes. It is felt that it would be an impossible task single handed, if a gate plan was not available. It was observed that between 0900-0945 hours, 28 scheduled arrivals were processed, each generating at least four activities.

13.3.6.3 The ramp agent does not originate aircraft changes under any circumstances and so never requires aircraft registrations. Even the recording of engine and block times is done on a flight number basis.

13.3.6.4 Gate and ramp personnel, excluding refuellers, are allocated to ramp areas and not to specific flights, as they arrive. The loudspeaker and electrowriter messages give them advance warning of arrivals.

Although very effective, the loudspeaker system can only be applied when the daily flight schedule exhibits the peaked nature of Delta's. All broadcasts can be clearly heard, mainly because they tend to be made at a time when the ramp is either empty or at least devoid of noisy departing flights. This would not be the case at O'Hare say, with United.

13.3.7 Flight Dispatch Centre.

This office is located off-line in the Head Office building, and controls all aircraft on the Delta network. It provides a flight planning service to all departures and creates arrival estimates for all stations.

Requests for aircraft changes are made by the Centre either on the basis of arrival estimates, station delays or unserviceability. In general, the following policies were applied before initiating such a request:-

i) Projected delays up to 30 minutes are accepted.

ii) Projected delay between 30 and 60 minutes are considered very carefully, especially concerning:

- a) passenger load on departure
- b) connecting load to departure which may be missed if change results in an on-time departure
- c) connecting load to departure which is already in position awaiting boarding
- d) planned continuity of crew through the planned turnround.

iii) Projected delay of over one hour requires all substitutions to be considered, and delays will be accepted on other flights to spread the effect.

13.3.7 iv) Aircraft on through flights normally require unserviceability before a change is made.

13.3.8 Equipment Control Centre.

This office performs a similar function to M.O.C. with American and the Routing Centre with United.

It is situated off-line at the Maintenance Base on the perimeter of Atlanta Airport.

The allocation of aircraft to cycles is controlled on a system-wide basis and no particular attention is paid to any one station.

The aircraft routers' main functions are to ensure that mandatory maintenance is performed at pre-determined stations and that unscheduled work is allocated throughout the system as efficiently as possible.

Delta, like American and United, do not permit the Centre to record flight punctuality on a real time basis. As a result, no aircraft changes due to non-technical delays can be initiated by the routers.

System-wide unserviceability is recorded and may result in a cycle change, but even in this case the decision to perform it rests with Flight Dispatch.

Requests for aircraft changes due to in flight and station delays are always originated by Flight Control. These normally take the form of change sequence DIRECT SWAP or INDIRECT SWAP.

13.4 Western Airlines.

13.4.1 Western has its Head Office and Maintenance Base at Los Angeles. It is basically a regional carrier centred on Los Angeles, though routes to Hawaii and Alaska are operated.

13.4.2 Los Angeles Airport.

The airport terminal buildings are sketched in figure 13.5. Western lease 10 gates from the airport authority and have complete control over them and the satellite building which services them.

13.4.3 Before approval of a schedule, a gate plan is formulated but it was not possible to ascertain what restrictions, if any, were put on separation times etc.

The exercise appeared to consider peak occupancy requirements alone.

13.4.4 Operational gate timetable - July, 1969.

Western had 74 scheduled departures daily, of which 25 were through trips. More than sufficient gates were available for this operation and as a result Western did not advocate the use of one gate timetable throughout the schedule period.

A new plan was created each day and could thus accommodate unscheduled turnrounds on a planned basis. This was only possible because of the size of the operation.

A typical plan is shown in bar chart form in figure 4 of appendix 13 and analysed in table 4. The relatively low gate utilisation is illustrated by the high value of 85.7 minutes for the mean station separation time.

13.4.5 Passenger handling.

This is identical to that described in 12.2.7 for United Airlines at Los Angeles.

13.4.6 Ramp Control.

Gate planning and allocation is not supported by an organisation comparable to United's Planning Centre. However, a ramp agent is positioned in the main terminal building and has radio, electrowriter and telephone as a means of communicating with other departments.

The planned allocation of aircraft to cycles is received between 0100 and 0200 hours each day. A gate plan is then created and distributed to Station staff. Since the satellite building is administratively divided into two equal sections, the agent attempts to schedule the same departures into each area daily. No attempt however is made to further regularise the allocation.

Having adopted a gate plan, Western are then very similar to the other Airlines studied. Gate changes are kept to a minimum and as much advance warning of them as possible is given.

When adding the gate information to the passenger information displays, it is assumed that the planned one will be used unless an electrowriter message to the contrary has been issued by the ramp agent.

Incoming aircraft are informed of their gates after landing.

13.4.7 Equipment Control Centre.

The Centre is located off-line in the Maintenance Base. Their function is identical with that of Delta Airlines.

APPENDIX 13.

Figures

1	Gate Timetable. American April '69. Bar Chart.
2	United plan, Los Angeles.
3	Delta gate plan, Atlanta June '69.
4	Western gate plan, July '69.

Tables

1	Analysis of American Plan.
2	Analysis of United plan, Los Angeles.
3	Analysis of Delta Gate Plan.
4	Analysis of Western Gate Plan.
5	Planned Number of Departures per Gate - 24 Hours.
6	Planned Number of Departures per Gate in period 0830-1900.

FIGURE I

AMERICAN AIRLINES — LA GUARDIA

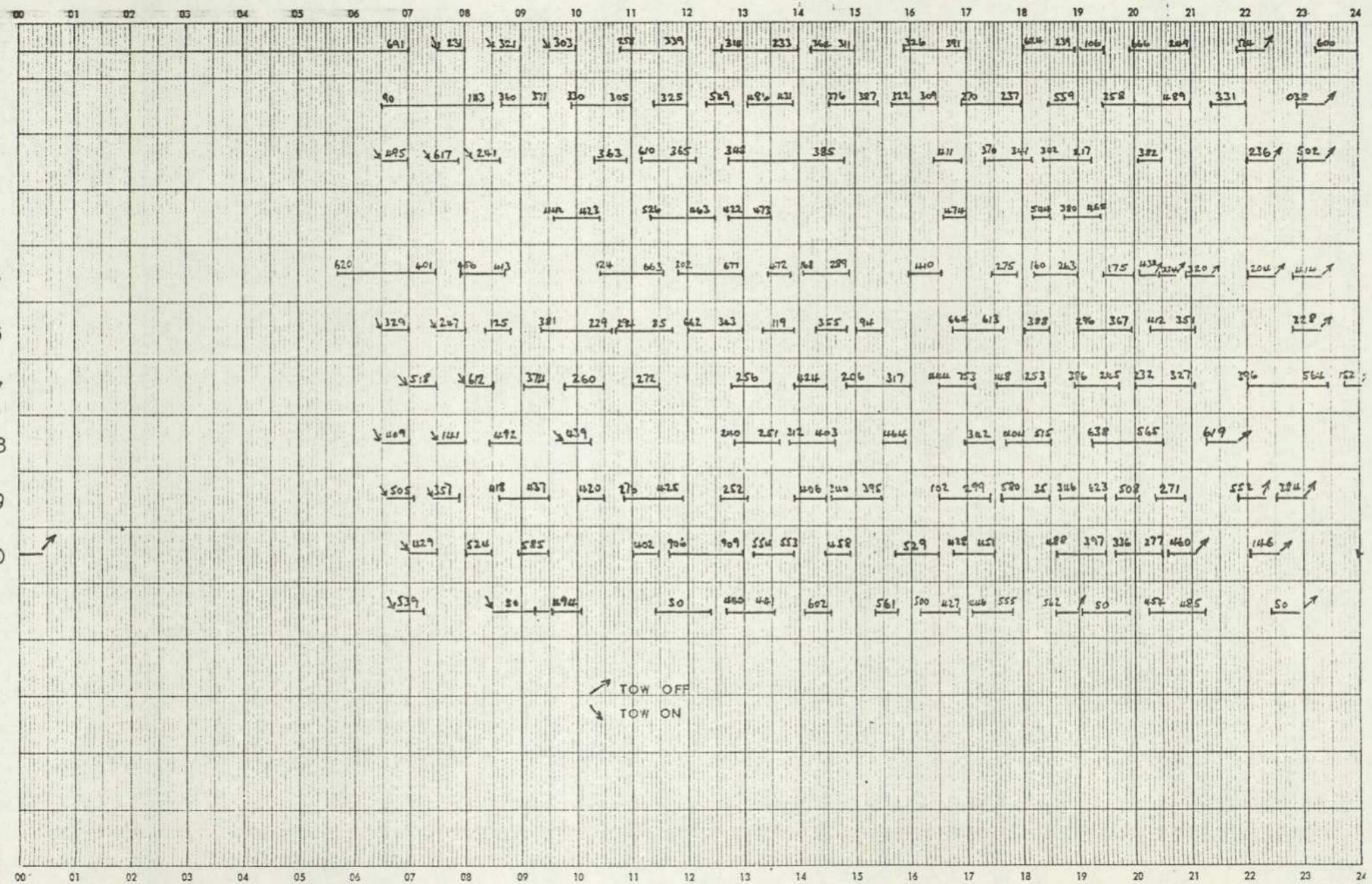
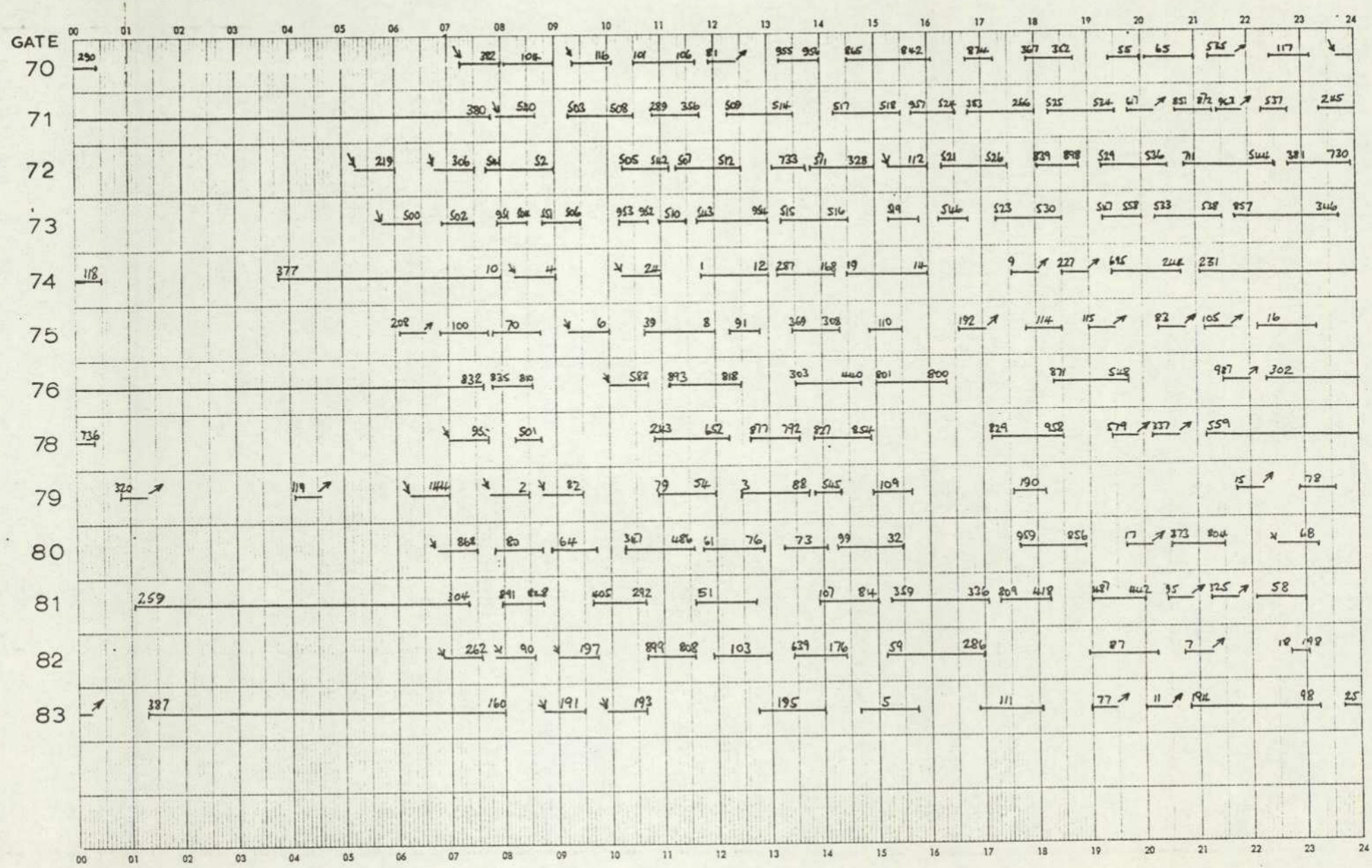


FIGURE 2

UNITED AIRLINES LOS ANGELES



DELTA AIRLINES — ATLANTA

FIGURE 3

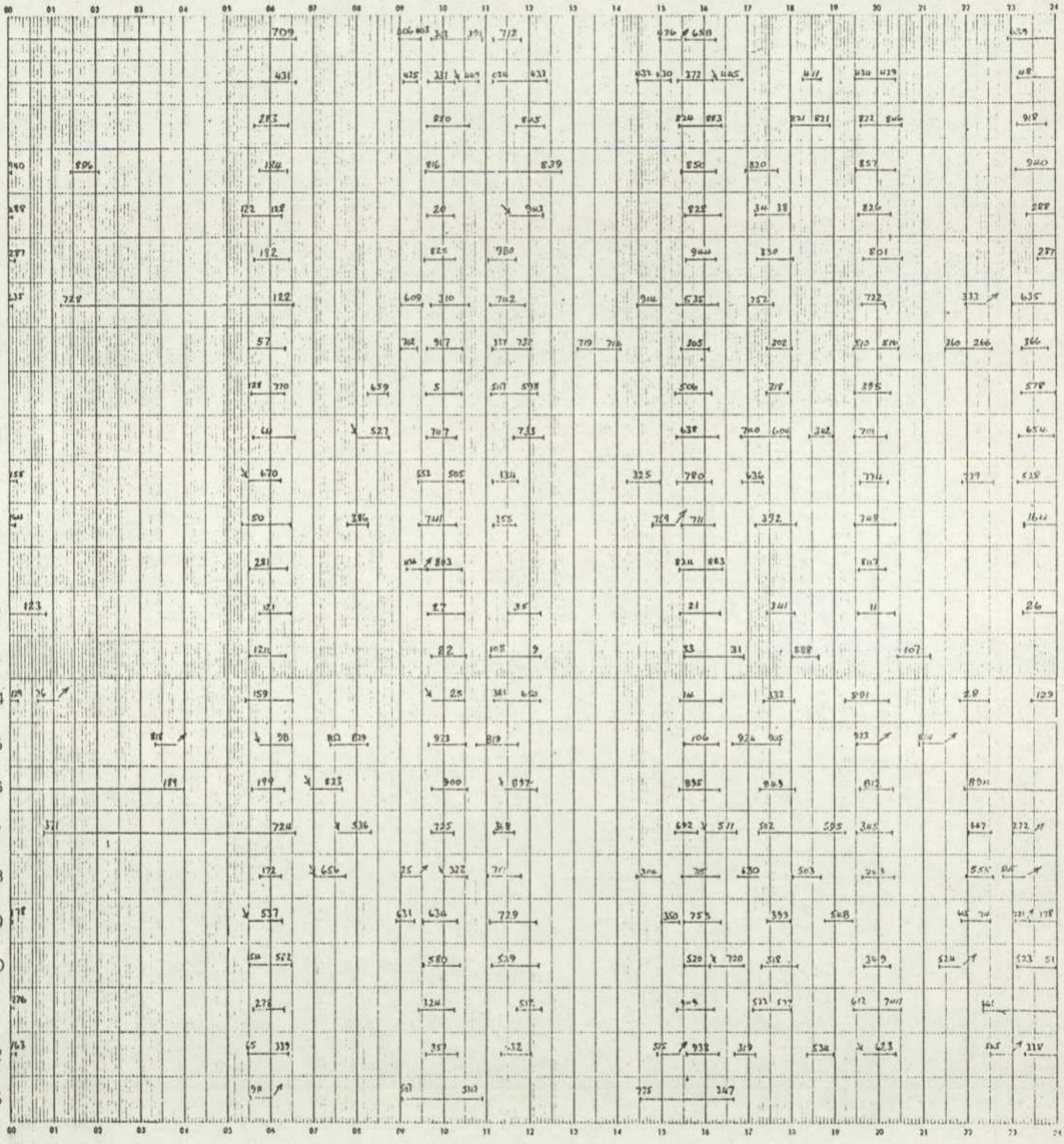


FIGURE 4

WESTERN AIRLINES – LOS ANGELES

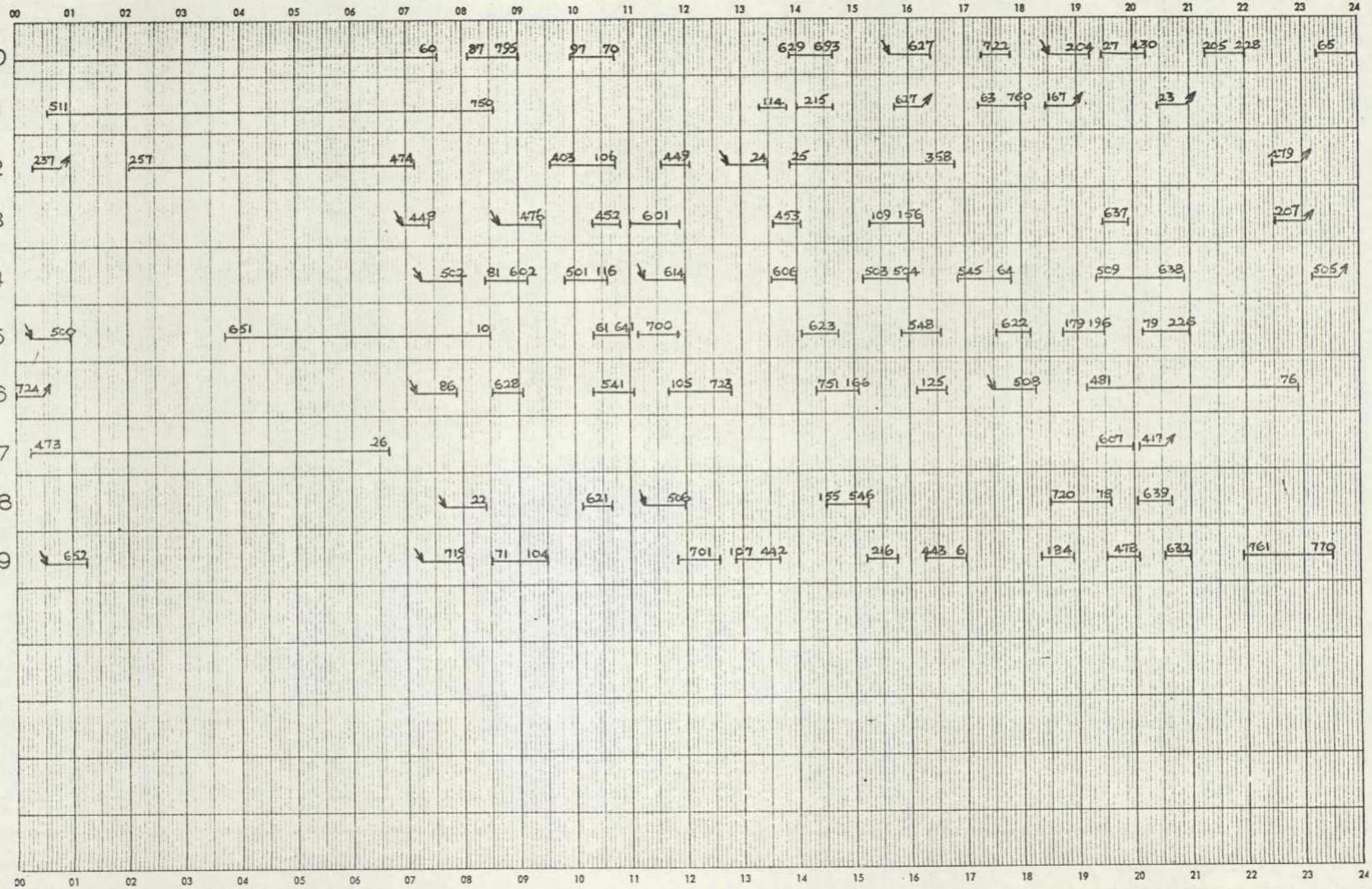


TABLE 1

AMERICAN AIRLINES, LA GUARDIA AIRPORT, APRIL, 1969

GATE	TIME SPAN	NO. OF OCCUPANCIES	SEPARATION TIMES MEAN	SEPARATION TIMES S.D.	OCCUPANCY TIMES MEAN	OCCUPANCY TIMES S.D.
1	0615-2316	12	32.6	20.3	52.4	16.6
2	0631-2255	12	25.2	11.8	56.9	26.0
3	0615-2257	11	43.0	37.3	48.1	27.6
4	0710-1951	7	66.0	61.3	42.5	17.0
5	0543-2250	13	33.2	26.0	45.9	24.2
6	0615-2248	13	30.7	28.4	45.7	15.4
7	0645-2348	13	30.7	18.1	48.1	17.3
8	0615-2118	12	30.7	18.2	44.6	14.3
9	0620-2232	13	31.0	29.4	43.7	13.2
10	0645-2400	13	38.1	29.9	41.5	14.3
11	0630-2227	11	43.0	27.6	44.0	12.4
TOTALS:		130	35.4	28.8	46.8	18.5

TABLE 2.

UNITED AIRLINES GATE PLAN, LOS ANGELES AIRPORT, JUNE, 1969.

GATE NO.	TIME SPAN	NO. OF OCCUPANCIES	SEPARATION TIMES MEAN	SEPARATION TIMES S.D.	OCCUPANCY TIMES MEAN	OCCUPANCY TIMES S.D.
70	0715-2340	13	26.7	13.9	49.1	18.2
71	0705-2319	13	21.4	12.6	53.6	18.6
72	0645-2245	11	23.7	19.5	63.5	19.4
73	0545-2144	13	25.0	12.7	48.7	19.0
74	0815-2103	8	38.5	30.4	57.5	23.2
75	0605-2210	13	32.1	15.5	42.1	15.1
76	0748-2219	7	61.0	43.4	63.4	22.2
78	0700-2109	8	53.9	48.9	52.2	22.4
79	0615-2254	9	65.1	65.4	45.9	15.6
80	0645-2230	10	36.1	37.7	58.4	15.4
81	0757-2205	9	35.6	20.8	58.7	23.6
82	0650-2245	9	47.2	35.3	58.9	23.6
83	0715-2344	9	50.2	35.1	59.7	35.0
TOTALS:		132	37.4	33.0	54.0	21.0

TABLE 3

DELTA AIRLINES GATE PLAN, ATLANTA AIRPORT, JUNE, 1969.

GATE NO.	TIME SPAN	NO. OF OCCUPANCIES	SEPARATION TIMES MEAN	SEPARATION TIMES S.D.	OCCUPANCY TIMES MEAN	OCCUPANCY TIMES S.D.
41	0859-2256	5	124.6	171.9	42.8	17.2
42	0905-2308	9	51.8	58.6	41.9	17.0
43	0538-2307	6	120.8	66.2	54.0	9.7
44	0545-2306	5	133.4	60.7	74.8	63.6
45	0521-2320	6	133.3	68.0	46.5	6.1
46	0538-2335	6	134.2	77.4	45.3	6.4
47	09-1-2300	8	65.4	53.9	39.5	11.1
48	0530-2314	9	70.1	41.7	48.1	13.3
49	0533-2313	7	105.9	57.8	45.6	12.8
50	0536-2310	8	83.0	63.7	48.8	10.9
51	0530-2306	8	88.8	63.5	43.3	10.1
52	0521-2316	8	88.5	60.8	45.9	13.9
61	0531-1933	4	162.8	123.4	47.8	12.8
62	0545-2314	6	127.3	63.2	47.5	6.0
63	0530-2026	5	120.6	76.3	58.6	18.1
64	0525-2326	7	100.6	64.8	53.9	10.5
65	0545-2057	7	80.4	73.1	49.9	11.1
66	0535-2155	7	92.0	54.4	48.0	4.0
67	0735-2300	8	67.9	69.5	47.8	30.2
68	0545-2247	10	57.4	43.2	44.8	18.8
69	0532-2322	10	68.3	65.4	38.7	14.5
70	0530-2306	8	85.5	70.5	46.5	11.8
71	0536-2220	6	118.5	55.6	48.8	10.5
72	0529-2317	9	78.8	68.6	39.9	9.1
35	0534-1430	2	197.0	25.5	71.0	58.0
TOTALS:		174	93.6	70.6	47.3	17.9

TABLE 4

WESTERN AIRLINES GATE PLAN, LOS ANGELES JULY, 1969.

GATE NO.	TIME SPAN	NO. OF OCCUPANCIES	SEPARATION TIMES MEAN	SEPARATION TIMES S.D.	OCCUPANCY TIMES MEAN	OCCUPANCY TIMES S.D.
50	0650-2316	9	64.9	50.2	44.7	6.1
51	0750-2028	6	88.8	100.4	37.5	8.8
52	0625-2230	5	119.6	132.0	73.4	59.7
53	0655-2233	7	94.7	62.1	39.3	12.8
54	0715-2310	8	68.0	36.5	51.4	19.7
55	0745-2010	7	65.1	44.1	41.3	2.9
56	0710-1910	7	58.1	19.6	44.7	12.3
57	0555-2005	2	382.5	533.9	42.5	3.5
58	0740-2004	5	102.6	72.1	46.2	12.1
59	0715-2155	9	56.7	40.5	41.1	10.1
TOTALS:		65	85.7	105.5	45.6	20.2

TABLE 5

PLANNED NUMBER OF DEPARTURES PER GATE

24 HOURS

LOCATION	NO. OF DEPARTURES	NO. OF GATES	DEPS/GATE
LA GUARDIA (AMERICAN)	120	11	10.9
O'HARE (UNITED)	218	21	10.4
LOS ANGELES (UNITED)	126	13	9.7
ATLANTA (DELTA)	185	25	7.4
LOS ANGELES (WESTERN)	74	10	7.4

TABLE 6

PLANNED NUMBER OF DEPARTURES PER GATE

0830 - 1900

LOCATION	NO. OF DEPARTURES	NO. OF GATES	DEPS/GATE	% OF DAILY DEPARTURES BETWEEN 0830-1900
LA GUARDIA (AMERICAN)	80	11	7.3	66.7
LOS ANGELES (UNITED)	89	13	6.9	70.6
O'HARE (UNITED)	135	21	6.4	62.0
LOS ANGELES (WESTERN)	48	10	4.8	65.0
ATLANTA (DELTA)	107	25	4.3	57.9

CHAPTER 14.

DESCRIPTION OF BRITISH EUROPEAN AIRWAYS AT LONDON HEATHROW AIRPORT

14.1 London Heathrow Airport (LHR).

14.2 LHR as a constraint on schedule construction.

14.3 Gate timetable summer 1974.

14.4 Passenger handling.

14.5 Ramp Control.

14.6 Aircraft changes.

14.7 Maintrol.

14 DESCRIPTION OF BRITISH EUROPEAN AIRWAYS AT LONDON HEATHROW AIRPORT.

BEA, or British Airways, European Division as it becomes from 1st April, 1974 is an intra-European Airline based on London Heathrow Airport.

It operates medium to short haul aircraft namely, Viscounts, Tridents, BAC 1-11's and Vanguards. Its operation is predominantly "hub and spoke" type out of London.

14.1 London Heathrow Airport (LHR).

Heathrow is operated and controlled on behalf of the British Government by the British Airports Authority (BAA).

The BAA retains considerable operational control over the terminals, concourses and gate areas. Certain major airlines including BEA have been granted "customary use" of certain facilities, but the freedom granted them within these areas falls far short of that given to the American based carriers, discussed in the previous chapter.

During the summer of 1974 BEA plan to operate 134 departures from 18 gates and 7 from off-pier stands.

There is a fundamental difference in the approach of the British and American authorities regarding control of the terminal areas as summarised below:-

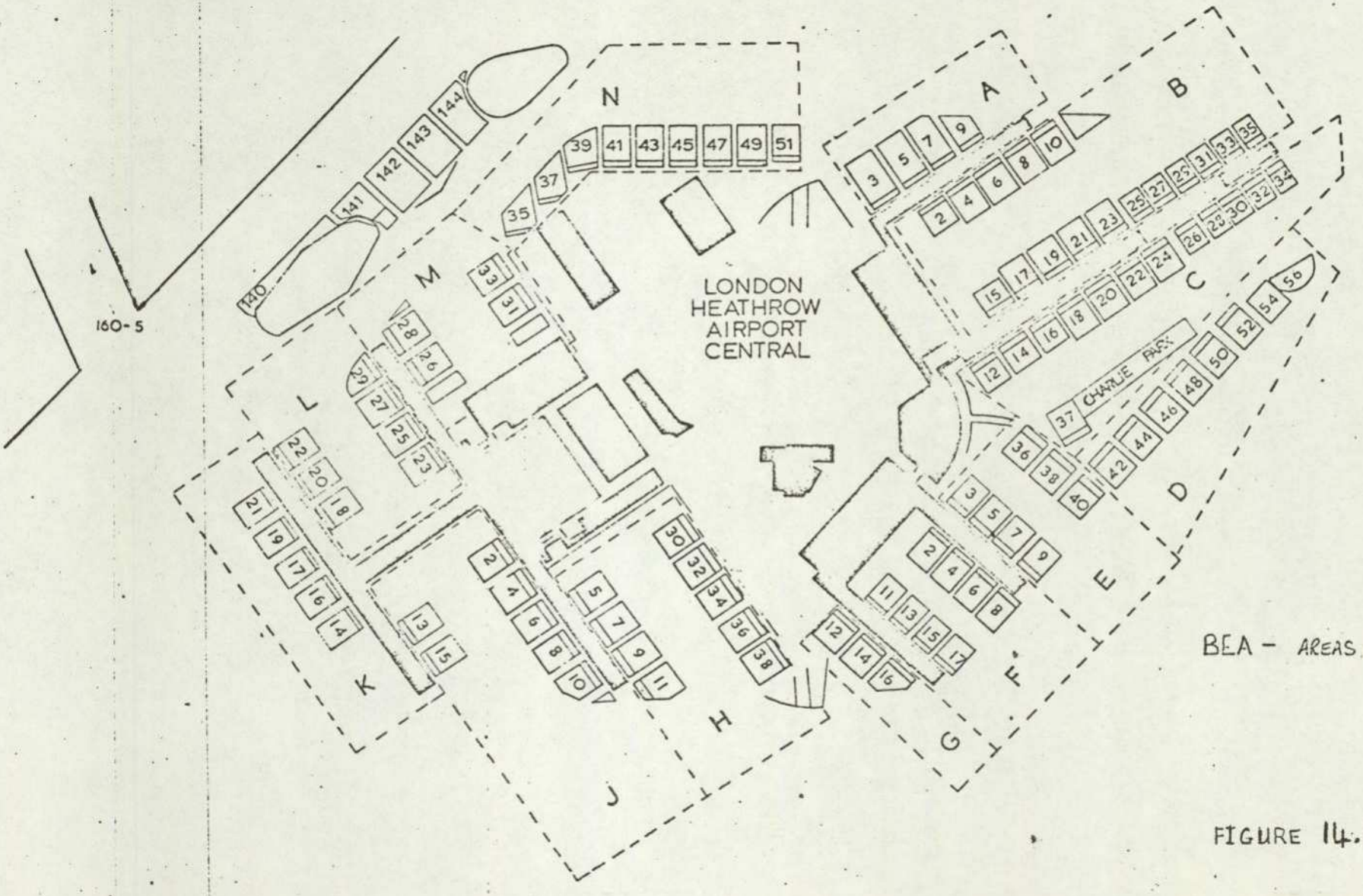
i) BAA's attitude tends to be that an aircraft accepted for landing will be provided with an operational parking area, though not necessarily a pier position. To do this, they require over-riding control over all parking positions.

ii) The American Authorities tend to be less considerate of non-scheduled movements. When an aircraft is accepted for landing, no guarantee of providing a parking position is given. Airlines who do not have their own gates must previously make an occupancy agreement with one of those who do.

iii) The BAA will not permit individual airlines to unilaterally allocate gates to their own flights. They do however allow certain airlines to request specific gates and in most cases accede to it.

iv) The maintenance and cleaning of gate areas are under BAA's control. Consequently, gates may be removed from service at a time unsuitable for the customary use airline.

STAND PLAN



BEA – AREAS A, B, C

FIGURE 14.1

14.2 LHR as a constraint on schedule construction.

BEA have developed a suite of programmes which evaluates different aspects of a proposed schedule. One of these is the required gate capacity. Input data for this module includes:

i) number of available Domestic gates
ii) number of available International gates
iii) number of available Domestic or International gates
iv) minimum separation time.

The output includes the required number of each gate type throughout the day and a comparison with the number available.

No delays and hence no aircraft changes are injected into the programme. Nor is the schedule amended in any way by the programme in an attempt to provide a match with available capacity. This must be done by altering the input data on the aircraft integrations. The internal allocation of flights to gates is not recorded in gate timetable form.

It is seen that gate capacity is a constraint on schedule development but only in terms of total gate numbers. No attempt is made to estimate % GTR, gate holds etc.

14.3 Gate Timetable, Summer 1974.

BEA's operation varies considerably from day to day, with many destinations being served on a less than daily basis. It is therefore necessary to produce seven gate plans for each schedule.

The timetable for Friday is the most congested and is shown in figure 1 of appendix 14. Its analysis is shown in table 1.

Separation times are seen to have a station mean of 37.1 minutes and a relative dispersion of 0.85. This excludes two positions which have only one planned occupancy each. One of these is a pier gate, the other an off-pier stand requiring coaching facilities for passengers.

This pier gate is regarded as spare or standby and BEA consider it essential to accommodate off-schedule movements from the other 17 pier gates. This philosophy is not unlike that of United, with one major difference. United reduce the number of available gates only at the schedule construction stage, but their operational plan utilises all gates.

14.3 BEA's gate plan, in terms of mean and relative dispersion of all separation times, is very similar to American's at La Guardia and United's at Los Angeles, provided that these two one-occupancy gates are omitted from the analysis.

14.4 Passenger Handling.

Until December, 1973, all passenger and baggage check in was performed at desks in the main terminal building.

Gate check-in is being introduced and is due to be complete by summer 1974.

Flight information is displayed on two electronic departure boards, one for international flights, the other for domestics. Loudspeaker announcements are also made.

The departure gate number is not shown until the operating aircraft has been positioned on it. This means that when it is announced, most passengers hasten to it and generate a queue either at the aircraft or the waiting lounge door. Conversely, there is only a very remote chance that the departure gate will be altered at a later time. This policy is expected to continue even after all check-in is done at the gates.

14.5 Ramp Control.

The control and co-ordination of all ramp activities are vested in the staff of "Terminal Control". This office is located on the second floor of the terminal building and overlooks the BEA customary use gates. The following staff are accommodated there:

i) Servicing Controller and Clerk.
ii) Co-ordinator.
iii) Departure Controller.
iv) Departures Assistant.
v) Arrivals Assistant.
vi) Radio Agent.
vii) Two Gate Controllers.
viii) Handling Controller.
ix) Refuelling Clerk.

14.5.1 Information Displays.

There are five main information displays which are summarised below.

i) Manually updated arrival and departures boards.

14.5.1 i) The arrivals board shows in chronological order, scheduled time of arrival, aircraft registration, flight number, originating station and next planned departure time. Estimated delays are not shown.

The departure board shows the scheduled departure time, destination, flight number, estimated arrival time of preceding movement if not already on station, the aircraft registration, and the gate number if known.

It is seen that the only links between the boards are formed by aircraft registration and subsequent or preceding movement times.

ii) Displays from computer system FIND.

Each agent has a Visual Display Unit linked to FIND. The information is similar to that on the boards and displayed in a similar manner. However, it is updated to include the latest arrival or departure estimates.

iii) Displays from computer system FICO.

Unlike FIND, FICO contains data about all flights and aircraft on the BEA network. It holds flight integrations and some key information on aircraft serviceability. It is more fully described in section 14.7.

No data is input to FICO from Terminal Control.

iv) Aircraft position chart.

A plan of the BEA facilities, including its off-line parking areas and maintenance base is wall mounted between the arrival and departure boards.

Magnetic plaques each bearing one aircraft registration are used to show the location of each aircraft at London.

v) Details of flights of all airlines, which ATC are holding in the "stack" are maintained by ATC staff. A closed circuit TV system broadcasts this information to many areas on the airport, including Terminal Control for the use of the gate controllers.

14.5.2 Communication Devices.

There are four main systems.

i) STC open box system linking Terminal Control with gate areas, check-in desks, engineering control points, etc.

ii) Direct telephone lines to nominated control points.

iii) Electro writer to BAA ground control, engineering control points, fuel companies and Maintrol (see 14.6).

iv) A company radio frequency for use only as a ground link to aircraft crew and towing crews.

14.5.3 Servicing Controller.

Responsible through his duty Superintendent to the Fleet Maintenance Manager, he co-ordinates the station maintenance effort.

He has the authority to withdraw an aircraft from service for technical reasons. He also provides estimates of required elapsed times for defect rectification.

He has no jurisdiction over other Terminal Control staff, nor vice-versa. Obviously a very close liaison is necessary.

14.5.4 Co-ordinator, responsible to the Ground Operations Superintendent.

He is responsible for all staff except the Servicing Controller and Clerk.

His duties are similar to his namesake with United, but he is less omnipotent.

14.5.5 Departure Controller.

He maintains a card record of the progress of each turnround and co-ordinates all ramp activity excluding engineering. He provides the link between Terminal Control and the gate areas via the STC system. No radio facility exists for his use.

14.5.6 Departures Assistant.

He is responsible for updating FIND regarding all departure details, including punctuality.

14.5.7 Arrivals Assistant.

He monitors the tape signals sent by ATC which describe all aircraft movements in the Heathrow terminal airspace. From this he updates the arrival data on FIND.

The FIND-FICO interface ensures that the relevant data on arrivals and departures input as above are automatically transferred to FICO.

14.5.8 Radio Agent.

The aircrew of a departure inform him of their start-up and push back time which he passes to the departures assistant. This is of particular merit when large scale start-up delays are necessary due to ATC delays.

14.5.9 Gate Controllers.

This is one of the main functions of Terminal Control. Since no operational gate plan is in use, the gate controllers allocate aircraft to gates on an ad-hoc basis using the up to date estimates available from FIND and FICO.

The general policy is that departures have a higher priority than arrivals in that a mixed operation turnround, i.e. domestic arrival, international departure, will be positioned where possible on an international gate.

A print out from FICO listing movements over any required time span is available to them on demand. This forms their working document.

They do not inform the aircraft directly of the planned gate, this being done by ATC who themselves are informed by Ground Movement Control, BAA. Thus having selected a gate, the BEA controller, under normal circumstances, passes it via an electro-writer to BAA about 10-15 minutes before arrival. At the same time, FIND is updated by the arrivals assistant.

It must be emphasised that within Terminal Control the information display boards lend themselves to the interpretation that an aircraft registration is being allocated a gate, and not a planned turnround identified by flight numbers.

Due to the method of performing aircraft changes, occasionally the next outbound sector of an arrival is unknown at the time of gate allocation. This is considered more fully in 14.6 and 14.7.

14.5.10 Handling Controller.

His duty is to allocate and control towing vehicle crews under the direction of the gate controllers.

14.5.11 Refuelling Clerk.

The fuel companies are advised via electro-writer of the uplift requirement and position of each aircraft.

14.5.12 It is seen that Terminal Control is the nerve centre for Heathrow's ramp activities. Although it does not directly control the movement of passengers, the time of gate allocation has a direct effect on it.

FIND is used to broadcast the gate decision, but since no gate timetable exists, all other sections can plan resources etc., only as far as occupancies which commence within fifteen minutes or so.

14.6 Aircraft Changes.

These can originate from any of three sources.

i) Terminal Control Co-ordinator.
ii) Servicing Controller.
iii) Maintrol (see 14.7).

14.6.1 From Co-ordinator.

These normally result from his identification of a planned turnround which would create a departure delay, due to a shortage of resources.

This normally co-incides with a late arrival but could be an on time movement carrying an awkward or very large cargo, etc.

Aircraft changes are occasionally initiated on account of the relative position of aircraft on the gates.

14.6.2 From the Servicing Controller.

If technical defects are identified on an aircraft during ground check, the Servicing Controller has the authority to remove it from its planned departure. He normally suggests a substitute aircraft where possible and provides an estimate of the time of serviceability for the original one.

Similarly, if the technical messages which precede the aircraft's flight arrival indicate that it will be unserviceable, he may instigate the change procedure immediately.

14.6.2 In all cases, requests for aircraft changes are referred to Maintrol for approval and broadcasting.

14.7 Maintrol.

This department is situation at Heathrow and performs a similar function to M.O.C. (American) and to "Routing Centres" (United).

14.7.1 The planned integrations minus aircraft registrations, are produced by FICO once daily about 2300 hours. It is one of Maintrol's responsibilities to allocate aircraft to these cycles in accordance with planned maintenance and aircraft restrictions.

Although FICO displays are available throughout BEA's offices, only Maintrol are permitted to alter these flight allocations. This may be requested from Terminal Control or from Operations due to a shortage of flight or cabin crew.

In addition, Maintrol may originate aircraft changes as a result of:-

i) The latest FICO estimate indicates a late arrival providing less than the minimum ground time at Heathrow.

ii) The occurrence of a defect on a previous sector since leaving Heathrow may preclude the aircraft's use to certain limited airports, or under certain weather conditions.

14.7.2 Method of implementing an aircraft change.

Using the FICO input terminals, the fleet controller removes the original registration from identified flight numbers. These need not comprise the total planned integration for that aircraft. The substitute aircraft is inserted, again to specified flight numbers which need not be all of those from which the original aircraft was removed.

For example, if an unserviceable aircraft were originally allocated to three return journeys from Heathrow, the controller may decide to provide a substitute for the first round trip, leave the second without an aircraft, and retain the original allocation on the third.

This illustrates the low priority which is accorded to the maintenance of planned turnrounds.

14.7.3 Maintrol are under management instruction to implement the minimum number of aircraft changes. These are recorded by counting the number of times one registration is overwritten by another. This method encourages aircraft substitutions for one return journey only, creating unscheduled turnrounds at each end.

APPENDIX 14

FIGURE 1 Gate Timetable, BEA Summer 1974.

TABLE 1 Gate Timetable Analysis.

FIGURE 1

BEA LONDON HEATHROW SUMMER 1974

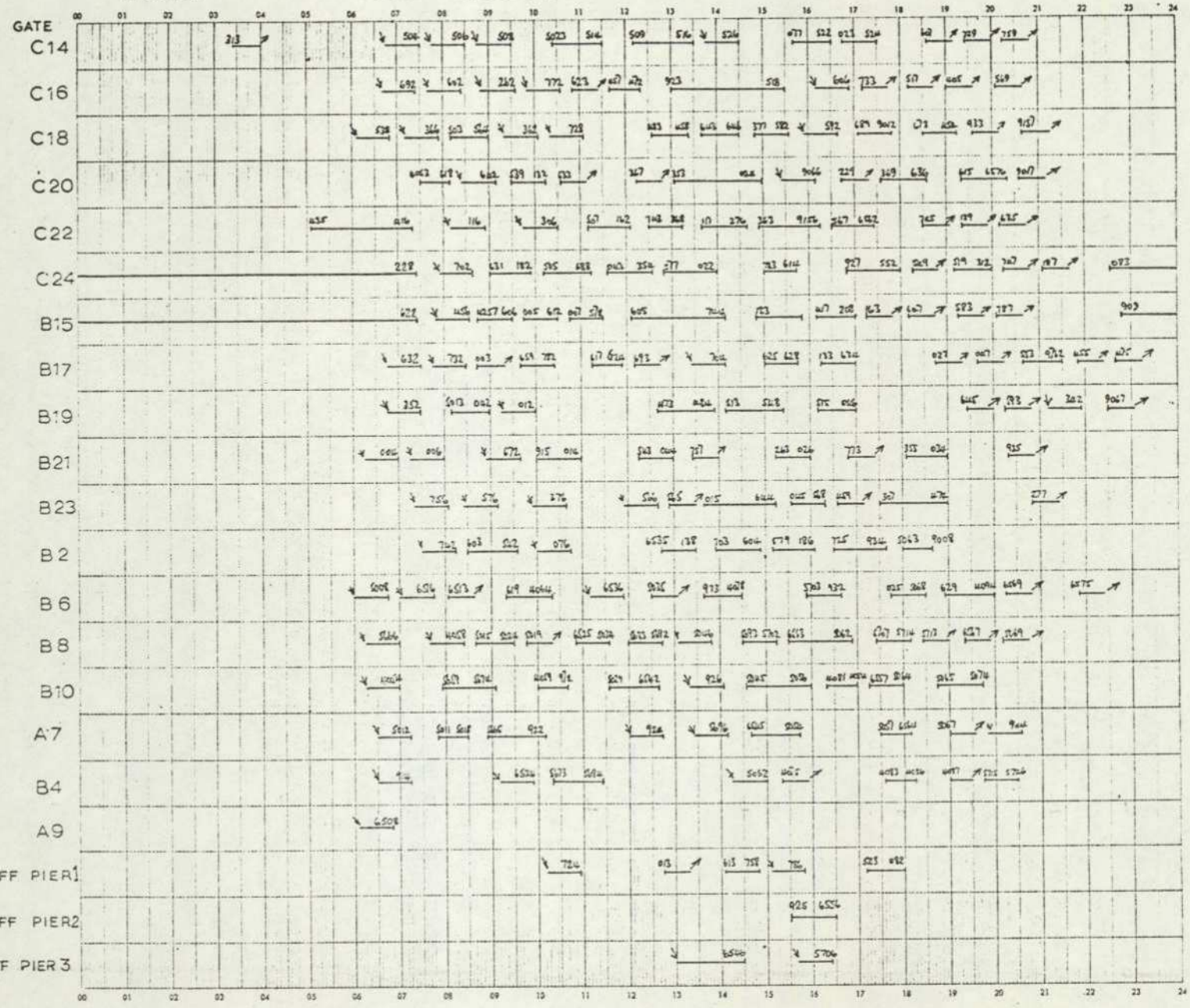


TABLE 1

GATE TIMETABLE ANALYSIS

BEA, LONDON HEATHROW SUMMER 1974

GATE NO.	TIME SPAN	NO. OF OCCUPANCIES	SEPARATION TIMES MEAN	SEPARATION TIMES S.D.	OCCUPANCY TIMES MEAN	OCCUPANCY TIMES S.D.
C14	0325-2015	11	44.1	45.5	46.7	13.5
C16	0640-2005	11	22.3	9.8	50.4	33.4
C18	0605-2040	12	27.5	20.9	45.4	4.0
C20	0730-2035	10	27.0	16.7	51.5	24.2
C22	0505-2010	10	31.5	18.4	59.0	29.8
C24	0640-2235	12	28.8	19.4	50.8	13.1
B15	0640-2250	12	30.8	32.5	50.0	24.8
B17	0645-2240	13	32.3	25.3	41.1	5.5
B19	0645-2230	9	54.0	56.9	50.6	14.9
B21	0615-2020	9	47.8	25.3	45.6	8.1
B23	0720-2050	9	36.7	34.3	53.3	22.6
B2	0730-1800	7	35.0	37.7	55.0	10.4
B6	0600-2150	11	40.5	22.5	46.8	10.1
B8	0615-2010	12	23.3	9.6	46.3	13.2
B10	0615-1845	8	39.4	16.1	54.4	16.8
A7	0630-1950	8	51.3	36.2	48.8	13.8
B4	0630-1945	7	70.0	59.3	43.6	11.1
A9	0605-0650	1	-	-	45.0	-
OFF-PIER	1010-1710	4	62.5	41.3	42.5	5.0
OFF-PIER	1300-1625	2	70.0	-	67.5	-
OFF-PIER	1530-1630	1	-	-	60.0	-
TOTALS:			37.1	31.6	49.1	17.6

CHAPTER 15

COMPARISON OF OPERATING PROCEDURES.

15.1 Organisation of Ramp Control.

15.2 Display of information in Ramp Control.

15.3 Equipment Control or Routing Centres.

15.4 Initial daily allocation of aircraft to flights.

15 COMPARISON OF OPERATING PROCEDURES.

15.1 Organisation of Ramp Control.

United was seen to operate under a centralised planning and control concept. All main stations have a Planning Centre where all information pertinent to a turnround is available.

BEA and American have adopted a similar but less comprehensive approach in their use of Terminal Control and the Ramp Tower respectively.

Delta and Western were seen to operate a much simpler system but for different reasons. Delta's is explained by the peaked nature of their schedule at Atlanta, while Western's small operation could not justify a more elaborate system.

It is considered that the most valid comparison is that of United, American and BEA.

15.1.1 The main difference between the two American carriers is that American prefer the Ramp Manager to have a good view over the gate areas. In order to keep the building size to a minimum, only the Manager, together with the arrivals and departures agents are accommodated in it. This places a high degree of reliance on the communications systems to other sections both for the receipt and dispersal of turnround information. The problem does not arise to the same extent in United's Planning Centre.

The most important common feature of the two approaches is that one man is charged with the total responsibility for all activities on the turnround. This includes the operational but non-technical aspects of aircraft maintenance. The technical foremen do not have the authority to withdraw an aircraft from a flight allocation. Their action is limited to declaring it unserviceable. The decision to request an aircraft change or a cancellation rests solely on the Ramp Manager or Co-ordinator, based on the estimates of the rectification time provided by the foremen.

15.1.2 BEA at Heathrow is fortunate in having accommodation in Terminal Control which not only affords a reasonable view of the gate areas, but which is also comparable in size to United's Planning Centre.

15.1.2 Apart from the fact that BEA do not operate from a formalised gate plan, the information available in and disseminated from the Control is similar to the data held in the Planning Centres.

The big difference lies in the allocation of turnround control and ultimate responsibility.

It was seen how:

i) The Servicing Controller is in charge of all station maintenance and reports directly to maintenance management.

ii) Ground Operations Superintendent is responsible for co-ordinating the non technical aspect of the turnround.

iii) Maintrol allocates the aircraft to flights based on arrival and serviceability estimates.

No one person has total responsibility and is charged with ensuring that the optimum decisions for BEA as a whole are taken.

Obviously the above three officials work very closely together, but occasions do arise when conflicts of departmental interest occur. In these cases it is invariably the wish of the strongest personality which prevails. It is felt that the inability of BEA to operate a gate timetable is caused in part by these conflicts.

15.1.3 The decision of BAA to retain ultimate control of all gates, including customary use ones, provides BEA with a further complication as far as gate allocation is concerned.

The airline is not permitted to inform incoming aircraft of their gates directly. No doubt on gate availability can be present in the gate agent's mind when he supplies the gate number to the Airport Control Tower. A decision must be taken by the agent allowing the prescribed time interval before arrival.

The position with American is slightly different. The FAA controller allocates gates in accordance with the plan supplied by the airline. He is contacted by the ramp agent only when a change is required. As a result, the agent is free to

15.1.3 concentrate on arrivals or occupancies which may conflict with the plan, in the knowledge that other unrelated movements are being handled correctly.

15.2 Display of information in Ramp Control.

This is an area in which the American carriers differ substantially from BEA, but less so among themselves. Most of the differences lie in the methods of presentation, some of which are listed below.

i) Closed circuit TV monitors of passenger displays.
ii) Wall charts using magnetic plaques.
iii) Sophisticated computer systems using individual visual display units.
iv) Individually maintained manual records.

The method selected obviously depends on the size and type of operation etc., but each display carries roughly the same type of information, i.e. flight number, aircraft registration and configuration, destinations, flight time and gate number.

The presentation media is considered to be of minor importance in relation to ramp control. It is the manner in which it is amended, controlled and interpreted which is significant. The physical layout of the display can emphasise one particular parameter which then will tend to be used as the key or identifying label for that data record.

15.2.1 The American carriers lay out their information in such a way that flight numbers become this key, and the other data form supplementary and descriptive fields. Thus an occupancy is identified by either two or one flight number(s).

This encourages staff of all levels to think in terms of "arrival XYZ operates departure ABC." This preserves the integrity of the aircraft cycles and consequently of scheduled turnrounds.

An aircraft change obviously breaks this integrity temporarily, but only so far as the affected turnrounds are concerned. Subsequent occupancies of the disrupted aircraft are formed by the original flight numbers, thus ensuring the minimum number of unscheduled turnrounds.

15.2.2 BEA however, use the aircraft registrations as a main data key, especially in Terminal Control and Maintrol. The flight numbers tend to become additional data attached to individual aircraft, except, of course, when the flight has no allocation.

For example, the departure board display in Terminal Control is arranged in chronological order with departure flight number, gate, aircraft registration and estimated arrival time shown. The latter two parameters provide the only links from the departure board to the arrival one. The reverse procedure is similar in that the arrival board does show for each arrival, its intended departure time together with aircraft registration.

Terminal Control's main activities were seen to be devoted to achieving punctual departures. This results in the departure boards assuming relatively more importance than the arrivals one, in that the latter is usually consulted first, and reference is made back to the arrival data. Such a process requires the aircraft registration and tends to promote its use as the prime identifier in the Control.

Aircraft changes generate a large number of alterations to the boards if the change sequence is of type DIRECT or INDIRECT.

15.3 Equipment Control or Routing Centres.

All the airlines studied were seen to have similar methods of allocating aircraft to cycles such that the maintenance plans are fulfilled. One important difference exists between the American carriers and BEA in this respect.

15.3.1 The Routing Centres or Equipment Controls of United, American, Delta and Western adopt a system wide approach. They have no special responsibility for any particular station, and do not receive estimates of flight punctuality.

They do not initiate aircraft changes for reasons other than maintenance, and even then infrequently.

They provide a service to all stations in that they approve or reject a station request for an aircraft change. If granted the disrupted aircraft always remain on their new cycles to completion.

15.3.1 As a result, no flight is ever without an aircraft allocation. This may involve a large delay, but the decision to accept it, request a further change sequence in the light of further information, or to cancel the service will not be taken by the Routing Centres.

It cannot be over emphasised that these Centres are concerned solely with maintenance commitments.

15.3.2 BEA however, permit Maintrol to play a significant and active role in the operational control of the turnrounds at Heathrow.

Having swapped aircraft on certain departures for any reason, Maintrol are not under pressure to complete the reallocation over the remainder of the cycles. Instead, either the original aircraft to flight allocation is retained for subsequent departures from Heathrow, or else the original allocations are removed and the flights left uncovered. Either way, unnecessary unscheduled turnrounds are caused leading to a total breakdown of any gate plan.

The results of a detailed study of the schedule reliability of BEA at LHR are shown in appendix 15.

It is seen that about 50% of the planned turnrounds were not achieved, and that this could be reduced to about 38% merely by swapping complete cycles, not just individual flights.

Equally significant, is the fact that at around ETA-15 minutes, the time when the aircrew are normally given their gate number, Terminal Control staff did not know the departure allocation of 6% of the arrivals. In addition, of the arrivals which have a further departure allocation, almost 25% of these allocations prove to be wrong.

Thus the gate planners are attempting to achieve good gate utilisation without knowing the gate requirements of at least 30% of all arrivals.

Prior to the introduction of FICO, aircraft changes were broadcast from Maintrol via electro-writers. To perform a complete cycle change, each flight number had to be transmitted with its new aircraft allocation. This was a long task and during a trial of it by author, was found to create unacceptable delays to Terminal Control and Maintrol. Thus only immediately affected flights were processed to produce the above poor statistics.

15.3.2 Since FICO has become operational, fewer flights are left uncovered and fewer late aircraft changes are performed. It is considered that the former could be further reduced by reallocating complete cycles where possible.

It has been shown previously that the Gate Timetable Reliability need not necessarily be lowered by the occurrence of unscheduled turnrounds, provided they are known sufficiently well in advance. This was clearly not happening in 30% of BEA's turnrounds and appears to be one of the main reasons why gate plans have proved unworkable.

With the American carriers, a turnround is altered after ETA-15 has been reached only when severe unserviceability occurs during the occupancy.

15.4 Initial daily allocation of aircraft to flights.

BEA and the American airlines have adopted different approaches to this problem. The latter attempt to link the operation of each day at the planning stage and to implement the plan. BEA on the other hand produce integrations on a daily basis and try to optimise them with respect to current aircraft disposition.

The approach of American, United and Delta is described in general terms in 15.4.1 while that of BEA is given in 15.4.2.

15.4.1 Before the start of a new schedule, the planned flight integrations for the complete schedule period are calculated. Overnight layovers and maintenance-check inputs together with normal daily turnrounds are included. Thus throughout the network, every flight arrival has a planned subsequent movement, until the end of the period.

This information is divided into daily integrations and circulated to all stations. Because United, American and Delta in particular show very little variation in flights from day to day, with the exception of weekends, only one data sheet is necessary, for each aircraft type. An example is shown in figure 1 of appendix 15.

Extra flights and charters are operated where possible by aircraft not allocated to these scheduled integrations, and are controlled on an ad hoc basis by the creation of additional cycles.

15.4.1 This method eliminates the need to allocate specific aircraft to originating departures from each station. The overnight stop-overs in particular, are not regarded as inviolate and can be altered in the same way and with the same constraints as apply to normal aircraft changes during the day.

One other important advantage exists. The maintenance staff know the ground time available to them, immediately the aircraft lands and can plan the amount of work which they can undertake. This obviously excludes rectification to critical or mandatory systems.

The reliability of the overnight integrations was not measured but an estimate from United personnel was that in excess of 95% of them was achieved. No evidence was found to suspect this claim.

The system was observed to operate smoothly but several reservations about it are required. These are:-

i) No additional information need be supplied to stations from the Routing Centres when punctuality and flight reliability is good. Thus no contact infers no change. This need not always appear to the stations as being the best decision for them and they will contact the Routing Centres for unnecessary confirmation.

ii) When large scale delays, diversions, unserviceability etc. occur the Routing Centres perform manual amendments to the integrations. These require distributions to affected stations. Thus sophisticated updating and communications must be provided for this eventuality.

iii) When extras are operated by aircraft on separate ad hoc integrations, the allocation of the total fleet viewed as a unit, need not be the optimum one, despite the two separate components being so.

iv) Station pre-printed working documents may contain several hand written updates each day, even before the operation has started.

15.4.2 BEA's operation varies considerably from day to day with many destinations being served by a less than daily frequency. Although major schedule changes occur but twice a year, a large number of minor alterations are planned within the summer and winter operations.

Whereas United can issue their integrations in the form of figure 1 at each schedule change, BEA would be required to issue one for each day of the week.

Since BEA's operation is so concentrated at Heathrow, a minimal number of permutations of turnrounds can be performed at other stations. It is therefore much simpler for BEA, to replan integrations than it is for United or American.

This is done by a suite of programmes every night when the complete flying programme and aircraft availability for the next day is known. Only turnrounds at Heathrow are considered. Those at outstations remain as per the original plan. Extra flights and aircraft type changes are included.

These optimum integrations are available to Heathrow staff via FICO during the preceding evening. Aircraft registrations are not shown nor are the arrivals which are planned to provide the aircraft for originating morning departures.

The aircraft are allocated by Maintrol who pass them to Terminal Control early in the morning. This procedure has two main drawbacks, listed below:

i) Overnight turnrounds have been created without reference to gate requirements. Domestic departures may be positioned on international piers. Aircraft in non-operational areas may be scheduled to depart some hours before those on gate positions.

In such circumstances Terminal Control may request aircraft changes. As seen earlier, the cycle changes are not necessarily completed at the time of request, and the seed of unnecessary unscheduled turnrounds later in the day is sown.

15.4.2 ii) At the start of the night shift, the engineers do not know the first departure time of each aircraft. They therefore have no guidance as to whether they may commence a lengthy rectification task without having to request an aircraft change, when the allocations become known.

Admittedly, when Maintrol make their aircraft allocations, they are aware of the state of the work in progress on the aircraft. However, they need not know of additional rectification tasks which have been identified during the planned work and which the licensed engineer has decided to postpone because he is unaware of the time available to him.

In an attempt to overcome this, BEA Maintenance have a target of 100% serviceability by 0600 hours. This is plainly restrictive and causes postponement of maintenance on some late departure aircraft for which both adequate time and resources exist.

Clearly it would be beneficial if the overnight turnrounds were available in time for the oncoming night shift foremen to study, before allocating his resources.

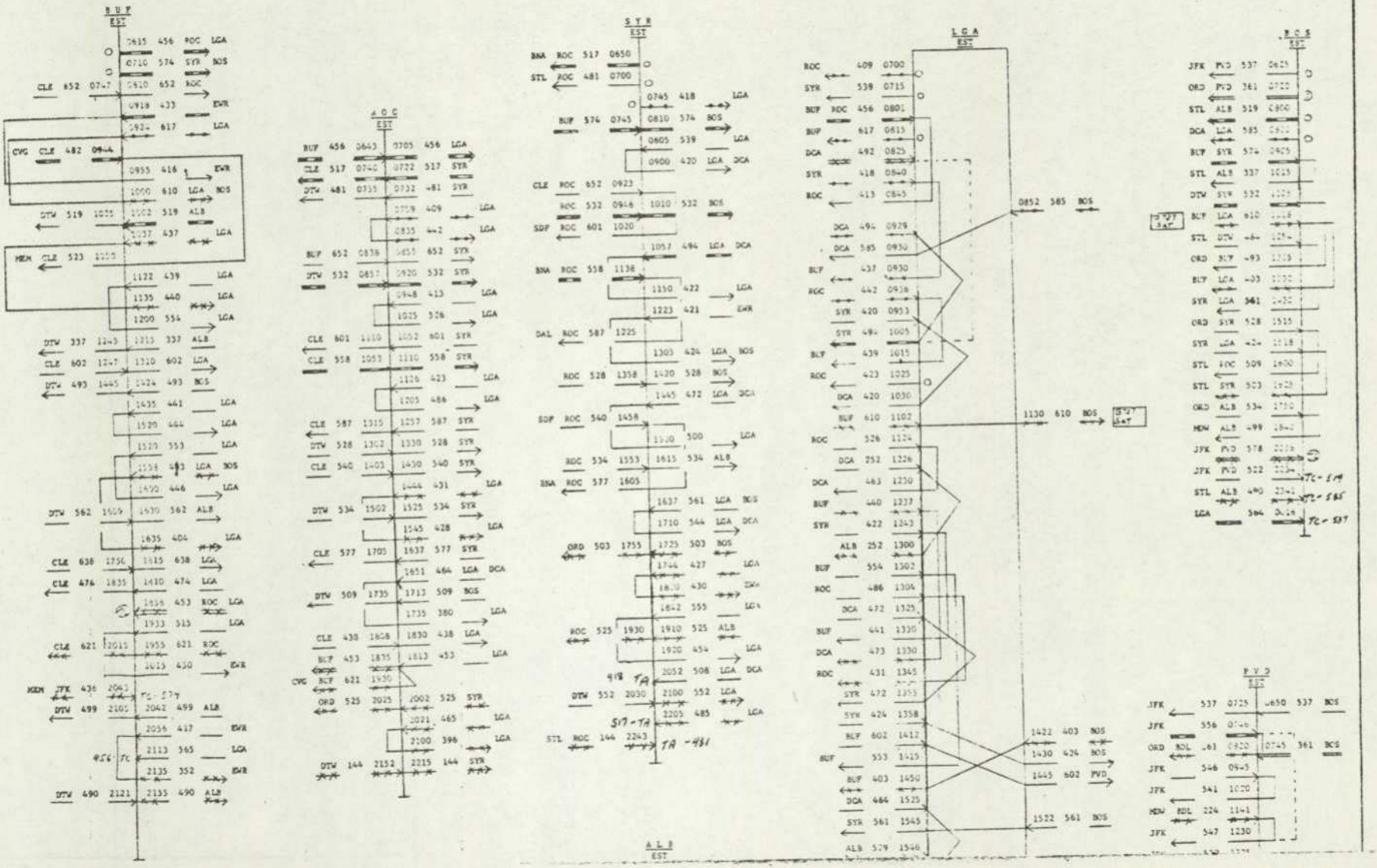
APPENDIX 15

FIGURE 1 Routing Sheet

Report on Reliability of Scheduled turnrounds at LHR.

EXTRACT FROM BAC 1-11 ROUTING CHART.

FIGURE 1



A STUDY OF THE RELIABILITY OF SCHEDULED TURNROUNDS AT

LONDON HEATHROW AIRPORT

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Introduction and Summary

The object of this study was to quantify the number of aircraft changes, the number of unscheduled turnrounds caused by such changes, and the origin of the re-allocation requests. It is also attempted to measure the frequency of arriving aircraft which do not have outbound flights allocated to them, or whose outbound sector later proves to be wrong.

The reasons for aircraft changes were ascertained by observation in Terminal Control over the period 0600 to 2300 hours. This was done for five periods of three days.

The success of the turnround, as planned when the ramp controller makes his gate allocation was recorded by analysing his personal work log. These took the form of arrival/tow slips for each gate arrival.

UNSCHEDULED TURNROUNDS

The reasons for unscheduled turnrounds have been very broadly classified as follows:

	Reason	Classification
1.	Unserviceability	
2.	Reactionary to unserviceability	
3.	Maintenance input requirements (either at base or outstations).	ENGINEERING
4.	Increased turnround to facilitate servicing.	
5.	Crew availability	
6.	Outstation limitations	
7.	Weather conditions	FLIGHT OPERATIONS AND OPS CONTROL
8.	Type change	
9.	Captain's refusal of aircraft	
10.	Late arrival.	
11.	Increase in turnround to accommodate large/extra/late pay-load to permit pier departure	GROUND OPERATIONS
12.	Original allocation adhered to on non-maintenance input cycles.	NON REQUESTED

Discussion

1. SCHEDULED TURNROUND RELIABILITY

From Table 1, it can be seen that Trident I's have the largest percentage of unscheduled turnrounds, but the difference between I's, II's, 1-11's and Vanguards is only around 4%. However, the size of the I operation magnifies this small difference considerably.

The Trident II turnrounds are longer than the Trident I, so Trident II's are often used as substitutions for Trident I's. The reverse is not the case.

The size of the One-Eleven disruption is higher than anticipated bearing in mind that London is not the One-Eleven major base. By studying the One-Eleven schedule, it can be seen that there are no more than three aircraft at London at the same time. Consequently, any "moving up" of aircraft causes a large reactionary disruption to the scheduled turnrounds.

Vanguards also have a low turnround success rate. This may be explained by noting the relatively high number in the "non-requested" category. When an aircraft change is made, the subsequent long turnround at London usually permits the aircraft to return to its initial allocation thus causing more unscheduled turnrounds.

In comparison the Viscounts and Comets have an expected high turnround success.

Table 3 shows the classification of requests for all aircraft over the three day period. It would appear that more requests originate in operations than from service control. This is not exactly true, because type changes were normally made due to unserviceability, but are classed as aircraft shortage and hence go to operations. Nevertheless, it is the servicing controller who makes the initial request.

Again from Table 3, 15.8% of the turnrounds are broken with no specific request having been made from any department for a change. They are caused purely by aircraft either being left on their original allocation after the initially disturbed flight or as happens in many cases, the affected aircraft are not allocated until their return. In the latter case, the subsequent allocation is not done with the scheduled turnrounds in mind.

Discussion

2. ARRIVAL SLIP INFORMATION

It can be seen from Table 6 that for an eleven day period, 6.3% of arriving flights which were not scheduled to go off service had no outbound flight planned for them at the time of stand allocation. On this basis the ramp controller can only allocate a stand on the status of the incoming flight and does not know the stand occupancy time and subsequent requirements for towing until the aircraft is designated to an outgoing flight.

The stand allocation takes place after the air debrief is received and although this, in many cases, makes the stand consideration easier the decision to tow off stand for maintenance is generally not made until the aircraft has been inspected on the ground.

Of the inbound flights, which at the time of stand allocation had an associated outward leg, only 75.6% proved to be the flight actually operated by that aircraft. Thus, aircraft changes, involving 24.4% of the turnrounds were made after STA -15 approximately, dependent on the following:

1. The maintenance state of the arriving aircraft.
2. Amended arrival estimates of turnround aircraft.
3. Alteration to estimates of the serviceability of aircraft already on the station.

Consideration is given to all these elements and what effect they may have on the aircraft already positioned on the piers. It can be seen that one aircraft, already allocated to a service can have as many as three or four changes to cycle before the final flight is agreed upon. These changes are then responsible for the figure of 24.4% wrong outbound legs and we then have the situation of a number of aircraft positioned on the incorrect piers too late to be towed off.

Increasing the reliability of the information affecting the outbound sector would result in the ramp controller being able to better evaluate the situation and be capable of acting more positively on the information presented to him.

Conclusions

1. The ground time of arriving turnround aircraft as planned at the time of stand allocation was changed for 24.4% of the turnrounds.

2. 6.3% of arriving potential turnround aircraft had no outbound leg and thus no ground time associated with them, again at time of stand allocation.

3. 36.8% of the total scheduled turnrounds were not accomplished because of operational reasons and in the interest of punctuality ("requested" changes).

4. 15.8% of the total scheduled turnrounds were not accomplished with no request for a change ever having been made ("non-requested" changes).

5. The above "non-requested" changes were caused because aircraft, changed from their original cycle earlier in the day, were not allocated to remain on their new cycles.

   a) Some aircraft remained on their initial cycles.

   b) Some aircraft were removed from their later initially planned flights and were re-allocated on an ad-hoc basis on their arrival.

SUMMARY OF UNSCHEDULED TURNROUNDS

1. BY AIRCRAFT TYPE OVER 3 DAY PERIOD

TABLE 1

AIRCRAFT	AVERAGE NO. OF SCHEDULED TURNROUNDS PER PERIOD	AVERAGE UNSUCCESSFUL		CLASSIFICATION			
		NUMBER	%	ENGINEERING	OPERATIONS	GROUND OPERATIONS	NON-REQUESTED
TRIDENT 1	108	62	57.4	13	19	6	24
TRIDENT 2	22	12	54.5	6	5	0	2
SUPER 1-11	30	16	53.3	5	9	0	2
VANGUARD	56	31	55.3	12	10	0	11
VISCOUNT	24	5	20.8	3	2	0	0
COMET	7	1	14.3	1	0	0	0

2. TOTAL FLEET ON DAILY BASIS

TABLE 2

DATE	AVERAGE NO. OF SCHEDULED TURNROUNDS	UNSUCCESSFUL		CLASSIFICATION			
		NUMBER	%	ENGINEERING	OPERATIONS	GROUND OPERATIONS	NON-REQUESTED
DAY 1	83	49	59	19	19	2	9
DAY 2	80	36	45	8	16	1	14
DAY 3	84	42	50	13	10	3	16

3. TOTAL TURNROUNDS - ALL AIRCRAFT TYPES, THREE DAY TOTALS

TABLE 3

TOTAL SCHEDULE TURNROUNDS	UNSUCCESSFUL		ENGINEERING		OPERATIONS		GROUND OPS.		NON-REQUESTED	
	NUMBER	%	NUMBER	%	NUMBER	%	NUMBER	%	NUMBER	%
247	127	52.6	40	16.2	45	18.2	6	2.4	39	15.8

% SUCCESS OF SCHEDULED TURNROUNDS, obtainable by eliminating those unscheduled turnrounds in the classification "non-requested".

It should be remembered here that if a flight is scheduled to go off services and actually does so, the turnround is not included in the following. Thus by eliminating the "non-requested" category, the number of turnrounds considered is affected.

TABLE 4

ACTUAL			NO "NON-REQUESTED"			NO "NON-REQUESTED" PLUS PROJECTED 30 MIN. DELAY ACCEPT		
NO. OF T/ROUNDS	NO. OF SCHED. T/ROUNDS	%	NO. OF T/ROUNDS	NO. OF SCHED. T/ROUNDS	%	NO. OF T/ROUNDS	NO. OF SCHED. T/ROUNDS	%
247	120	48.6	242	151	62.5	242	162	67.0

Broken down into a daily and fleet type basis the above table becomes:

TABLE 5

DATE	A/C TYPE	ACTUAL			NO "NON-REQUESTED"			NO "NON-REQUESTED" PLUS ACCEPT PROJECTED 30 MIN. DELAY		
		NO. OF T/ROUNDS	NO. OF SCHED T/ROUNDS	%	NO. OF T/ROUNDS	NO. OF SCHED T/ROUNDS	%	NO. OF T/ROUNDS	NO. OF SCHED T/ROUNDS	%
29.1.70.	TRIDENT 1	38	14	36.8	37	19	51.4	38	22	57.9
	TRIDENT 2	6	3	50.0	6	4	66.7	6	4	66.7
	SUPER 1-11	10	8	80.0	10	8	80.0	10	8	80.0
	VANGUARD	19	5	26.3	19	7	36.8	19	9	47.4
	VISCOUNT	8	3	37.5	8	3	37.5	8	3	37.5
	COMET	2	1	50.0	2	1	50.0	2	1	50.0
5.2.70.	TRIDENT 1	34	19	55.9	33	24	72.7	33	26	76.5
	TRIDENT 2	6	3	50.0	6	3	50.0	6	3	50.0
	SUPER 1-11	10	3	30.0	10	5	50.0	10	5	50.0
	VANGUARD	19	8	42.1	16	11	68.7	16	11	68.7
	VISCOUNT	8	8	100.0	8	8	100.0	8	8	100.0
	COMET	3	3	100.0	3	3	100.0	3	3	100.0
10.2.70.	TRIDENT 1	36	13	36.1	34	23	67.6	34	27	79.5
	TRIDENT 2	10	4	40.0	10	5	50.0	10	5	50.0
	SUPER 1-11	10	3	30.0	10	3	30.0	10	3	30.0
	VANGUARD	18	12	67.7	18	15	83.4	18	15	83.4
	VISCOUNT	8	8	100.0	8	8	100.0	8	8	100.0
	COMET	2	2	100.0	2	2	100.0	2	2	100.0

ARRIVAL SLIP SUMMARY

Incoming flights shown as going off service, and actually doing so, are completely ignored in all totals below.

TABLE 6

DATE	TOTAL TURNROUNDS CONSIDERED	NO. OF ARRIVALS WITH UNKNOWN OUT-BOUND	PERCENTAGE UNKNOWN	NO. OF ARRIVALS WHOSE SHOWN OUTBOUND IS WRONG	PERCENTAGE WRONG
29.1.70	66	8	12.1	16	24.2
30.1.70	80	7	8.8	22	27.5
31.1.70	62	2	3.2	21	33.8
1.2.70	58	3	5.2	16	27.6
2.2.70	80	3	3.8	17	21.2
3.2.70	77	3	3.9	17	22.6
4.2.70	76	7	9.2	22	29.0
5.2.70	70	6	8.6	12	17.1
7.2.70	60	3	5.0	12	20.0
8.2.70	59	4	6.8	18	30.5
10.2.70	70	2	2.9	12	17.2
TOTAL:	758	48	6.3	165	24.4

CHAPTER 16

COMPARISON OF PERFORMANCE OF THE FOUR U.S. AIRLINES

16.1 Gate Timetable Reliability.

16.2 Arrival Punctuality.

16.3 Departure Punctuality.

16 COMPARISON OF PERFORMANCE OF THE FOUR US AIRLINES.

For the purposes of this project, the airline performances were compared using arrival and departure punctualities together with the Gate Timetable Reliabilities.

16.1 Gate Timetable Reliability.

Table 16.1 below shows the mean % GTR as calculated from station records for a period of 30 days. The separation time mean and relative dispersion of the relevant gate plan are also listed.

Airline	Airport	Separation Times		Mean % GTR
		Mean (Mins)	Rel. Disp.	
American	LGA	35.4	0.82	74.5
United	LAX	37.4	0.88	64.6
United	ORD	45.0	0.90	73.0
Western	LAX	85.7	1.23	83.8
Delta	ATL	93.6	0.77	91.4

TABLE 16.1

The daily variations of GTR are shown in figures 1, 2 of appendix 16.

16.1.1 The mean % GTR values are plotted against MSST and the relative dispersions in figures 3 and 4 respectively.

Figure 3 illustrates practical agreement with the simulation results. In fact it extends the applicability of the MSST dependency. It appears that gate plan reliability will improve with increasing MSST, irrespective of the plan, flight schedule, punctuality, procedures etc.

16.1.2 Figure 4 illustrates that a linear relationship does not exist between % GTR and relative dispersion when considering different schedules. This does not invalidate the claims made in section 9.7 where the simulation results are analysed.

GATESIM ascertained that for a given flight programme, the gate plan reliability would be improved by reducing the relative dispersion of the separation times.

This applies to each of the plans represented in figure 4 but does not suggest a link between them.

16.2 Arrival Punctuality.

The arrival data and the % GTR values apply to the same time period within each station. The former is listed below in tables 16.2 and 16.3.

Airline	Airport	% of Total Arrivals less than X Minutes Late						
	X	1	11	21	41	61	91	121
American	LGA	26.5	58.2	74.1	87.4	93.0	96.4	98.2
Delta	ATL	20.1	58.5	78.5	91.2	95.6	98.2	99.1
Western	LAX	12.0	48.0	71.4	88.7	93.6	96.5	97.7
United	ORD	49.1	83.7	94.0	98.4	99.2	99.5	99.9

TABLE 16.2

	% of Total Arrivals in Band Widths						
Delay size (minutes)	≤ 0	1-10	11-20	21-40	41-60	61-90	91-120
American	26.5	31.7	15.9	13.3	5.6	3.4	1.8
Delta	20.1	38.4	20.0	12.7	4.4	2.6	0.9
Western	12.0	36.0	23.4	17.3	4.9	2.9	1.2
United	49.1	34.6	10.3	4.4	0.8	0.3	0.4

TABLE 16.3

The data was not recorded for United at Los Angeles.

16.2.1 It is apparent that significant differences exist in the arrival performance with United and Western exhibiting the two extreme values. There is no merit in attempting in this project a detailed study of the reasons for these differences. They exist, either by design, chance or inefficiency and their effect on the gate plan is the only concern here.

United at O'Hare has almost 50% of its flights arriving on time or early. This means that gate changes and/or gate holds can be expected more frequently than with the other carriers.

However, from table 16.3 it is seen that in the 1-10 minutes delay range, the airlines are comparable and United's performance differs predominantly in the range 11-40 minutes. This implies that UAL should experience fewer requests for aircraft changes. It was seen in previous chapters than an aircraft change when known sufficiently in advance need not generate a gate change.

On balance it is suggested that the value of GTR achieved by United is slightly lower than would apply if the arrival punctuality were more in line with the other 3 airlines.

16.2.2 The effect of Delta's arrival punctuality on its gate plan is not considered to be significant because of the high frequency of long turnround times caused by their peaked operation.

16.2.3 Western, in the above sample, has the worst punctuality performance in each of the delay band widths shown. Some part of this can be attributed to the difference in size of their operation. Western do not have the range of possible aircraft changes that United has, and is consequently forced to accept more reactionary delays. This will tend to produce more gate changes since the larger delays although forseen cannot be reduced by creating a cycle but not a gate change.

The delayed turnround is accepted together with any interference with the next occupancy.

The value of GTR achieved by Western is considered to be slightly depressed by the airlines poor arrival punctuality. It should be noted that two opposite punctuality performances (i.e. UAL and WAL) produce the same effect on GTR.

16.3 Departure Punctuality.

The absolute departure performance was made available only by United at O'Hare and even then only as a list of actual movement times.

This is the result of a practice by the airlines of measuring departure punctuality in terms of deviation from the planned turnround time. In fact it is the station performance which is being monitored since this device eliminates the reactionary departure delay caused by a late arrival. Indeed it can highlight a station as being highly efficient in dealing with late arrivals even though its absolute departure performance may be abysmal.

American, for example, recorded the total number of departures with a delay in excess of 5 and 15 minutes merely as two global figures, but analysed in detail all late departures, irrespective of length, caused by the planned turnround time being exceeded.

One side effect of this method is that, once again, the integrity of a turnround is emphasised to ramp personnel. It is the turnround which is the complete entity not merely the departure.

Tables 16.4 and 16.5 below show the performances of the four airlines at La Guardia, O'Hare, Atlanta and Los Angeles. The data was not available for United at Los Angeles.

DEVIATION OF GROUND TIME FROM PLAN

% of total departures in each bandwidth is shown.

TABLE 16.4

Actual-plan Deviation (Mins)	> 20 gain	11-20 gain	6-10 gain	0-5 gain	1-5 loss	6-15 loss	16-30 loss	31-60 loss
American	2.1	13.9	15.0	37.0	15.6	7.8	4.0	2.8
Delta	3.3	14.5	18.6	36.3	12.2	10.0	2.7	1.4
Western	1.2	17.2	22.0	31.0	13.3	10.1	3.1	1.6
United	1.8	15.2	21.5	24.5	18.2	12.1	3.3	2.2

CUMULATIVE DEVIATION FROM PLANNED GROUND TIME.

TABLE 16.5

Actual-plan deviation (Mins)	more 20 gain	more10 gain	more 5 gain	sked or better	less 6 loss	less 16 loss	less 31 loss	less 61
American	2.1	16.0	31.0	68.0	83.6	91.4	95.4	98.2
Delta	3.3	17.8	36.4	72.7	84.9	94.9	97.6	99.0
Western	1.2	18.4	40.4	71.4	84.7	94.8	97.9	99.5
United	1.8	17.0	38.5	63.0	81.2	93.3	96.6	98.8

There is little merit in analysing in detail the above relative performances because of their high dependancy on the original turnround times. However it is clear that no great differences exist between the airlines. Consequently, the observations made in section 16.2 regarding the effect of punctuality on GTR values are not altered.

APPENDIX 16

FIGURE 1 - Daily variation of % GTR, American, Delta, United.

2 - Daily variation of % GTR, Western, United.

3 - % GTR variation with MSST.

4 - % GTR variation with Relative Dispersion.

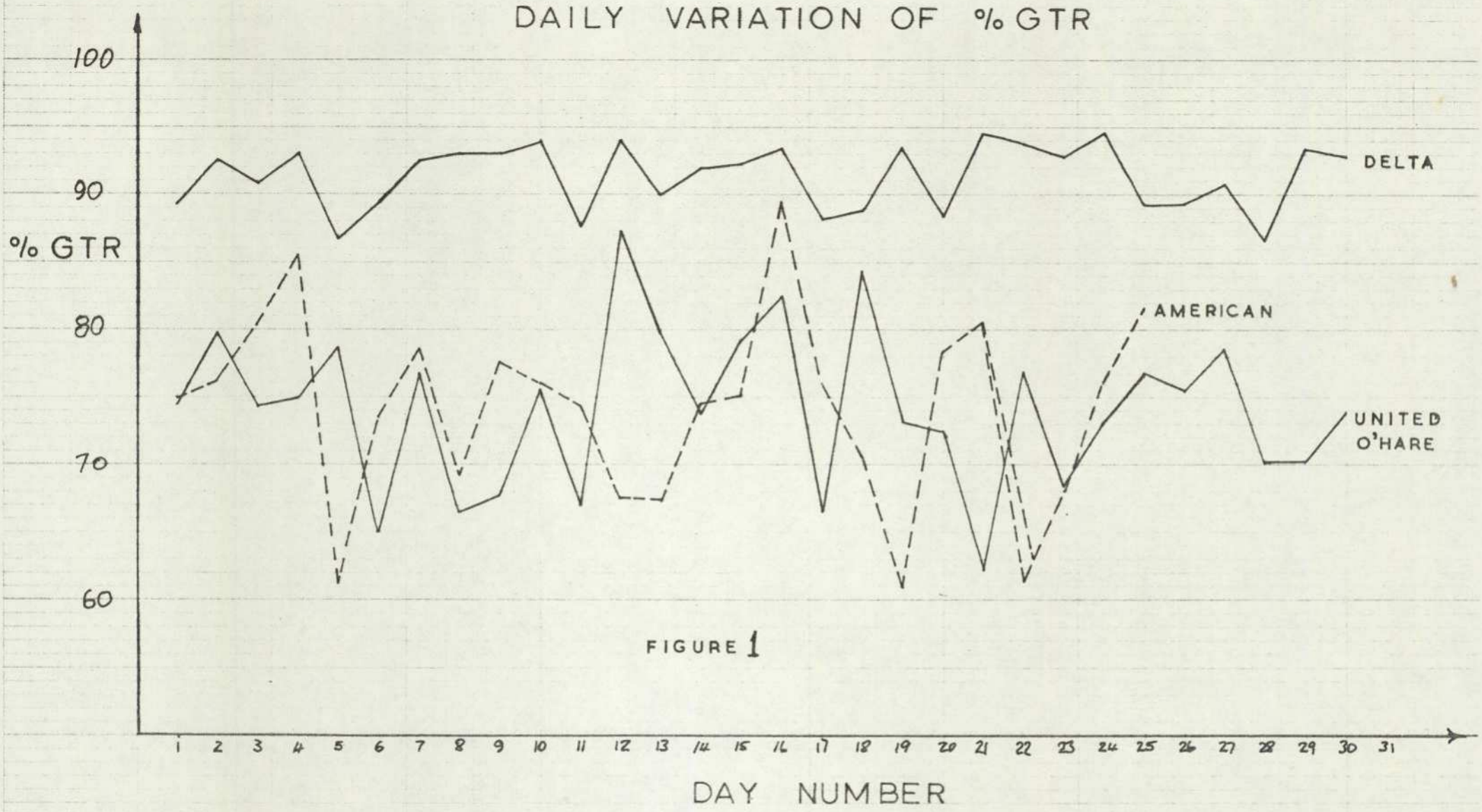
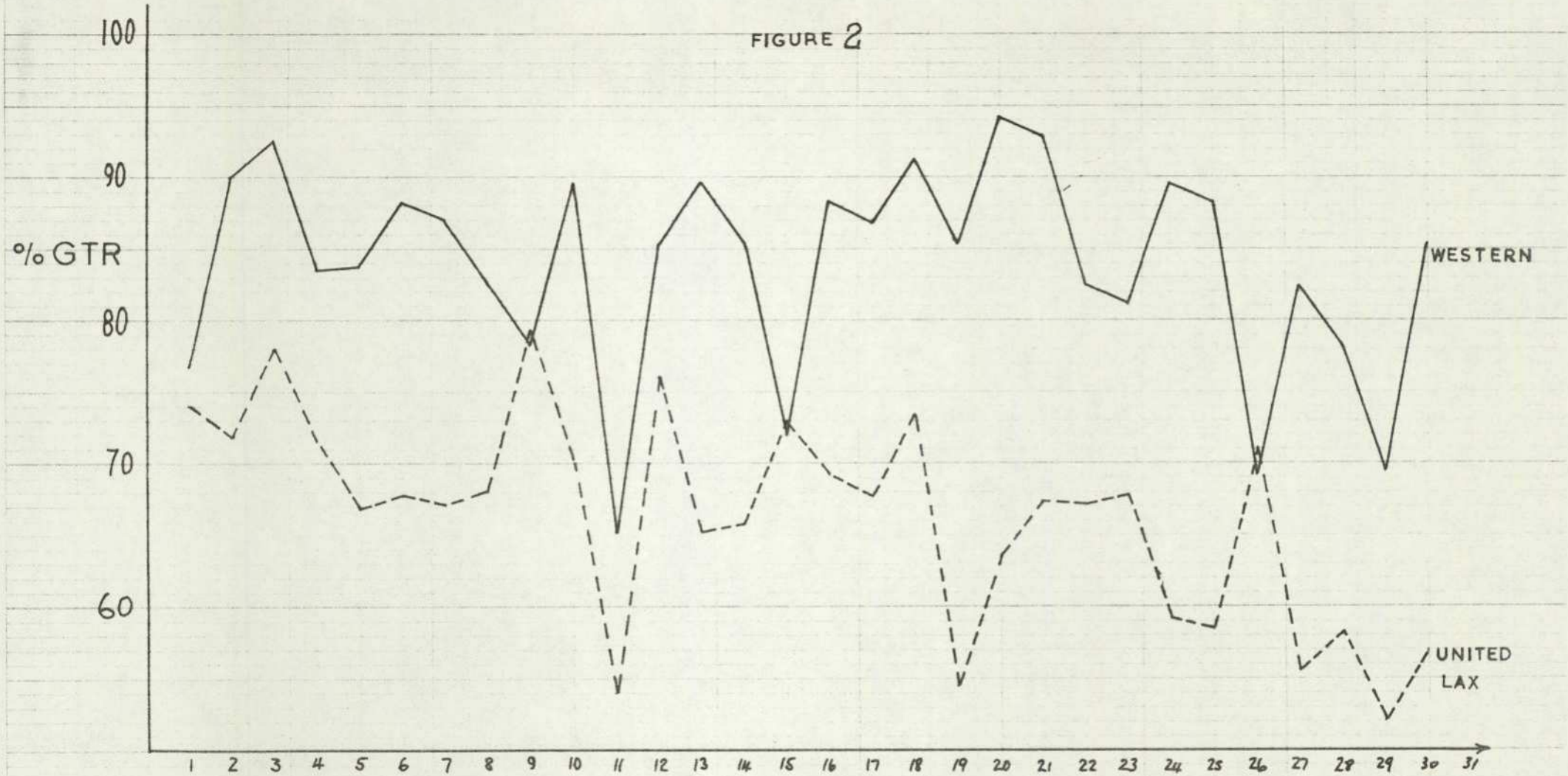

DAILY VARIATION OF % GTR
100
90
% GTR
80
70
60
DELTA
AMERICAN
UNITED
O'HARE
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DAY NUMBER

FIGURE 1

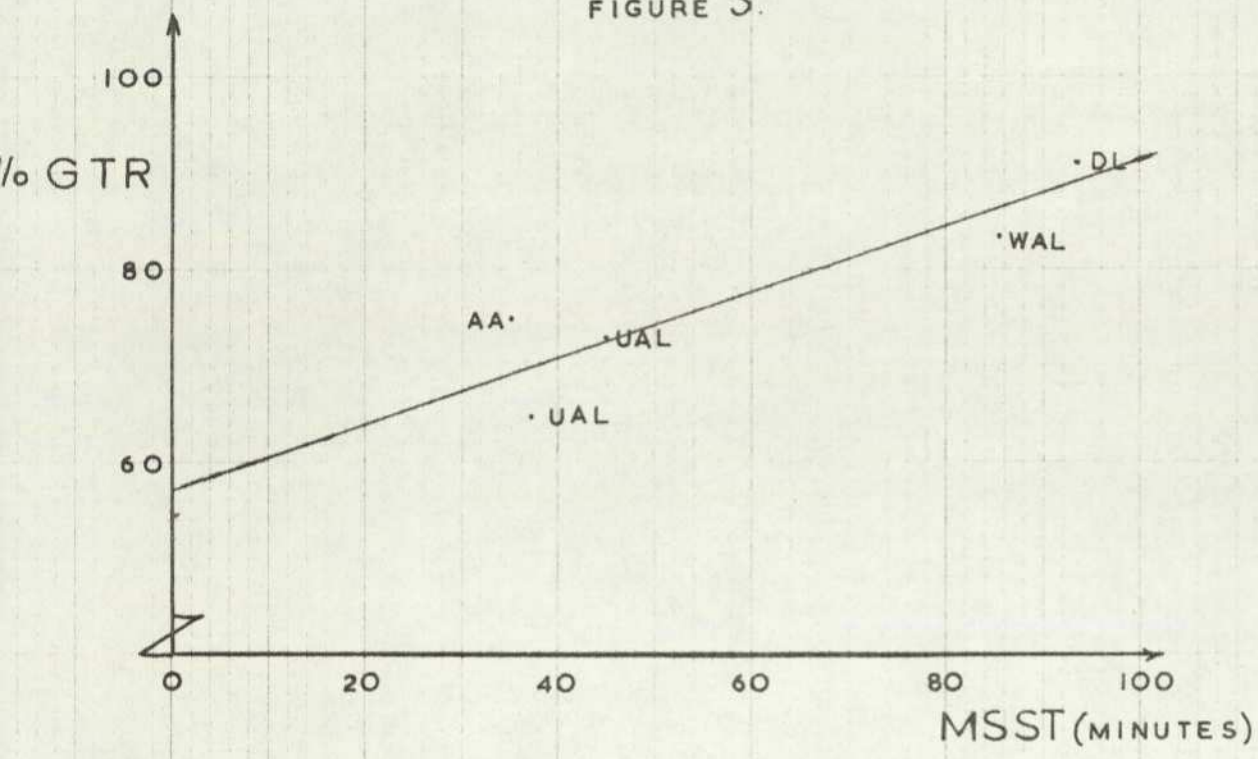
DAILY VARIATION OF %GTR

FIGURE 2



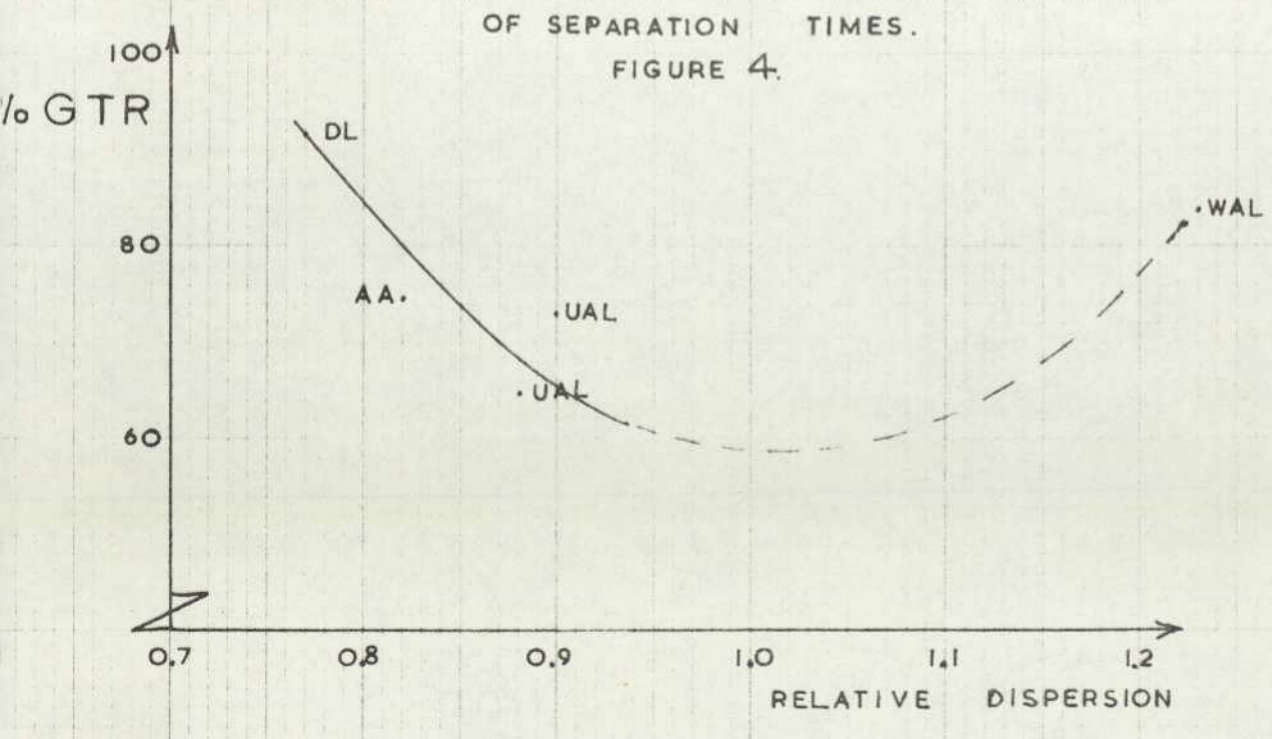
VARIATION OF %GTR WITH MSST

FIGURE 3.



VARIATION OF % GTR WITH RELATIVE DISPERSION OF SEPARATION TIMES.

FIGURE 4.



CHAPTER 17.

ESTIMATION OF GTR VALUES.

17.1 Method when actual and simulated values are available.

17.2 Method when only simulated values are available.

17.3 Example of estimating technique using BEA's summer 1974 schedule.

17.4 Comparison of BEA's estimated GTR with United.

17.5 Feasibility of BEA's summer 1974 plan.

17 ESTIMATION OF GTR VALUES.

This chapter deals with the situation where a gate timetable is being introduced into an operation for the first time. There is no history of the performance using gate plans under similar conditions and operating restrictions.

The operation of the summer schedule 1974 for BEA at London Heathrow Airport is used as an example.

17.1 In the case of United Airlines at O'Hare, where the gate plan was simulated and observed, it was possible to compare the actual GTR value with that from the simulation, after the effects of un-simulated conditions had been estimated.

It was seen in previous chapters that under the most severe input delay conditions, UAL1's simulation produced a GTR value of 81%. In chapter 12, it was deduced that this could be 7-17 percentage points too high, when the unsimulated conditions peculiar to United were applied. This coincides with the recorded value at O'Hare of 73%.

When a new plan is introduced by United, based on a new flight schedule, an estimate of the results which would be achieved by subjecting it to simulation under GATESIM, can be obtained from the graphs of appendix 10. The relevant corrections can then be applied to obtain the estimate of the actual performance.

17.2 In BEA's case, the conditions are slightly different in that there is no way of checking the simulated GTR value and the corrections to it, against the actual results. It is suggested that the following is a realistic approach.

17.2.1 The results of simulating BEA1 and BEA2 should be compared with those of plans UAL 1-5, and any gross differences noted.

17.2.2 The dependancies ascertained for UAL 1-5 and BEA1, 2, should be applied to the parameters of the new gate plan, BEA3, say.

17.2.3 The corrections which applied to United's operation should be studied and their application to BEA's operation should be considered. Any additions or deletions should be made.

17.2.4 These new corrections should be applied to the plan BEA3.

17.3 The above method is now applied to the summer 1974 gate timetable for BEA at London Heathrow.

17.3.1 Comparison of BEA1, 2 with UAL 1-5.

The variation of GTR was discussed in section 10.4. It was shown how the MSST-GTR relationship developed for United plans did not apply to the absolute BEA1 and 2 results.

However within the BEA plan, it was seen how the GTR values rose with increasing MSST and with decreasing value of the relative dispersion of separation times in accordance with the principle developed for UAL. It is claimed that in such a complex situation it is reasonable to assert that the difference in flight schedule is the predominant reason for the discrepancy in the absolute values. This is an obvious simplification bearing in mind the discontinuities produced by UAL 2 and 4, even though these 2 plans do have a different resource level. In fact the above assertion must be made if any attempt to estimate a value of GTR for BEA3 is to be made.

The departure punctuality was seen not to vary to any extent with a change in gate plans.

17.3.2 The values for MSST and relative dispersions of separation times for BEA1-3 are repeated in table 17.1 below.

	MSST (Mins)	Rel.Disp.	Simulated % GTR
BEA1	59.2	0.62	87.7
BEA2	46.7	1.52	80.2
BEA3	37.1	0.85	?

The most severe input delay condition is stated.

TABLE 17.1

If a linear relationship between MSST and GTR is assumed, BEA3 would demonstrate a GTR value of around 74%.

If the relative dispersion is used, again assuming a linear relationship, a value of around 85% would be expected.

In section 9.5 it was claimed that the relative dispersion relationship was more critical than the MSST one. This referred to a condition when the MSST values under discussion were of comparable size unlike the above plans BEA1-3.

17.3.2 It would therefore appear that a value nearer 74% than 84 should apply and that the relative dispersion dependancy should be discredited in these circumstances. However, reference is made to table 1 and figure 1 of appendix 14 where BEA3 is shown and analysed.

A large amount of scatter in the number of occupancies per gate is apparent with two positions having only one occupancy, one with only two and one with four. The two single occupancy gates are ignored in the analysis and the effect on the computed scatter of separation times of the other two gates is less than would be expected. This is because the long vacant times are not regarded as a separation time.

In fact BEA3 is tending towards a LOFI policy with the occupancies being concentrated on 10 gates each with 10 or more occupancies. This policy is not reflected as a high relative dispersion value because of its success in reducing the occupancies on some gates to such an extent that their separation times are ignored.

Consequently, the relative dispersion dependancy need not be discredited. It is suggested that its influence together with that of the MSST value would produce a GTR value in the range 78-80%.

17.3.3 The corrections applied to the simulated results of the United plans were as follows. The simulated GTR should be reduced by these values.

Effect of extra flights	2	percentage points
Effect of aircraft unserviceability	5-10	percentage points
Effect of long delayed turnrounds	0-5	percentage points
Total Correction	7-17	percentage points

These are now treated in turn and applied to the operation of BEA3.

i) Extra flights.

It was seen in chapters 12 and 13 that United's policy was to regard "extras" precisely as their name implies, i.e. they are additional to the normal schedule and do not normally interfere with the planned aircraft integrations. Hence any disruption to the gate timetable is caused by interference of imposed occupancies with the

17.3.3 i) original ones and is not the result of unscheduled occupancies caused by aircraft cycle changes required by the extra.

BEA is able to operate slightly differently because of the availability of the computer systems FIND, FICO and the batch scheduling programmes. The aircraft cycles are computed daily using the batch programmes and form the basic data for FIND and FICO which were briefly discussed in chapter 14. The aircraft cycles, so obtained, incorporate any extra flights planned for the next day and are constructed in line with the scheduling policies of the airline. The changes to the original plan are not normally significant.

All turnrounds are known to station staff in the early hours of the morning several hours before the start of the days operation. Thus if a gate plan were in operation sufficient time would exist to update all gate information so that in fact, no occupancy should be regarded as "unscheduled" as understood in the context of this work.

It is felt that there is no need to make an allowance similar to that of 2% with United on account of known extra flights.

ii) Effect of aircraft unserviceability and cycle changes.

In the case of United the 5-10% correction was an allowance for effects of unserviceability experienced during turnrounds and which resulted in aircraft changes mainly of type DIRECT or INDIRECT swap.

Technical studies within BEA have shown that the inherent mature serviceability level of the Trident range of aircraft is comparable with that of the Boeing 727 types. Consequently it would seem that the 5-10% correction factor to the GTR value should be applied to BEA3.

However, the reluctance of BEA to ensure that where possible aircraft changes are of type DIRECT or INDIRECT, was seen to create an atmosphere that the planned integrations have little validity and can be altered at a whim.

17.3.3 ii) In the sample study summarised in appendix 15, it was seen that almost 16% of the turnrounds were unscheduled when in fact the relevant departures could have been operated using the planned turnrounds. This in itself need not create a similar number of gate changes provided that the new turnrounds are known well in advance of aircraft arrival. The study showed however that over 24% of all arrivals not planned to go off service had in fact at the time of gate allocation, either no departure allocated to it or else the wrong one. These two figures are related and the elimination of unnecessary cycle changes will result in a large reduction in the amount of wrong data used at gate allocation time.

Of the 16% of turnrounds which were unnecessary, not all would incur a gate change to the departure if a gate plan were in use because the turnround may have been available for reference long before its occurrence. A conservative estimate is that 5% of departures would be involved in a gate change on this account. In addition it is necessary to estimate the effect of the 24% of arrivals whose cycle is changed after the gate has been selected.

Before any corrections have been applied, the gate plan was estimated to have a GTR value of about 80%, i.e. 20% of departures left from the wrong gate. This figure must be applied to the above 24% in order that a wrong gate departure is not counted twice. It is deduced that about 19% of arrivals could have gates allocated to them in accordance with the gate plan but will in fact operate departures on a substitute cycle, and from the wrong gate for those departures.

It is emphasised that the introduction of FICO etc., has reduced the 24% to an estimated average of nearer 12%. This results in the correction to GTR being nearer 9% than 19%.

In total, the effect of aircraft changes, in the main caused by unserviceability and flight operation requirements, is estimated to require a correction of about 29-34 percentage points before the introduction of FICO and about 19-24 points after.

17.3.3 iii) Effect of long delayed turnrounds.

This does not apply to BEA because of the absence of through flights which normally constitute such occupancies.

17.3.4 It is seen that the only significant corrections are those generated by the exclusion of unserviceability data from the simulation, together with the method of implementing aircraft cycle changes. The current factor is about 19-24% points.

The estimated value of GTR from the simulation was seen in section 17.3.2 to be in the range 78-80%. From the above, the achievable value for the summer 1974 schedule is estimated to be 54-61%.

17.4 This value is low when compared to United's performance, but when the effect of unnecessary unscheduled turnrounds and unnecessary late aircraft changes are removed, the GTR value increases into the range 68-75%. This coincides with the plots shown in figures 3 and 4 of appendix 16 where actual values of GTR are graphed against MSST and the relative dispersion of separation times respectively.

17.5 Before the introduction of FICO, the same gate plan could have an expected GTR value of about 44-51%. Since this is an average figure, considerably lower values could have been expected on a daily basis. It is not therefore surprising that the concept of a gate was discredited and never implemented. Even the present achievable level of 54-61% is considered very low and will cause the merit of the plan to be questioned.

It is submitted, however, that the reason for these low values is not one of gate plan inadequacy, or the inherent result of operating a hub and spoke type operation. They are predominantly caused by the method of implementing aircraft changes and by the attitude of mind that it is the departure alone, and not the turnround as a complete entity, which is of paramount importance.

If these methods and attitudes were altered there is no reason why the gate plan could not become an accepted operational tool as it is with the American airlines.

CHAPTER 18

OTHER RELATED SIMULATIONS.

18.1 United Airlines - turnround simulation.

18.2 American Airlines - gate requirement simulation.

18.3 American Airlines - simulation of Central Lounge Concept.

18 OTHER RELATED SIMULATIONS.

In this chapter, a brief description of simulations developed by United and American Airlines is given, as far as they concern gate allocation and utilisation.

18.1 United Airlines.

In the author's knowledge, the only relevant simulation developed by United in connection with gate utilisation was conceived as a method of ascertaining the basic cause of severe baggage unloading delays being experienced at O'Hare.

It was not at all clear which, if any of the following possibilities, was the culprit:-

i) Baggage facilities in the terminal itself.
ii) "Baggage train" congestion at entrance to terminal, airside.
iii) Lack of capacity on the roadways alongside the piers. This could be a localised problem caused by the gate timetable scheduling occupancies, such that specific sections of roadways are over congested at certain times.
iv) Interline baggage in the transfer area.

18.1.1 It is obvious from the above that the majority of the programme complexities was related to baggage handling activities associated with each gate occupancy. This immediately required that any departure delay be generated by station performances and not randomly selected as in GATESIM. Conversely although the gate timetable forms part of input data, its reliability was not being studied, so a simple gate allocation procedure was adopted.

18.1.2 The simulation can be divided into 3 main sections,

i) arrival time assignment
ii) gate assignment
iii) on gate processing.

The latter is by far the largest. Figures 1-6 of appendix 18 show in flowchart form the activities performed at each stage.

18.1.3 It is seen that the original gate plan is adhered to as closely as possible. Gate changes are effected by inserting the inbound aircraft on to the first gate which meets certain constraints, which do not include minimum disruption to departing flights.

18.1.4 Aircraft changes are not permitted.

18.1.5 Arrival delays are independent of any departure delay at previous stations.

18.1.6 Departure delays are created by adopting the policy that the flight may leave only when certain activities have been performed. Completion of aircraft defect rectification is one such requirement. Because aircraft changes are not permitted, the data collection problems described in section 7.7.5 are not encountered to the same extent.

18.1.7 The output includes:-

i) Departure punctuality showing reasons for delays.
ii) Gate holds.
iii) Baggage delivery time from aircraft to passenger pick up point.
iv) Queuing time of baggage vehicles at points between aircraft and terminal building.
v) Efficiency of terminal building baggage handling equipment.

18.1.8 Although a value could be computed for GTR, it would bear little resemblance to that achieved by GATESIM, because of the inadequate gate and aircraft change procedures. United recognise that the programme has severe limitations when applied to a problem for which it was not designed, they do not attempt to use it to evaluate gate plans other than to estimate the effect of a new plan on baggage delivery performance.

18.2 American Airlines.

Two simulations concerning gates are described. Both are concerned with ascertaining total gate requirements and make no attempt to estimate their operational reliability.

18.2.1 The first was developed for use on a real time basis at the schedule planning stage to ascertain the total gate requirement. In addition it enables an estimate to be made of:

i) Best mix of gate types to service the fleet schedule.
ii) Number of back up gates required to prevent excessive aircraft delays due to schedule bunching caused by in-flight or ground congestion.
iii) Any flights which are particularly vulnerable to delays as a result of gate congestion.

18.2.2 Flight delays can be injected but no aircraft changes are invoked to alleviate them. The delays are generated in a manner not unlike that used in GATESIM, but without any connection between departure time and arrival back at the same station. Departure times are ascertained by combining the actual arrival time with a random sample from a distribution of deviation from scheduled ground time.

18.2.3 Since the simulation was designed for use by schedule planners in real time mode, a fast programme execution time was essential. This affected the method in which these delays were apportioned. One possibility was to compute the delay to each movement, before any gate allocation is performed, then to chronologically sort them before allocating gates on the selected policy (FOFI,LOFI, etc.). Alternatively, the gate assignment could have been performed at scheduled arrival time although not classifying the gate as occupied until the actual arrival time. If, for instance, the FOFI policy was adopted, the latter method cannot ensure its accurate implementation. However, American found that the computer time required to perform the sort necessary under the first alternative was too high. As a result, the second less accurate approach was adopted.

18.2.4 The input includes:-

i) The flight schedule in chronological order, with no indication of aircraft cycles.
ii) Minimum separation times.
iii) Total number of available gates.
iv) Aircraft/gate restrictions.
v) Delay distributions.

18.2.5 The output includes:-

i) Gate timetable.
ii) Mix of gate types.
iii) Gate holds and delays caused by them.
iv) Analysis of gate plan.
v) Identification of any flights with recurrent delays.

18.2.6 It is emphasised that the resultant gate plan is not necessarily the one to be used operationally, but merely demonstrates that sufficient resources have been provided. No attempt can be made by this programme to estimate the plan's reliability.

18.3 The second simulation developed by American was designed to evaluate the Central Lounge concept, under which several gates are served by one passenger check in point with one large holding lounge.

18.3.1 Throughout this thesis, the advantages of using a gate plan as apposed to ad-hoc gate allocation has been extolled. GATESIM has been used to identify the best method of scheduling occupancies, to estimate GTR values for airlines already operating a plan, and finally to ascertain if such a plan could be implemented by those airlines not already convinced of its feasibility.

18.3.2 In a report describing their simulation of the central lounge concept, American Airlines re-iterate their conviction that a gate plan is necessary and practical. Indeed they advance the theory by claiming that one of the main reasons for planning on a 15 minute minimum separation time is the passenger processing time at the gate lounge and that this could be reduced by separating the lounge and gate plans.

It is considered worthwhile to reproduce their comments as written in the introduction to the above report. They are:

"For present terminal configurations and operating procedures it is necessary to set up advance gate assignment schedules for all flights so as to match lounge requirements with aircraft operations. This tends to introduce inefficient use of space for a number of reasons.

1. Passenger assembly procedures in the lounge may tie up a gate for a longer time than required to turn the aircraft leading to poor ramp space utilisation.

2. Having to "park" a plane at a gate position longer than needed to assemble passengers for a flight leads to poor lounge utilisation.

3. A gate assignment schedule, to be of any use at all, must be reliably adhered to, which means some "padding" has to be inserted between gate assignments as protection against flight schedule variation. This leads to possibly decreased utilisation of both lounge and ramp space.

The primary advantage of a central-lounge terminal concept is that a lounge schedule is not required. While some sort of ramp schedule will be necessary for spotting ground equipment and personnel it is at least free of the need to consider lounge requirements at a gate. It is therefore reasonable to hypothesize that the central lounge concept would require fewer gate positions to service a given flight schedule."

18.3.3 The simulation generates delays and early movements in a way similar to GATESIM and processes the flight activities in chronological order after delay allocation. No aircraft changes are permitted. Gates are allocated at arrival time on a LOFI basis with no reference whatsoever to a gate timetable. The minimum separation time forms part of the input data. A series of runs for 3 particular stations were performed with input values of 5, 10, 15 and 20 minutes. At two stations, La Guardia and Dallas, it was found that when the minimum was reduced to 5 minutes, one gate could be "saved", but no reduction was possible at O'Hare. No significant difference in punctuality rates was experienced between the two resource levels.

18.3.4 American concluded from these figures that the Central Lounge concept reduced the gate requirement and did so by permitting tighter scheduling on gate areas now not restricted by passenger check-in requirements. It is suggested by the author, that this conclusion is based on insufficient evidence and that the simulation is incapable of providing the additional necessary information.

18.3.5 The simulation allocated gates with no reference to a gate plan but used actual movement times, scheduled on to the ramp in the LOFI manner. Such a method of gate allocation ensures the most efficient use of the ramp in terms of total gate utilisation only. It does not take into account the fact that it is achieved at the expense of GTR and that the advantages to be gained by operating a gate plan are reduced.

18.3.6 In item 3 of the above quotation from the American Airlines report, the need for gate timetable reliability is emphasised, yet the effect on it of a reduction in the number of gates by introducing a central lounge was not quantified.

18.3.6 This is of particular importance to an airline already implementing a gate timetable and reaping its benefits. When its reliability reduces significantly, these benefits rapidly disappear and delays are incurred to an extent greater than if the plan did not exist at all.

For example, GATESIM estimated that a reduction in GTR of up to 12% could be expected if United operated under 18 gates instead of 20 at O'Hare. This may or may not be critical depending on the actual values.

18.3.7 It is therefore submitted that the evaluation of a Central Lounge concept would have been complete if the results from American's simulation had been studied in conjunction with gate timetable reliability estimates as produced by GATESIM. On its own, however, the former merely becomes another exercise in occupancy juggling with no consideration being given to the associated operational problems. As such it is a valuable tool and can be used to demonstrate the gate savings which can accrue from reducing gate separation times, provided a concurrent exercise demonstrates that any associated movement in the gate timetable reliability will have no effect on flight punctuality or station resource requirements apart from gates.

APPENDIX 18

FLOW CHARTS OF UNITED'S TURNROUND SIMULATION.

FIGURE 1	General Outline.
2	Input and Output.
3	Arrival time assignment.
4	Gate assignment.
5	On gate processing.
6	Manpower Availability.

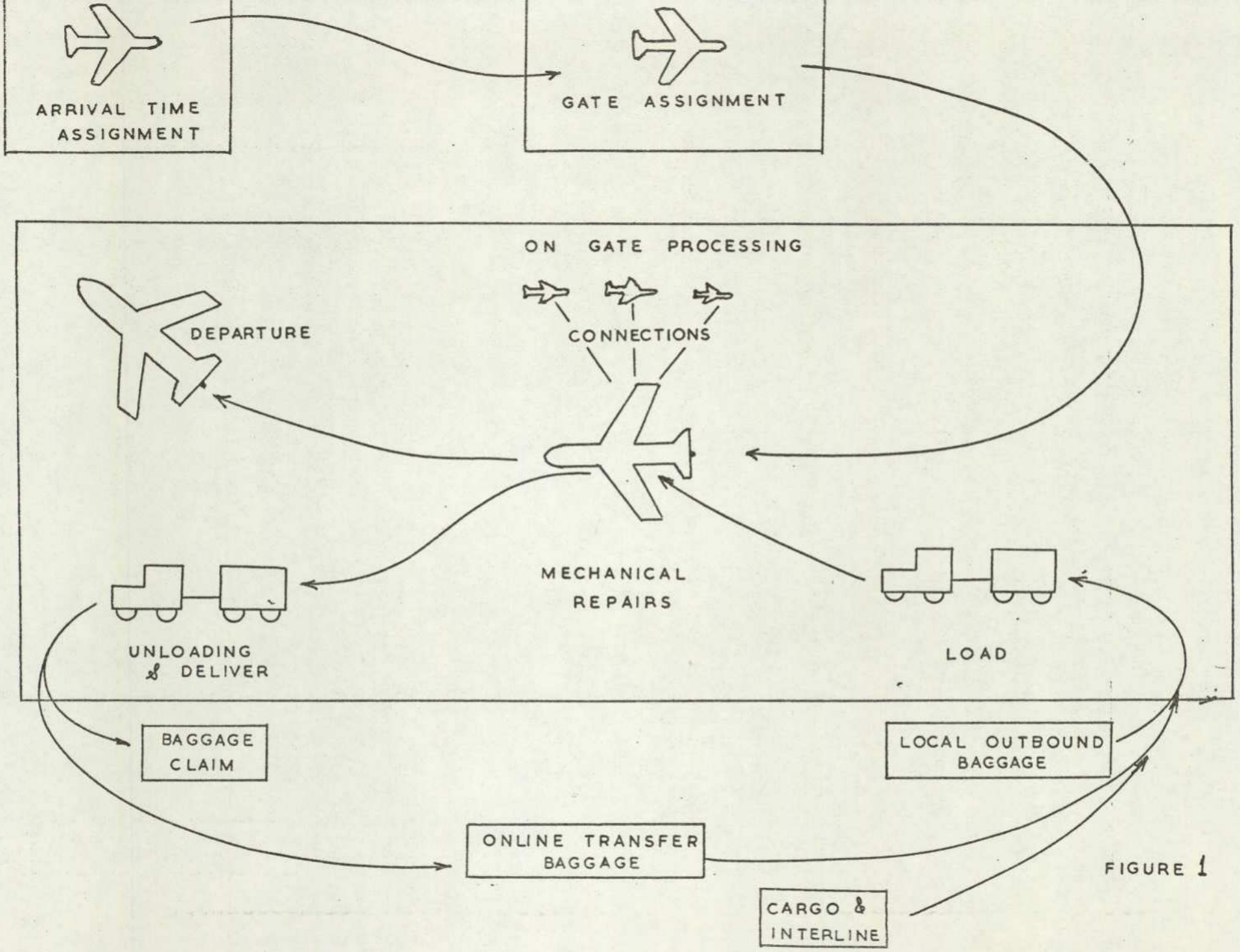

ARRIVAL TIME ASSIGNMENT
GATE ASSIGNMENT
ON GATE PROCESSING
DEPARTURE
CONNECTIONS
MECHANICAL REPAIRS
UNLOADING & DELIVER
LOAD
BAGGAGE CLAIM
LOCAL OUTBOUND BAGGAGE
ONLINE TRANSFER BAGGAGE
CARGO & INTERLINE

FIGURE 1

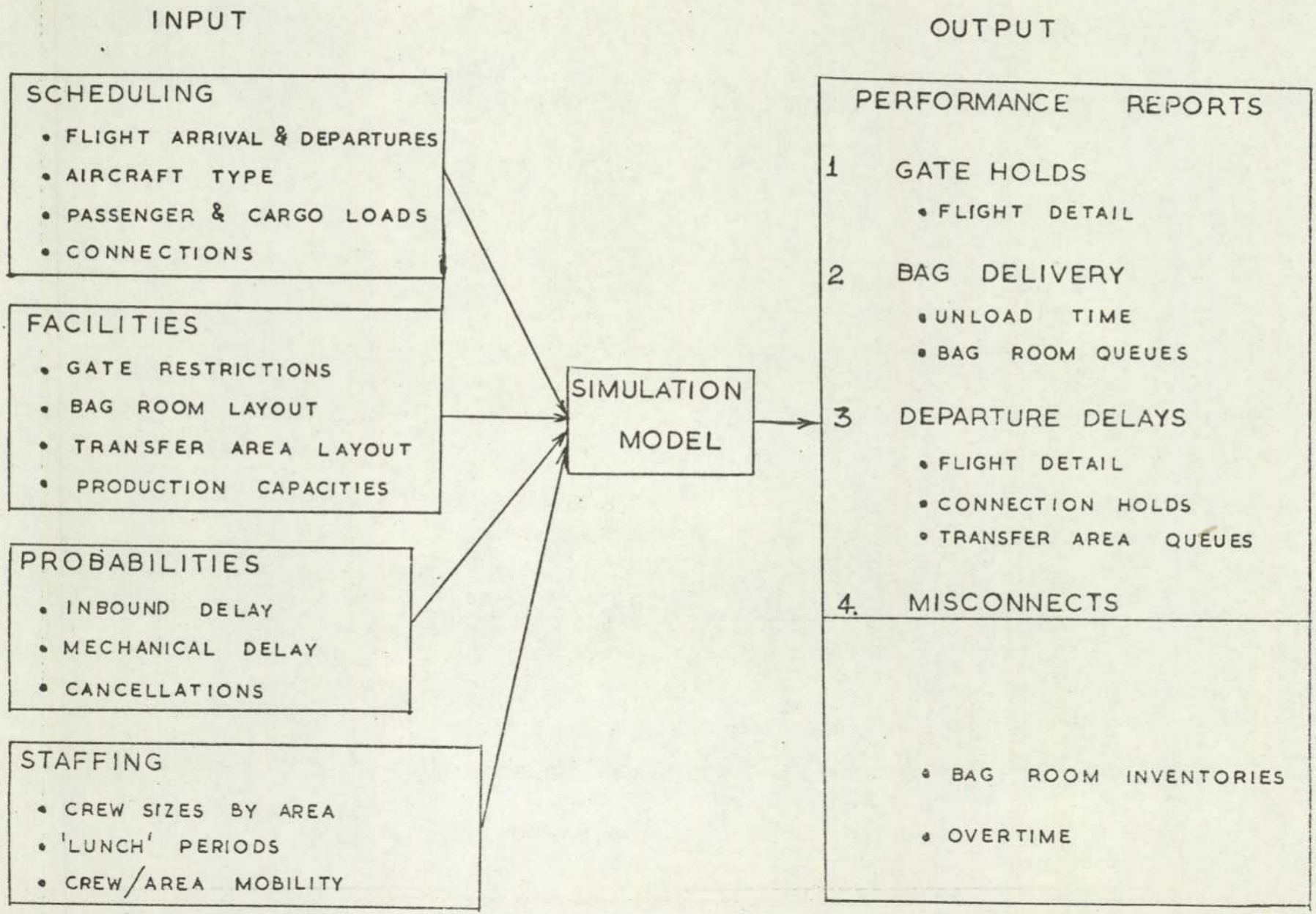

INPUT
SCHEDULING
• FLIGHT ARRIVAL & DEPARTURES
• AIRCRAFT TYPE
• PASSENGER & CARGO LOADS
• CONNECTIONS
FACILITIES
• GATE RESTRICTIONS
• BAG ROOM LAYOUT
• TRANSFER AREA LAYOUT
• PRODUCTION CAPACITIES
PROBABILITIES
• INBOUND DELAY
• MECHANICAL DELAY
• CANCELLATIONS
STAFFING
• CREW SIZES BY AREA
• 'LUNCH' PERIODS
• CREW/AREA MOBILITY
SIMULATION MODEL
OUTPUT
PERFORMANCE REPORTS
1 GATE HOLDS
• FLIGHT DETAIL
2 BAG DELIVERY
• UNLOAD TIME
• BAG ROOM QUEUES
3 DEPARTURE DELAYS
• FLIGHT DETAIL
• CONNECTION HOLDS
• TRANSFER AREA QUEUES
4. MISCONNECTS
• BAG ROOM INVENTORIES
• OVERTIME

FIGURE 2

STEP 1 — ARRIVAL TIME ASSIGNMENT

ARRIVAL TIME = SCHEDULE ± VARIATION

VARIATION DETERMINED BY:-

- RANDOM SELECTION OF WIND FOR THE DAY
- SELECTION OF DISTRIBUTION BASED ON

  WIND

  FLIGHT LENGTH

  FLIGHT DIRECTION

- RANDOM SELECTION FROM CHOSEN DISTRIBUTION

FIGURE 3

STEP2 - GATE ASSIGNMENT

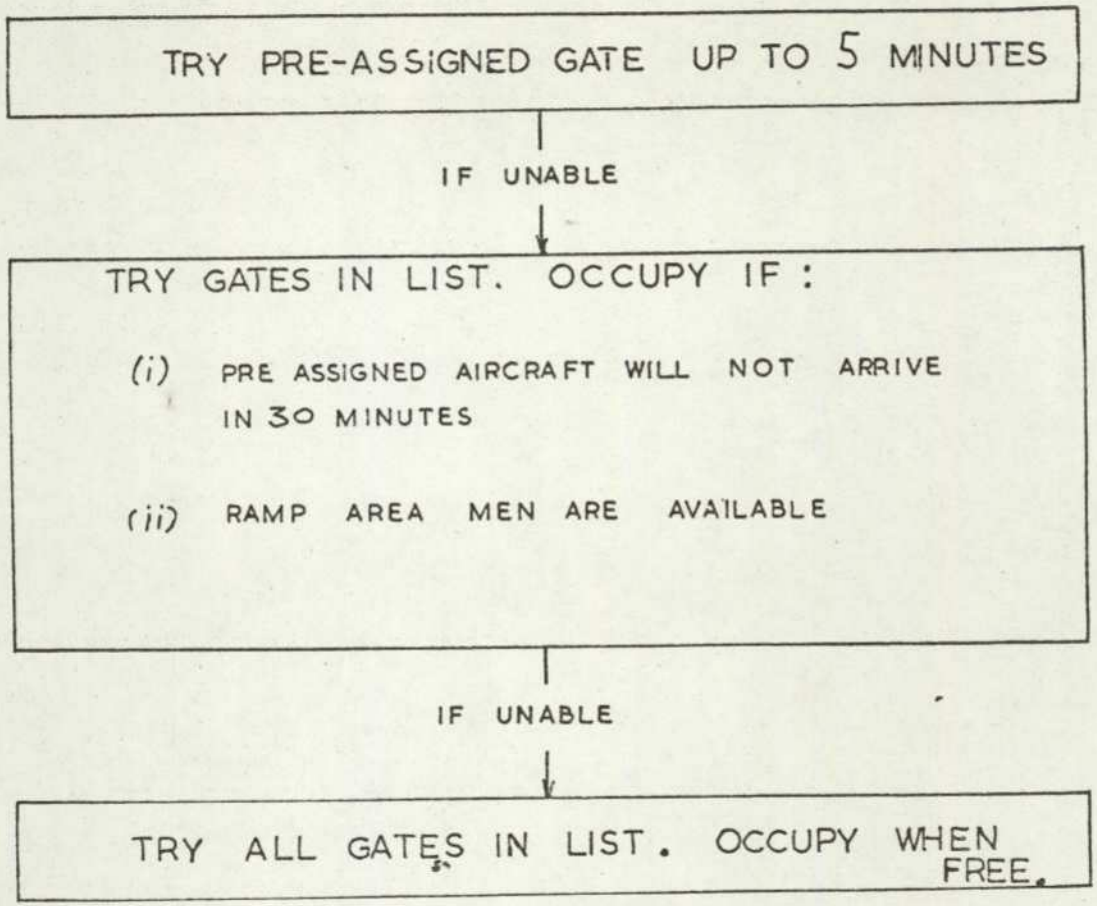


FIGURE 4

STEP 3 - ON GATE PROCESSING

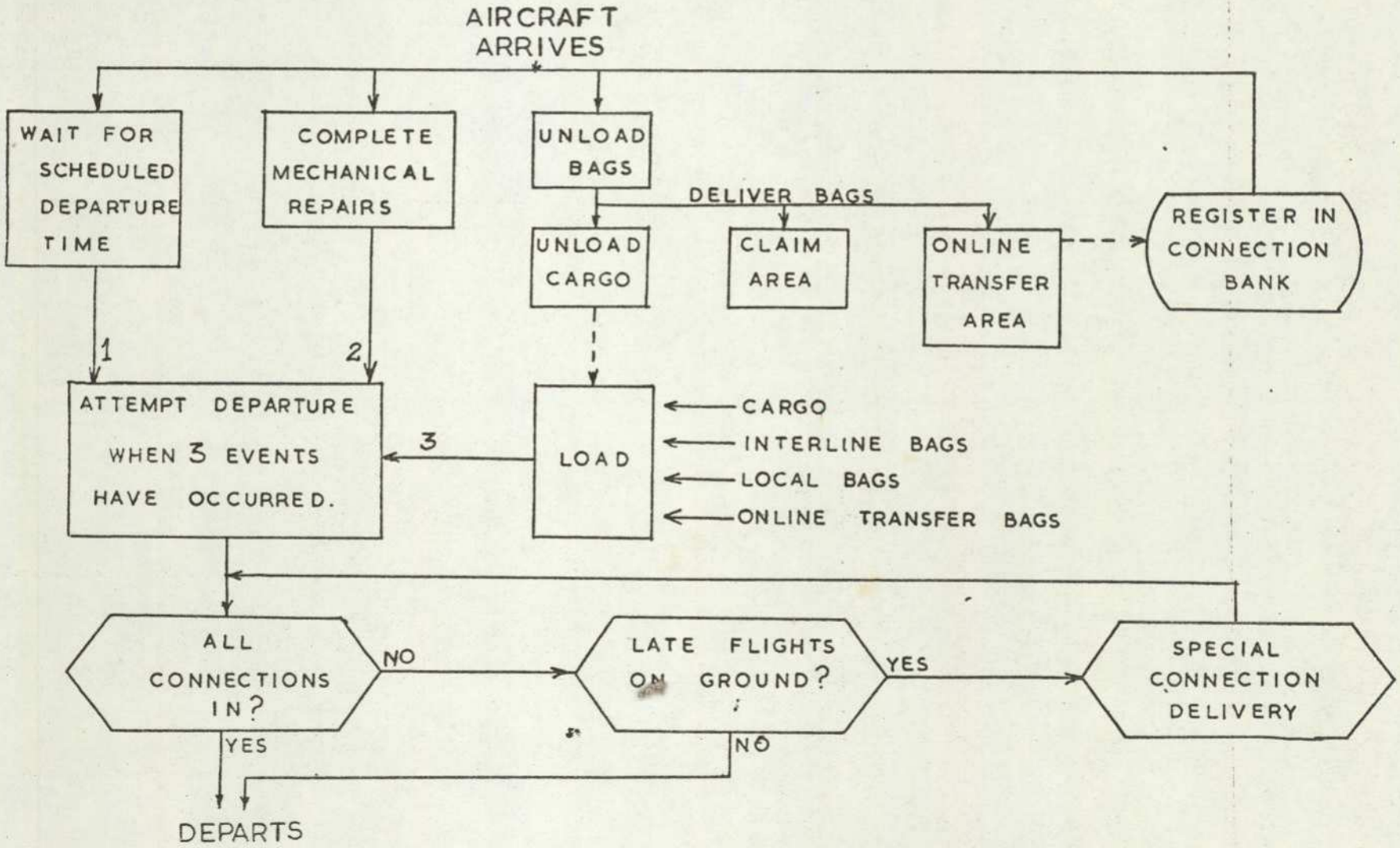


FIGURE 5

SUBROUTINE – MANPOWER AVAILABILITY

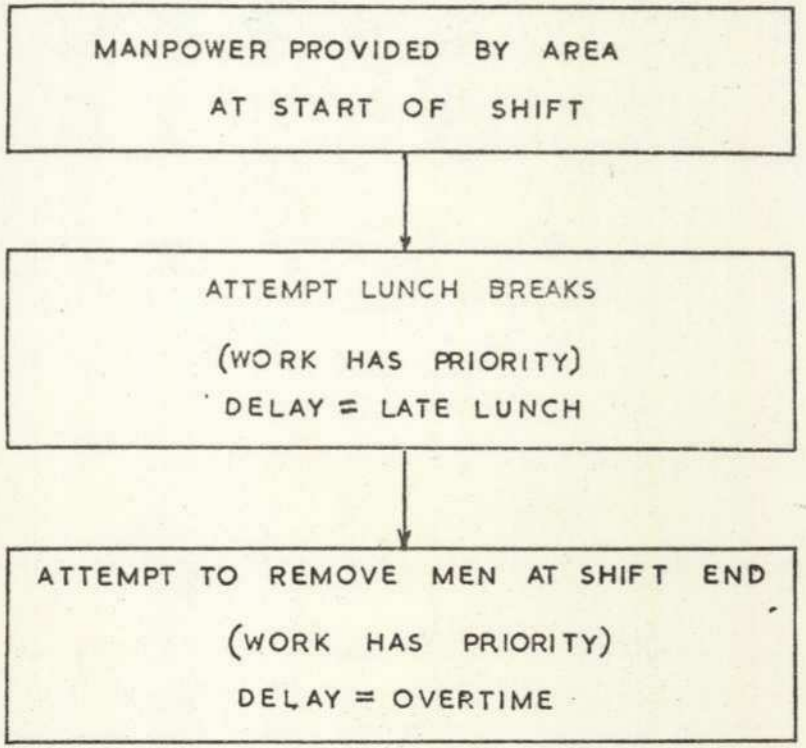


FIGURE 6

ERRATA

Page 22 — Section 4.4.2

Delete line 6 and insert
"GDEPNO (A, B+1) at time GTD (A, B+1)"

PAGE 68 — Section ii)

Delete line 3 and replace with
"A2=false) T4-T1 $\geqslant$ M1 and T2-T3 $<$ M1".

PAGE 69 — Section 5.7.2.1

Delete line 10 and replace with
"DEP(CAUSE3, CAUSE4) - ARR (CAUSE1, CAUSE2) $\geqslant$ M1".

PAGE 70 — Last two lines

Replace T2 with T3 and replace T3 with T4

PAGE 77 — Second paragraph

In line 12 delete "TD (C, Y1)" and replace with
"TD (C, D1+E1-R1+Y1-G1)".

PAGE 89 — Section 5.15.2.2

Delete lines 9-12 and replace with "The integer BEST.VD.. is assigned the value of the mean delay per delayed aircraft".

PAGE 91 — Item i)

Delete line 2 and replace with "per delayed departure".

PAGE 98 — Under diagram

Delete "b" and replace with "A-".

PAGE 144 — Section 6.10.3

In line 18, delete "DEPG" and replace with "GDEP".

PAGE 153 — Section 7.6.3

The reference in line 5 of the second paragraph should read 7.6.1.

PAGE 154 — Top Line

Insert "Separation" after "station average".

PAGE 154 — Section 7.6.4

The reference in line 13 of the second paragraph should read 7.6.1.

PAGE 199 — Section 9.4

In second line of second paragraph replace "delays" with "days".

PAGE 199 Section 9.4. Cont.

In line 6 of second paragraph, delete "also shown" and replace with "shown in appendix 11".

PAGE 208 Section 9.6.2

In line 5 of second paragraph delete "UAL4" and insert "UAL2".

PAGE 258 Section 10.1.1

In second line delete "LESS" and replace with "MORE".

PAGE 286 Figure 20

On the vertical axis, replace "Holds/100 departures" with "total time held/100 departures".

PAGE 289 Line 12

The left hand side of the equation has been omitted and should be $\hat{\sigma}^2$ to become

$$\hat{\sigma}^2 = \frac{N}{N-1} \cdot \frac{\sum_1^K s^2}{K}$$

PAGE 317 Section 12.7.7

In line 2 replace "table 2" with "table 4".

PAGE 401-405

Replace pages 404 and 405 with the attached 404A and 405A. This causes the following insignificant changes to the texts on pages 401 and 403:-

Page 401 - In last paragraph replace 15.8% with 15.4%
Page 403 - In item 3, replace 36.8% with 36.0%
- In item 4, replace 15.8% with 15.4%

PAGE 429

The following reference should be inserted at the end of the chapter.

"Report on analysis of Gate Reductions with Central Lounge concepts".

Prepared by American Airlines, New York, December 1968.

SUMMARY OF UNSCHEDULED TURNROUNDS

1. BY AIRCRAFT TYPE OVER 3 DAY PERIOD

TABLE 1

AIRCRAFT	NO. OF SCHEDULED TURNROUNDS	UNSUCCESSFUL		CLASSIFICATION			
		NUMBER	%	ENGINEERING	OPERATIONS	GROUND OPERATIONS	NON - REQUESTED
TRIDENT 1	108	62	57.4	13	19	6	24
TRIDENT 2	22	12	54.5	6	5	0	1
SUPER 1-11	30	16	53.3	5	9	0	2
VANGUARD	56	31	55.3	12	8	0	11
VISCOUNT	24	5	20.8	3	2	0	0
COMET	7	1	14.3	1	0	0	0

2. TOTAL FLEET ON DAILY BASIS

TABLE 2

DATE	NO. OF SCHEDULED TURNROUNDS	UNSUCCESSFUL		CLASSIFICATION			
		NUMBER	%	ENGINEERING	OPERATIONS	GROUND OPERATIONS	NON-REQUESTED
29.1.70	83	49	59	19	19	2	9
5.2.70	80	36	45	8	14	1	13
10.2.70	84	42	50	13	10	3	16

3. TOTAL TURNROUNDS - ALL AIRCRAFT TYPES, THREE DAY TOTALS

TOTAL SCHEDULE TURNROUNDS	UNSUCCESSFUL		ENGINEERING		OPERATIONS		GROUND OPS.		NON-REQUESTED	
	NUMBER	%	NUMBER	%	NUMBER	%	NUMBER	%	NUMBER	%
247	127	51.4	40	16.2	43	17.4	6	2.4	38	15.4

% SUCCESS OF SCHEDULED TURNROUNDS, obtainable by eliminating those unscheduled turnrounds in the classification "non-requested".

It should be remembered here that if a flight is scheduled to go off service and actually does so, the turnround is not included in the following. Thus by eliminating the "non-requested" category, the number of turnrounds considered is affected.

TABLE 4

ACTUAL			NO "NON-REQUESTED"			NO "NON-REQUESTED" PLUS PROJECTED 30 MIN. DELAY ACCEPT		
NO. OF T/ROUNDS	NO. OF SCHED. T/ROUNDS	%	NO. OF T/ROUNDS	NO. OF SCHED. T/ROUNDS	%	NO. OF T/ROUNDS	NO. OF SCHED. T/ROUNDS	%
247	120	48.6	241	152	63.0	241	163	67.6

Broken down into a daily and fleet type basis the above table becomes:

TABLE 5

DATE	A/C TYPE	ACTUAL			NO "NON-REQUESTED"			NO "NON-REQUESTED PLUS ACCEPT PROJECTED 30 MIN. DELAY		
		NO. OF T/ROUNDS	NO. OF SCHED. T/ROUNDS	%	NO. OF T/ROUNDS	NO. OF SCHED. T/ROUNDS	%	NO. OF T/ROUNDS	NO. OF SCHED. T/ROUNDS	%
29.1.70	TRIDENT 1	38	14	36.8	37	19	51.4	37	22	59.5
	TRIDENT 2	6	3	50.0	6	3	50.0	6	3	50.0
	SUPER 1-11	10	8	80.0	10	8	80.0	10	8	80.0
	VANGUARD	19	5	26.3	19	8	42.1	19	10	52.6
	VISCOUNT	8	3	37.5	8	3	37.5	8	3	37.5
	COMET	2	1	50.0	2	1	50.0	2	1	50.0
5.2.70	TRIDENT 1	34	19	55.9	33	24	72.7	33	26	76.5
	TRIDENT 2	6	3	50.0	6	3	50.0	6	3	50.0
	SUPER 1-11	10	3	30.0	10	5	50.0	10	5	50.0
	VANGUARD	19	8	42.1	17	11	64.7	17	11	64.7
	VISCOUNT	8	8	100.0	8	8	100.0	8	8	100.0
	COMET	3	3	100.0	3	3	100.0	3	3	100.0
10.2.70	TRIDENT 1	36	13	36.1	34	23	67.6	34	27	79.5
	TRIDENT 2	10	4	40.0	10	5	50.0	10	5	50.0
	SUPER 1-11	10	3	30.0	10	3	30.0	10	3	30.0
	VANGUARD	18	12	67.7	18	15	83.4	18	15	83.4
	VISCOUNT	8	8	100.0	8	8	100.0	8	8	100.0
	COMET	2	2	100.0	2	2	100.0	2	2	100.0