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ROYAL SIGNALS & RADAR ESTABLISHMENT

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A SIMULATION STUDY OF LANDING TIME ALLOCATION PROCEDURES FOR USE IN COMPUTER-ASSISTED AIR TRAFFIC MANAGEMENT SYSTEMS

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TITLE: A SIMULATION STUDY OF LANDING TIME ALLOCATION PROCEDURES FOR USE IN COMPUTER ASSISTED AIR TRAFFIC MANAGEMENT SYSTEMS

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DATE: April 28, 1989

Abstract

During busy periods at major airports, inbound aircraft have to queue for use of the landing runway. In future air traffic systems it is likely that controllers will be able to make use of computer-proposed landing sequences and speed control advice. One proposed method for allocating aircraft landing times in such systems is the 'Time Horizon' method. According to this method, a preferred landing time is calculated for each aircraft some way out from the airport, and a planned landing time is allocated at a fixed time before the aircraft's preferred landing time.
This memorandum reports on a computer simulation study to demonstrate and quantify the effect of the time horizon method.

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Contents

1 Introduction

The current level of air traffic movements in the UK means that at major airports for some periods during a day, incoming aircraft have to queue. Despite attempts to schedule aircraft in advance, the variability of the wind and other factors means that actual aircraft arrival times are randomly displaced from scheduled arrival times. This leads to peaks and troughs in the arrival pattern. During a trough, runway time may be lost and a queue forms during later peaks. Aircraft must keep moving so the queueing time is absorbed either by flying a longer than minimum path to the runway, or by flying closed loops in holding stacks. This delaying activity is centred in the airspace around the airport.

In recent years studies have been carried out into the possibility of absorbing the queueing time earlier in an aircraft's flight [1]. Computers can be used to predict well in advance when each aircraft would reach the runway if there was no other competing traffic and assuming the aircraft's preferred height and speed profiles. These preferred landing times can be used to allocate planned landing time slots. The allocation of a landing time slot must take into account other traffic and the separations that must be maintained between aircraft.

Once the preferred and allocated landing times are known, the amount of queueing delay is also known and the required delay absorption can be planned, assuming that landing time slots are not moved once allocated. Speed control is used as much as is possible, being combined with path stretching and stacking when delay is sufficiently large [2]. The overall effect is to smooth the flow of aircraft near the airport and to reduce delay.

The air traffic control system is required to be fair to all aircraft operators and all types of traffic, in the sense that inevitable delays are distributed evenhandedly. While amounts of delay suffered by individual aircraft may vary widely, mean delay values suffered by any single operator or a type of traffic should not. Any computer-based tool which proposes a landing sequence must also be fair in this sense. This consideration is an important one for computer assistance because if a computer program has some unfairness in its method of landing time allocation, it is likely to be systematically unfair.

The Time Horizon method [1] has been proposed as a landing time allocation method which distributes mean delay evenhandedly. According to this method, a planned landing time is allocated when the aircraft is a fixed time interval away from its preferred landing time.

This memorandum reports on a computer simulation study of the Time Horizon Method. It was shown by simulation that:

a) If most of the traffic has landing times allocated according to the Time Horizon method but a small proportion has landing times allocated systematically before or after the rest, then the small proportion will suffer respectively less or more delay than the rest.

b) In a system where no attempt is made to employ a Time Horizon method, there is a strong correlation between lateness of landing time allocation and amount of delay suffered.

It should be noted that this study was concerned with how delay is distributed, rather than with sum total delay suffered by all aircraft.

2 The Time Horizon method

The way in which delay is distributed among the various types of aircraft is very sensitive to the precise point in flight where the landing time allocation is made.

This can be illustrated by considering two sets of aircraft which have the same preferred landing times. If, for example, one set is allocated landing time slots twenty minutes before their preferred landing times and the second set fifteen minutes before, then the set with the earlier allocation (twenty minutes) have an unfair advantage. They have first choice of the available landing time slots so that when the second set are looking for landing time slots five minutes later, they find the most useful ones are already allocated. The average delay of the fifteen minute set will be greater than that experienced by the twenty minute set.

The only way to be completely fair in the way delay is distributed, is to allocate a landing time to an aircraft when it is a fixed time from its preferred landing time. This method of allocation is the time horizon method and an aircraft is allocated a landing time slot as it crosses the time horizon.

As well as being fair, the time horizon method has another advantage. Landing time slots are allocated in order of preferred landing time. This means that each landing time allocated is always later than landing times previously allocated. Landing times therefore follow on from each other and the gaps of unallocated time are minimised. This would not be so if the allocation method meant that some aircraft received their landing times before others. In this case, large gaps of unallocated time would occur and although some of this time can be allocated to other aircraft it is not always possible to use it all completely. Small gaps of unallocated time remain which effectively lead to lost runway capacity and greater delays.

The simulation described in this report studied the delay experienced by aircraft which did not receive their landing time slots at the time horizon in order to gain some idea of how unfair an allocation method could be if deviations from the time horizon method were allowed to occur.

3 Deviations from the time horizon method

A deviation from the time horizon method occurs when an aircraft is allocated a landing time slot before or after crossing the fixed time horizon. The aim of the simulation was to demonstrate the advantages of the method by looking at the mean delay of aircraft deviating from it.

In this study, two types of possible deviation were used and the mean delay of both the affected aircraft and the overall set was examined.

The first type was constant deviation where a certain proportion of arrivals were allocated their landing time slots either a constant time before or a constant time after the time horizon. This situation could occur in the real world if, for example, traffic entering a sector from a particular direction were consistently given landing time slots early or late. A comparison was made of the delay suffered by aircraft with differing amounts of deviation ie. 5,10,15 mins early or late. Also the percentage of aircraft suffering delay was altered and the effect on delay examined.

The second type was random deviation where all aircraft in a group were allocated landing time slots at random times ranging from ten minutes before the time horizon to ten minutes after. This effectively corresponds to a situation where a time horizon method is not used. With landing time slot allocation occuring at a random time before preferred landing time it is possible to see how delay is related to allocation time.

4 The simulation

The situation being modelled was that of aircraft approaching an airport and requiring to land. As an aircraft crossed the time horizon a landing time was allocated which effectively booked the runway at some specific time in the future. If an aircraft did not receive a landing time at its preferred landing time then it had to queue. The problem of aircraft queueing is particularly serious during the peak traffic periods. These periods last about four hours and occur in the morning and in the evening. Since this is the time when most delay is experienced, only aircraft arriving in the peak periods were simulated. Since traffic peaks do not last long enough for the queue of aircraft to reach a steady state it was necessary to collect delay statistics from the simulation of a large number of short peak periods each lasting four hours.

The simulation had to include an arrivals process and a service process. The arrivals process modelled a typical arrival pattern. In an attempt to timetable arriving aircraft, a scheduling committee allocates landing time slots to aircraft six months or more in advance [3]. If aircraft could keep to these times then there would be little delay. This is not possible for various reasons, for example the effect of wind, delays on the ground and restrictions on flow. The result is that aircraft arrive in a fairly random manner.

In this simulation the arrival times of aircraft in a peak period were modelled by first creating an array of ordered arrival times (similar to those produced by the scheduling committee). These were then disordered by the addition of a normally distributed random perturbation with a standard deviation of 27 mins [4]. Since the standard deviation is several times larger than a typical inter-arrival time, the actual arrival order was very different from the scheduled arrival order.

A traffic peak does not exist in isolation, some traffic is scheduled to arrive before and after it. If no account were taken of this, the disordering process would significantly reduce the number of aircraft landing within the four hour period. To include this effect in the simulation, aircraft arrival times were generated for periods outside the peak but with a 50% traffic intensity. Delay statistics were only collected for aircraft arriving within the peak period (after perturbation).

The service process was modelled by assuming a constant runway service time of 1.78 minutes. Runway service time consists of the time occupying the runway plus the time the runway is unavailable to following aircraft because of ATC separation rules. Service time does have a constant component due to the type of aircraft landing and those following. But there is a random component caused by the ability of the pilot and controller to keep the aircraft in an ideal position. Although this random component exists the value of it is not known to the landing time allocation process which is operating long before runway service.

The deviation from the time horizon meant that aircraft were considered for landing time slots in an order that was not the same as the arrival order.

An aircraft being considered early had the deviation amount subtracted from its arrival time at the time horizon. Similarly, an aircraft being considered late had the deviation amount added to its arrival time at the time horizon. Landing times were allocated in the new displaced order and delay calculated with respect to the original landing time.

5 Results

5.1 Constant deviation

In Figure 1, a number of curves are plotted for mean delay as a function of traffic intensity. The curve marked 'no displacement' shows how mean delay varies with traffic intensity when all allocation is done at the time horizon. The other curves show mean delay of the displaced 10% of aircraft who have landing time slots allocated before or after the time horizon. For the fraction of aircraft not receiving landing times at the time horizon, it can clearly be seen that allocation before the time horizon leads to reduced mean delay, and allocation after the time horizon leads to increased mean delay.

For example, at 95% traffic intensity (a figure often used for scheduling purposes), the 10% of aircraft allocated landing times 5 minutes early (ie. before the time horizon) experience 2.7 minutes less delay. The 10% of aircraft allocated landing times 5 minutes late suffer 4.4 minutes extra delay.

Figure 2 indicates what happens when the percentage which deviate from the time horizon is varied. As the percentage increases, the mean delay curve (for this percentage) moves back towards the 'no displacement' curve. This is as expected: if 100% were displaced this would correspond to changing the time horizon itself, and thus to a 'no displacement' situation.

5.2 Random allocation

The main results showing how mean delay varies with allocation time are in Figure 3. The figure illustrates that if the time horizon is not used, delay is correlated with nearness of allocation to preferred landing time. An aircraft allocated its landing time slot a long time before its preferred landing time suffers less mean delay than an aircraft receiving its landing time slot only a short time before. For example, at a traffic intensity of 95%, an early allocation of 10 minutes before the time horizon gives 4 minutes less delay, with 5 minutes giving 2 minutes less delay. A late allocation of 5 minutes after the time horizon gives rise to 6.3 minutes extra delay, with 10 minutes leading to 10.1 minutes extra delay. The rate of increase in mean delay for aircraft with late allocation is greater than the rate of decrease for early aircraft.

6 Conclusions

Computers can be used to help smooth the flow of aircraft into airports by allocating landing time slots early in an aircraft's approach and absorbing some delay en-route. In order to distribute mean delay evenly among all traffic, landing time slots for all aircraft need to be allocated at the same fixed time before their preferred landing times ie. as each aircraft crosses the time horizon. This memorandum has demonstrated how mean delay may be unfairly distributed if a computer-based landing time allocation method not adhering to the Time Horizon principle is used.

It has been shown that any deviation from the time horizon leads to changes in the distribution of mean delay. The biggest change occurs among aircraft allocated landing time slots late. These aircraft suffer considerable increases in mean delay and are at the greatest disadvantage from an unfair landing time slot allocation method. Aircraft which are allocated landing time slots early experience less delay than they might have, but this is at the expense of the other aircraft who received their landing time slots at the time horizon.

There is a strong correlation between lateness of landing time allocation and amount of delay suffered.

The time horizon is a simple and fair method of landing time slot allocation. To not use it, or to apply it to some aircraft only, leads to unfairness between aircraft.

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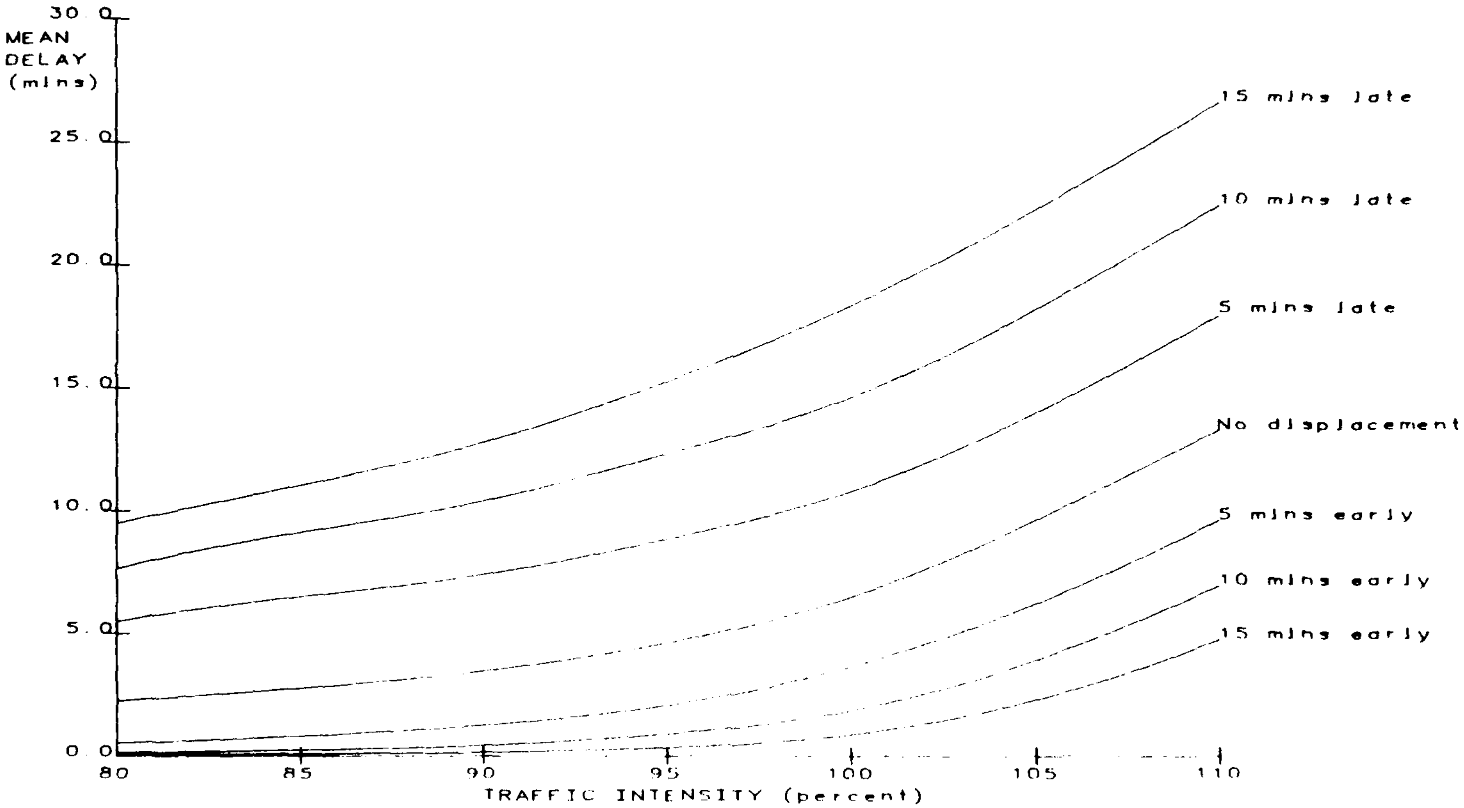
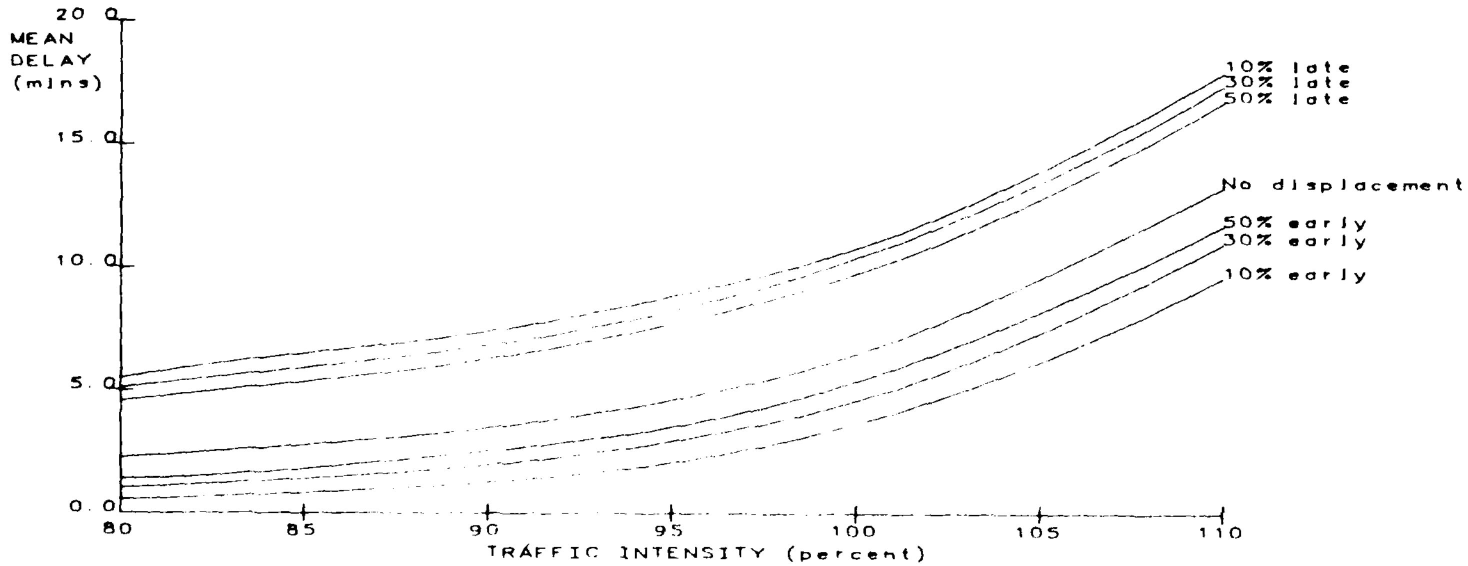
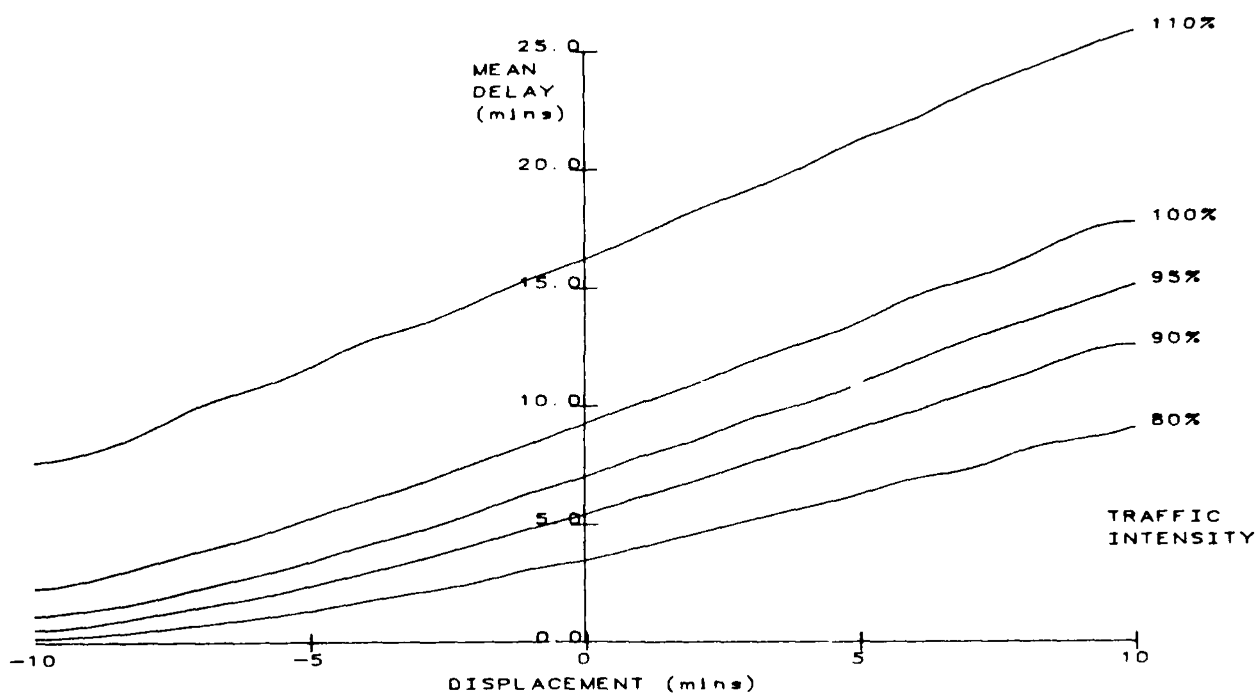


FIGURE(1) EFFECT OF DISPLACEMENTS FROM THE TIME HORIZON



FIGURE(2) EFFECT OF VARYING PERCENTAGE OF AIRCRAFT DISPLACED



FIGURE(3) EFFECT OF ALLOCATION TIME WHEN NOT USING THE TIME HORIZON

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Abstract

During busy periods at major airports, inbound aircraft have to queue for use of the landing runway. In future air traffic systems it is likely that controllers will be able to make use of computer-proposed landing sequences and speed control advice. One proposed method for allocating aircraft landing times in such systems is the 'Time Horizon' method. According to this method, a preferred landing time is calculated for each aircraft some way out from the airport, and a planned landing time is allocated at a fixed time before the aircraft's preferred landing time.

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