SIMULATION OF AN AIRCRAFT CONTAINER SYSTEM

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Abstract

This paper describes a simulation, written in GPSS/360 which models a system of container deployment for Boeing 747 aircraft. The simulation uses as input a flight schedule together with deadload demand distributions between city-pairs in the system and models the operating system of both aircraft and containers in some detail. The output from the program is the number of containers required at a station to satisfy a specified standard of service. The immediate purpose of the model is to help in minimising the stockholding of containers at individual stations and to suggest possible improvements in the system itself.

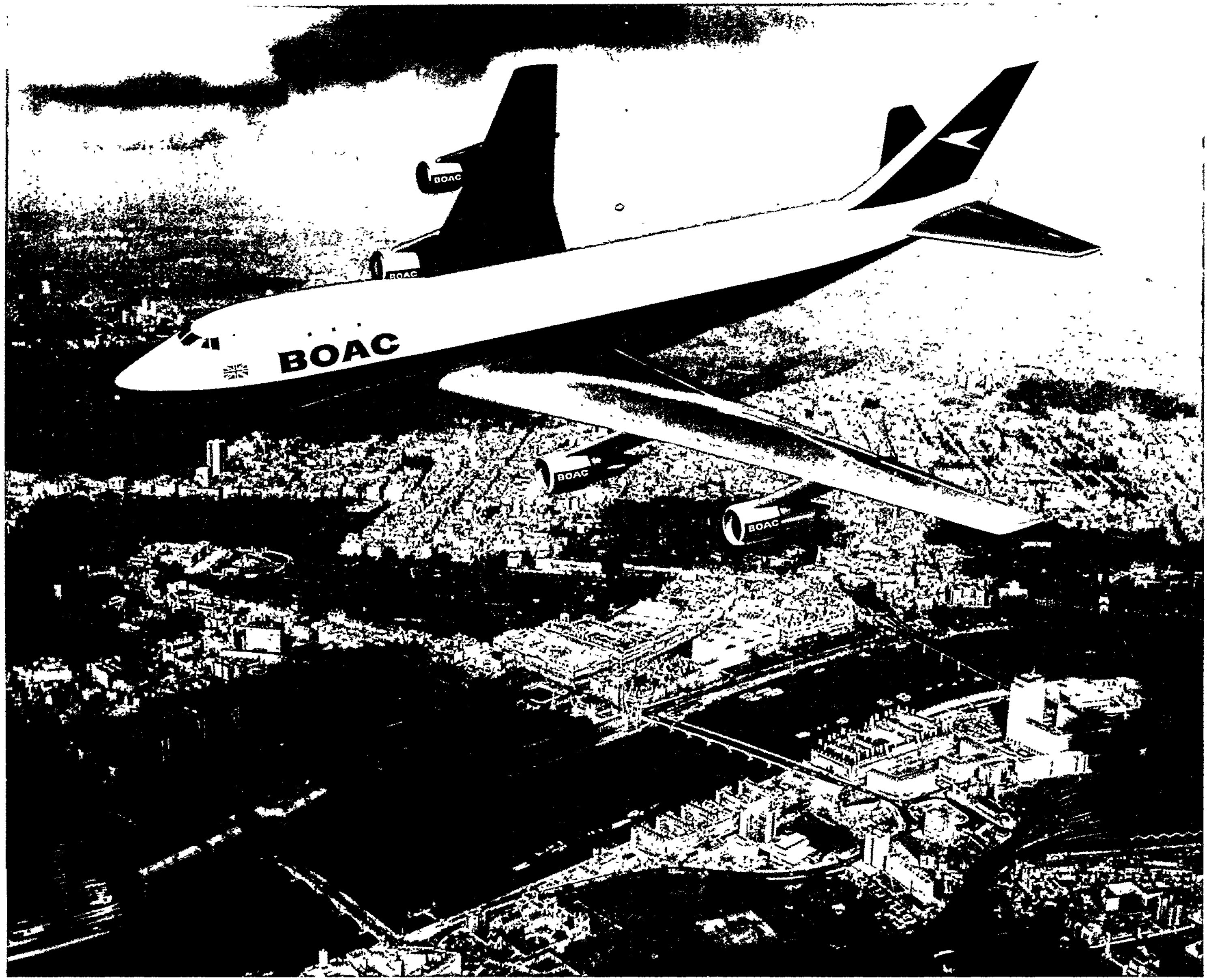
1. THE PROBLEM

The advent of Boeing 747 aircraft (illustrated in Figure 1) with its greatly increased capacity over the present generation of aircraft both for passengers and deadload brings with it many problems of ground handling if the turnround time is to be kept at the same level expected of present day aircraft. Such a condition is essential for the effective utilisation of the aircraft.

In order to minimise the problems in the handling of deadload it was decided to carry nearly all deadload in the B747 in containers, instead of by the present method of either loose stowage (for passengers' baggage, mail and most cargo) or palletisation (for some cargo). The B747 will have a capacity of 30 half-contour containers located in two compartments. BOAC plans eventually to operate 12 of these aircraft with flights calling at over 30 stations, and all the containers will be dual purpose so that any container can carry any form of deadload. A typical BOAC container is illustrated in Figure 2.

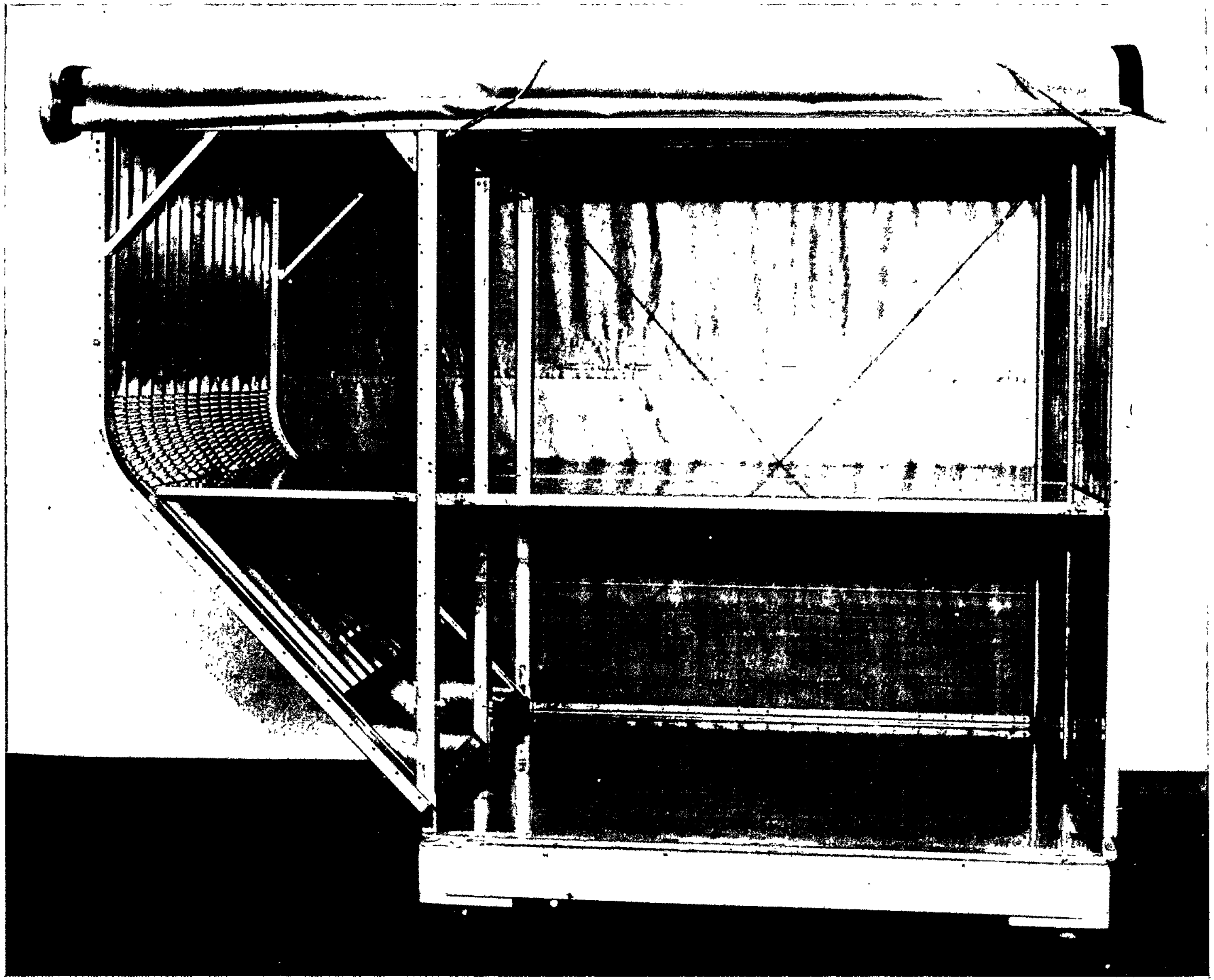
At any station there will be an appreciable turnround time for containers to be unloaded and made available for re-use. This will necessitate the holding of a stock of containers at each station since an aircraft cannot normally wait for containers to be unloaded from and then reloaded on to it. These station stocks had to be calculated by BOAC Traffic Branch so that they would both be able to order sufficient containers to meet the needs of the airline and also stock enough containers at individual stations round the world with some confidence that they would be deployed properly.

The phasing into service of the 12 aircraft will be over a period of three years starting from April 1970 and containers will be ordered from 1969. Thus it is not essential to evaluate container requirements for all stations at once and, it is hoped, errors due to present uncertainty about operation of the system will be removed as more experience is gained about the operation. In fact in the first two years there will only be 7 stations on-line; the rest will be added at the start of the third year.



ARTISTS IMPRESSION OF THE BOAC B747 OVER LONDON

FIGURE 1



A DUAL-PURPOSE B747 CONTAINER FIGURE 2

2. DESCRIPTION OF THE SYSTEM

2.1 SYSTEM CONSTRAINTS

The operation of the system as envisaged at present is for each aircraft to always carry the full complement of containers (30) whether these containers are full or empty. Also there will be no mixing of different kinds of deadload in the same container and there will be no mixing of the same kind of deadload destined for different stations. Thus each station en-route will have at least one container for each type of deadload (provided, of course, there is some present for it). Moreover containers not being carried will always remain at an airport and will not be despatched either to agents or customers outside. These constraints might be removed at some later date and it was a requirement of the simulation model that such changes could be incorporated so that various operating strategies could be tested and evaluated.

2.2 THE OPERATION OF A SERVICE

The details of the operation can be best described with an example of an individual service. Therefore consider the BOAC service BA501. This will operate over the route London(LHR)/New York(JFK)/Bermuda(BDA) and then return over the same route.

At varying times before the aircraft leaves LHR containers must be removed from stock and filled with deadload for both JFK and BDA. Containers for cargo will be loaded before containers for mail and containers for passengers' baggage will be loaded last of all. Two extra containers will be used for crews' baggage and oddments. Finally enough empty containers must be removed from stock in order to ensure the aircraft carrying the full complement of 30.

Similarly at varying times before the aircraft is due to depart from JFK containers must be removed from the stock there and filled with deadload for BDA. When the aircraft arrives at JFK containers destined for that station must be unloaded, leaving those for BDA untouched, and, depending on the time that the aircraft is on the ground, possibly made available for re-use. A short time before the flight departs for BDA the containers filled at JFK must be loaded on to the aircraft. Empty containers might have to be removed from stock in order to ensure that the full complement is carried or some may have to be added to stock if it is necessary to replace empty containers initially in the aircraft by full ones.

The same sequence of events is carried out at BDA where freight destined for both JFK and LHR is loaded. Figure 3 illustrates these events in flow-chart form.

2.3 ABSTRACT FORMULATION

In essence then there is a continuous system with points where containers are being moved in and out of stock. The times at which this alteration of stock takes place depends on the times of arrival and departure of aircraft linking these points and carrying containers from each point to several others. The amount of stock removed and replaced is directly related to the deadload to be carried between points in the system.

3. PRELIMINARY WORK

As can be seen from the above there are two basic data requirements which are essential to any solution method to the problem. The first is a knowledge of the schedule of B747 operations and the second is the probability of demand for cargo, mail and passengers between any two points in the network. There are also certain system 'constants' which must be known: amount of cargo that can be carried in a container, average number of pieces of baggage per passenger and, finally, information has to be known on the times prior to departure or after arrival of an aircraft that containers for a given type of deadload have to be removed or replaced in stock.

A preliminary study of the problem was made and an attempt at the determination of station

TYPICAL SEQUENCE OF EVENTS AT A STATION FIGURE 3

TIME IN MINS	
-240	- CONTAINERS FOR CARGO REMOVED FROM STOCK & FILLING COMMENCED
-180	- CONTAINERS FOR MAIL REMOVED FROM STOCK & FILLING COMMENCED
- 60	- CONTAINERS FOR BAGGAGE REMOVED FROM STOCK & FILLING COMMENCED
0	- TIME OF ARRIVAL OF AIRCRAFT
5	- CONTAINERS REMOVED FROM AIRCRAFT
10	- UNLOADING OF CONTAINER CONTENTS BEGINS
30	- SOME CONTAINERS MADE AVAILABLE FOR RE-USE IF NECESSARY
35	- FULL CONTAINERS STORED ON AIRCRAFT
40	- ADDITIONAL EMPTY CONTAINERS PUT ON A/C IF NECESSARY
45	- AIRCRAFT DEPARTS
120	- CONTAINERS REPLACED IN STOCK
180	- CONTAINERS REPLACED IN STOCK
360	- CONTAINERS REPLACED IN STOCK

stockholding with 2 services and 3 stations in the system was made by hand. This was done by a deterministic pencil and paper simulation, using average demands. It was hoped that it would not be necessary to simulate the larger system and that reasonable results could be obtained by a simple deterministic approach.

However it was found that, because of the presence of multi-sector services (i.e. flights visiting more than one station before returning to base), it would not be feasible to keep track of the location of all containers and to bear in mind possible capacity constraints. Therefore it was decided to build a simulation model of the complete system incorporating the real-world details (such as variable demand) which would also have the additional pay-off of being able to test different operating strategies.

4. MODEL FORMULATION

4.1 CHOICE OF LANGUAGE

The only choice of programming languages available was between the general purpose scientific languages (Fortran and PL/1) or GPSS. Having had prior experience of writing a small queueing simulation in PL/1 and finding it unsuitable in terms of both development time and program size it was readily apparent that a special purpose simulation language would have to be used and as GPSS was the only one available it was chosen. In fact it can be said (with more than a little hindsight) that, data input apart, GPSS is ideal for this problem mainly because of the elegant way in which an aircraft schedule can be simulated. It is this cyclic schedule which is at the heart of the program.

4.2 DEFINITION OF EVENTS

The main problem associated with building a simulation model in GPSS was to decide what were the important events in the system. At first thought it seemed that a straightforward simulation of the aircraft flight pattern would be sufficient as all events associated with a change in stockholding of containers are directly related to the movement of aircraft through the stations. However it soon became apparent that the removal of containers from stock occurs at some time <u>prior</u> to an aircraft <u>arrival</u> at a station and replacement of containers in stock occur at some time <u>after</u> an aircraft <u>departure</u> from a station. Thus one of the important events (removal from stock) is directly actuated by an event (aircraft arrival) which occurs at a later time. Therefore, as in any simulation, events must be clearly defined in ascending chronological order, it was decided to have two GPSS transactions connected with flights - one was the flight itself and the other was a 'dummy' flight which would follow exactly the same route as the actual flight but precede it in time by the smallest amount necessary to ensure that the first removal of containers from a station stock would not occur before the arrival of this dummy flight at a station.

Thus if no containers were removed from stock before, say, 6 hours prior to an aircraft arrival then the dummy flight would precede the actual flight by 6 hours.

4.3 DESCRIPTION OF THE MODEL

In the model the dummy flight transactions trigger off new transactions which simulate the withdrawal of containers from stock whilst the actual flight transactions trigger off other transactions which simulate replacement of containers. Sampling for demand between two stations en-route is performed by the dummy flight transaction at the time of its arrival at a station and the number of containers needed for this sampled demand is stored directly in parameters of the transactions which represent container withdrawal. When the actual flight transactions 'arrive' at a station the number of containers carrying each type of deadload is stored in a parameter of the respective replacement transactions and immediately prior to departure the number of new containers destined for stations en-route is stored. Also at this time the number of empty containers necessary to make the complement up to 30 is found and empty containers either withdrawn or added to stock.

Thus in the GPSS model there are transactions representing the actual flight, the 'dummy' flight, container withdrawal and container replacement. The container stocks are represented by GPSS storages. There is one user chain for each flight related to containers which have been withdrawn from stock but have not been loaded into the aircraft; there is also a GPSS group for each flight. This has no real-world significance but provides a means of either altering or storing numbers of containers in one transaction by means of another.

A simple flow-chart which shows the interrelationship of entities in the model is contained in Figure 4.

5. PROBLEMS OF DATA

There are two items of data input to the model which, by their nature, have to be forecast. One of them is the range of times prior to an aircraft arrival that containers for the different types of freight will be removed. As BOAC has had no previous experience of containerization, forecasts based on the present method of palletization have had to be used.

Once the B747 is in operation much more precise information will be available concerning this aspect and simulation results for future years should be correspondingly more accurate.

The second forecast item of data is the probability distribution of deadload demand between city-pairs in the system. Deadload is split up into the three categories cargo, mail and passengers' baggage. The form in which these distributions were calculated was in terms of the number of occasions over a period that an aircraft would carry a specified range of weight (for cargo and mail) or a specified range of numbers of passengers. It should be appreciated that these have been forecast using existing data for the present generation of aircraft and although rates of growth of traffic have been allowed for, the problems associated with forecasting demand for a much bigger aircraft are difficult and it is impossible at this time to estimate what the probable error of the forecasts are.

In the model samples are taken from the above distributions and using the data on container capacities the required number of containers needed to carry the sampled demand is calculated. Again problems arise solely because the system is not yet in operation: it is not known how far 'topping-up' of containers will be practicable. Thus in the example of BA501 it might be possible to add deadload going from JFK to BDA to the containers already on the aircraft which were loaded at LHR for BDA. Uncertainty about this should be resolved very quickly once the system is functioning.

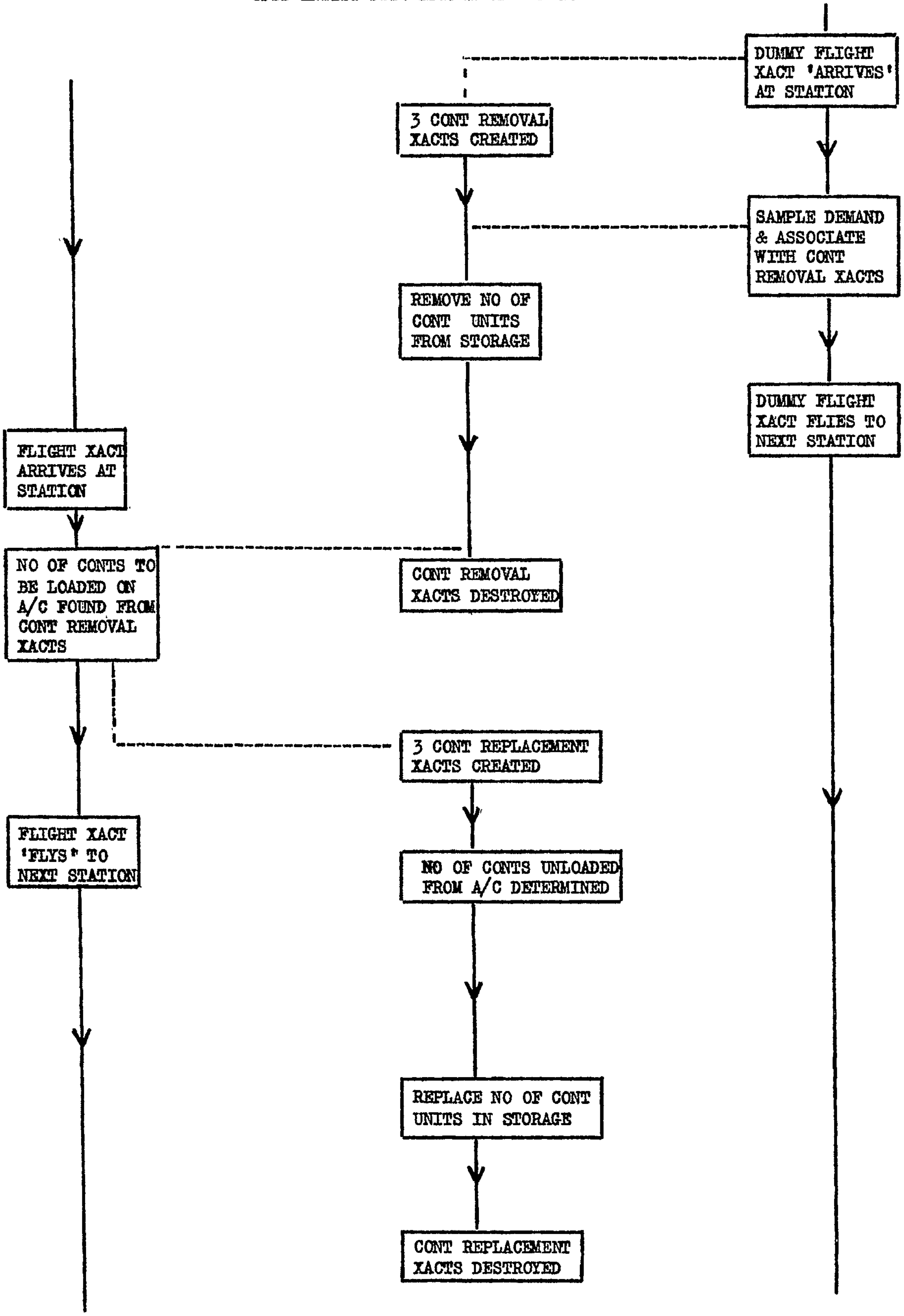
6. OPTIONS OF THE MODEL

As mentioned previously a major requirement of the model was that changes in the operation of the system could be easily incorporated into the model. At present an option exists in the model for only carrying full containers on board, enabling this policy to be compared with the standard policy of carrying a full complement of containers where they are needed. Also facilities exist in the model to specify, if topping-up should be used, how much space should be available in a container to allow this.

7. INFORMATION FROM THE MODEL

Although the system does not keep track of <u>individual</u> containers full information is kept on containers carrying each type of deadload from

GPSS ENTITY DESCRIPTION OF STATION EVENTS FIGURE 4



one station to another. As the immediate requirement of the model is to simply estimate container stockholding the output consists of tables and graphs for each station showing the distribution of the numbers of containers out of stock after a demand has occurred. The results are then discussed with BOAC Traffic Branch and together some agreement is reached regarding what constitutes an acceptable shortage risk and hence an acceptable stock level, bearing in mind such imponderables as damage to containers.

8. BASIC RESULTS

Up to date the model has been run with a maximum of 5 services and 7 stations. The overall number of containers needed to provide a 100% level of service varies from about 320 to 350 depending on the turnaround times for containers carrying different kinds of deadload. With a 95% level of service the number required varies from about 275 to 300.

It has also been found that an increase in container turnaround times from 12 hours to 20 hours makes no difference to container requirements at some stations. The range of turnaround times over which no extra containers are needed is, of course, only a function of the schedule since no delay distributions have yet been built into the model. However it is felt that the complication of delays need not be incorporated until some idea has been gained about the sensitivity of the model to the various time parameters.

9. RESOURCES USED

The development of the simulation program started in February 1969. Only the author, an operational research analyst, has been working on the project up to date. The initial development stage including testing took about 2 man-months to complete and involved about 80 computer runs taking about 200 minutes of computer time. As data becomes available another 2 man-months has been spent in collating it and running the model.

The number of cards in the program including both input and output requirements is about 1500 and the number of GPSS blocks is around 275. The program occupies about 90K bytes of storage on an IBM360/65 and a run simulating 5 flights and 7 stations for 18 months takes about 13 mins of computer time.

It is not anticipated that a large increase in the number of flights and number of stations input to the model will increase the storage requirements by an unacceptably large amount but it is possible that some refinements will have to be made to the model if the running time increases drastically. However with the decreasing cost of computer time (particularly with the advent of multi-programming) it seems more important to economise in storage requirements rather than in time.

10. PRESENT USEFULNESS AND FUTURE APPLICATION OF THE MODEL

As has been emphasised in the paper this simulation is a model of a system which has not yet come into operation and, moreover, a system unlike any which the airline has operated previously. Consequently much of the information required for the model is only available as estimates. However this does not reduce the present usefulness of the model because, as observed earlier, little confidence can be placed in the accuracy of manual analytical methods of determining optimum stockholdings. In addition the simulation will be an aid in determining which data items are 'sensitive' and hence which are critical to the efficiency of the operation of the system.

Hence the effect of reducing container turnaround times, for example, can be quantified and in this way the model may determine the ranges within which the times must lie to avoid severe financial penalties.

Future developments include the examination of strategic policies with regard to the container system e.g. allowing containers to be used for carrying cargo outside airports to and from agents' warehouses. It may also be used to examine short term planning procedures for control and movement of empty containers between stations.

Looking a little further ahead into the future it is hoped that it will be possible to extend the model to look at the problem of the way cargo loads are allocated to flights in order to evaluate the 'goodness' of a schedule in terms of the distribution of elapsed times for the transportation of cargo loads.

David M. Grant is currently an Operational Research Officer with British Overseas Airways Corporation. He obtained a B.A. in mathematics from Brasenose College, Oxford and an M.Sc. in statistics from the University of Leeds. Before his post with BOAC his career included a brief spell in O.R. with the electricity supply industry.