TRANSPORT and ROAD
RESEARCH LABORATORY

Department of the Environment
Department of Transport

TRRL LABORATORY REPORT 767

A STUDY OF SOME FACTORS AFFECTING BUS SERVICE PERFORMANCE

by

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Public Transport Division
Transport Operations Department
Transport and Road Research Laboratory
Crowthorne, Berkshire
1977
ISSN 0305–1293

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ABSTRACT

Various measures aimed at improving the operation of a bus service have been examined using the results of TRRL surveys and simulation modelling. Service 9 of the Bristol Omnibus Company was chosen as a basis for the study. The main findings were:

(i) in the evening peak period improved time-keeping could reduce the mean passenger waiting time by 5 per cent;

(ii) reducing bus-boarding times to the lowest values observed elsewhere in the United Kingdom could bring about reductions of 8 per cent in the mean waiting time and 10 per cent in the mean on-bus travel time in the evening peak period;

(iii) when there was a persistent need for cancellations, waiting times could be reduced by rescheduling designed to make the scheduled complement compatible with available resources: when an average of one bus was missing from the service considered, the reduction was estimated to be of the order 10 per cent of the waiting time for a full service, in both peak and off-peak periods:

(iv) use of more realistic run-time allocations would generate closer adherence to schedule: in the evening peak period this might reduce the mean waiting time by between 3 and 8 per cent.

1. INTRODUCTION

In recent years much research has been carried out into possible ways of improving the quality of bus services and this has been reviewed in a recent Transport and Road Research Laboratory (TRRL) report[1]. It includes consideration of schemes which give buses priority over other traffic, the use of improved operational control systems and new types of bus service, such as dial-a-bus. There are, however, some factors affecting conventional bus services which have a significant effect on the level of service offered to the public and which seem to offer scope for improvement, but on which little quantitative information is available. These include the accuracy of time-keeping on the road, the bus-boarding and-alighting processes, methods of dealing with staff or vehicle shortages and bus scheduling. This report describes an attempt to evaluate the improvements that could be brought about by changes in these aspects of operations. The evaluation relies to a large extent on experiments carried out with a simulation model of a bus route. The model was used in previously reported work[2], where it was set up to represent Service 9 of the Bristol Omnibus Company in the evening peak period. Solely for convenience it has been used in that form for the present study (there was no more specific reason why Service 9 should have formed the basis for the work).

Although results obtained from use of the model applied to the evening peak period some consideration was given to off-peak periods by other means wherever possible. It is recognised that the work suffers from the limitations of simulation modelling, and that Service 9, while being typical of cross-town services in Bristol, may not be representative of those in other towns. Nevertheless, the results should provide an initial indication of the orders of magnitude of improvements that might be obtained by means of the changes considered.

2. THE MODEL AND THE SERVICE MODELLED

A full description of the model has been given in Reference 2. It includes routines to simulate passenger arrivals at bus stops, the boarding and alighting processes, individual bus running between consecutive stops, variation of parameters with time of day and the operation of other bus services on the route. Various data are output following a simulation run, including mean passenger waiting time and mean bus headway computed over all stops on the route. Surveys carried out in October 1971 and October 1972 enabled the model to be calibrated to represent Service 9 during the period from 1530 until 1800.

Figure 1 is a map of the route (not to scale) showing the position of all the bus stops and the merge points with the other bus routes which run in parallel with Route 9 for a considerable distance. To economise on computer time there is a less than one-to-one correspondence between the 62 stops of the real route and the 40 stops used in the simulation: stops which have similar patterns of passenger arrivals have been grouped together as indicated on the route map.

The route runs from its suburban terminus close to the bus garage at Winterstoke, eastward through the busy shopping district of Bedminster, then north-east to the periphery to Bristol city centre; here it turns east and runs along a major traffic corridor (the Bath Road) to the suburb of Hanham, where the second terminus is also close to a bus garage. The round-trip length of the route (Winterstoke-Hanham-Winterstoke) is 22.4 km, and the scheduled time for this distance is 96 minutes off-peak, including a 9 minute layover at each end of the route. In the peak periods this time is increased to 103 minutes with layovers ranging from 5 to 10 minutes at each end of the route. The service on the route is worked by 8 buses in the inter-peak period, with scheduled headways of 12 minutes, while during the peak periods the number is increased to 11, with scheduled headways of 9 minutes. These buses run according to a published timetable. However, there are also a few buses which are scheduled to run along certain parts of the route during the peaks, which are not listed in the timetable. These buses run on Route 9 subject to availability and usually in tandem with one of the normal service buses. Although they were included in the original work with the model it was subsequently found that their running had very little effect on the mean passenger waiting time on the route (reducing it by approximately 0.1 minutes) and so, for convenience, they have been excluded from this work.

Some available evidence[3] indicates that a great majority of passengers arrive randomly at bus stops when scheduled bus headways are less than 10 minutes. Since survey data suggest that this is generally true on Route 9 in the evening peak, the assumption is incorporated in the model. However, as headways increase above 10 minutes, more and more passengers use knowledge of the timetable to correlate their arrivals with bus arrivals in order to minimise waiting time. In off-peak periods Service 9 headways are 12 minutes and so there will be a mixture of random and timed arrivals. Discussion given in Sections 5 and 6, takes account of the likelihood of timed arrivals in off-peak periods.

3. TIME-KEEPING

Some of the points made in this section were discussed previously in Reference 2 but are restated here for the sake of completeness.

Bus crews arriving at a terminus at the end of a scheduled trip* are usually entitled to a minimum layover period, agreed upon by the bus company and the trade unions, before commencing their next trip. Although bus layover periods allocated in the schedule may be longer than this, the excess is regarded as recovery time which must be forfeited by those crews which are running late in order to make up lost time. Any bus arriving at a terminus more than the specified minimum layover period before the scheduled departure time should, in theory, leave exactly on time, while any bus arriving later should wait the agreed minimum period before departing.

The three day survey of Service 9 during October 1972 showed that in the afternoon off-peak period, 12.00 to 15.30, 100 per cent of all trips should have commenced on time: in the peak period, 15.30 to 18.00, the corresponding figure was over 80 per cent. Many of them did not do so. Time-keeping errors, of up to five minutes, were observed in the terminal departure times; some buses left early, particularly in the peak period, while others left late.

Such errors had a marked effect on the service regularity. This can be seen from Figure 2, which compares the observed departure pattern from one terminus on one day of the survey with the pattern which would have been observed had the time-keeping been exact. Although the departure time of any one bus was not in error by more than a few minutes, the overall effect, when spread over a number of buses, was to impart considerable irregularity to the service.

The effect of this irregularity on passenger waiting time can be assessed roughly by using the following equation[4], which gives the theoretical mean waiting time $\overline{t}_W$ for passengers arriving randomly at a bus stop at a constant average rate, assuming that all are able to board the first bus which comes:

$$\overline{t}_W = \tfrac{1}{2}\overline{h} + \frac{\text{var h}}{2\overline{h}} \qquad \text{...} (1)$$

Here $\overline{h}$ is the mean service headway at the stop and var h is the variance of the headway distribution.

It is true that during the evening peak period the average passenger arrival rate does vary and buses are sometimes full so the results given by the above equation must be treated with reserve. Nevertheless the equation can be used to illustrate the comparative effect on passenger waiting times of two different headway distributions, there being no obvious reason why these factors should influence the waiting time in one situation differently from that in the other.

The values of $\overline{t}_W$ calculated for the two distributions, A and B, in Figure 2 are 4.71 minutes and 5.60 minutes respectively, a difference of 19 per cent, suggesting that time-keeping errors did cause a significant increase in passenger waiting times on this route.

The effect of time-keeping on headways and passenger waiting time, with the existing schedule in

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* In this report a trip will be defined as a single journey between two termini.

operation, is illustrated in Table 1, which shows the results of simulation runs* under various conditions of adherence to schedule on leaving the termini. Each run simulated the full scheduled service from 15.30 to 18.00.

TABLE 1

The effects of time-keeping with the existing schedule

Conditions of simulation	BUS HEADWAYS		PASSENGER WAITING TIMES	
	Mean (minutes)	Standard deviation (minutes)	Mean (minutes)	Percentage greater than 15 minutes
Departures from termini as observed in the 1972 survey	9.63	5.38	6.26	7.1
On-time departures from termini	9.73	4.96	5.95	5.7
Departures from termini having an equal probability of being one minute early, on time or one minute late	9.75	5.37	6.00	5.8

With the rather poor time-keeping observed during the survey the mean passenger waiting time was 6.26 minutes. When the avoidable time-keeping errors are eliminated, the service is more regular, as indicated by the reduced standard deviation of bus headways, and the mean passenger waiting time is reduced by 0.31 minutes (approximately 5 per cent).

In costing the value of changes in waiting time for economic assessments it is usual, for consistency, to value all waiting times at the same monetary rate, whatever their length. Nevertheless, in any given situation passengers will have an expectation of the amount of time they must wait before a bus arrives that is derived from the published timetable, and it is reasonable to suppose that they will find time spent waiting in excess of this expectation particularly irritating. During the evening peak, for example, the majority of Service 9 passengers arrive at stops randomly and can therefore expect to wait for up to one scheduled headway (at least 9 minutes), but may become annoyed if they have to wait longer. Throughout this report the percentage of passengers waiting more than 15 minutes will be quoted as a rough measure of the number experiencing this annoying 'excess' waiting time and changes in this number, as well as the overall mean waiting time, will be considered. The results quoted in Table 1 indicate that improved time-keeping can reduce this percentage by up to 20 per cent.

* The results obtained under the various service operating conditions which are quoted in this report are the mean of the results obtained from 24 simulation runs, unless otherwise stated, with differing sets of initialising numbers for the random number generators incorporated in the model. This ensures a good statistical sample.

In practice time-keeping can never be perfect, but the results given in the last line of Table 1 show that if the avoidable errors can be kept down to a minute or less the greater part of the benefits can still be gained.

4. BUS-STOPPED TIMES

The time which a bus spends at a stop while passengers board and alight depends on a number of factors such as the type of bus in use, the fare structure, and the fare-collection and ticket-issuing systems. The boarding time in particular can vary considerably from one situation to another. Service 9 is worked by one-man-operated Bristol RE buses. These have two doors and are provided with a transmission interlock, which prevents the doors from being open while the bus is moving. The fare structure is fully graduated and the drivers collect fares and issue tickets manually. Because the buses have two doors, boarding and alighting can occur simultaneously.

In the simulation program the time taken for one passenger to board the bus, t_b, is selected randomly from a distribution of boarding times. The selected time is multiplied by the total number of passengers boarding the bus, N_b, to obtain the total boarding time. This procedure is adopted, rather than the choice of a separate boarding time for each passenger, because experimental observations indicate that the standard deviation of the total boarding time is more nearly proportional to the number of passengers boarding than to its square root, so that each boarding event cannot be considered to be independent of the others. The alighting time t_a for each of the N_a passengers who alight is also selected from a distribution and the total stopped time of the bus t_s is obtained by taking the greater of the boarding time or alight time and adding this to a constant dead time C. Thus

$$t_s = C + \text{Max}\ (N_b\, t_b,\ N_a\, t_a) \qquad \text{...} (2)$$

The shape of the boarding and alighting time distributions used, together with their mean values, were derived from the work of Cundill and Watts[5]. The values used to represent the existing conditions on the route were $\overline{t_b}$ = 5.5 seconds, $\overline{t_a}$ = 1.2 seconds and C = 5.5 seconds.

Cundill and Watts studied routes, worked by one-man-operated buses and having a graduated fare structure, throughout the country. They found that routes in Kingston-upon-Hull had the shortest bus-stopped times. These used Leyland Atlantean buses with no door interlock system in conjection with a Bell Punch 'Autofare' fare collection system, which links a fare-box to a ticket issuing machine. If the values describing boarding and alighting times in the input data set are amended to be those measured in Hull (mean boarding time per passenger, $\overline{t_b}$ = 2.5 seconds, mean alighting time per passenger, $\overline{t_a}$ = 1.2 seconds and dead time, C = 2.5 seconds)a significant improvement is observed in the simulated bus service, as shown in Table 2.

The headway results given in Table 2 show that the reduced stopped times lead to a significant reduction in bus bunching on the route, the percentage of headways less than 4 minutes and greater than 16 minutes being reduced by 28 and 31 per cent respectively. This improved service regularity, together with the reduced mean bus headway resulting from shorter stopped times, leads to a decrease in the mean passenger waiting time of 0.40 minutes (approximately 6 per cent), and the number of passengers waiting for more than 15 minutes is reduced by 38 per cent.

The results discussed above are in accord with the conclusions of Newell and Potts[6] who used a

TABLE 2

The effects of changes in boarding and alighting time parameters.
(The form of time-keeping at termini is that observed in practice. The schedule revision referred to in the Table is described in Section 4)

Conditions of simulation	BUS HEADWAYS				PASSENGER WAITING TIMES	
	Mean (minutes)	Standard deviation (minutes)	Percentage less than 4 minutes	Percentage greater than 16 minutes	Mean (minutes)	Percentage greater than 15 minutes
Present schedule, present boarding and alighting times (C = 5.5 seconds, $\bar{t}_b$ = 5.5 seconds $\bar{t}_a$ = 1.2 seconds)	9.63	5.38	14.7	12.1	6.26	7.1
Present schedule, revised boarding and alighting times (C = 2.5 seconds, $\bar{t}_b$ = 2.5 seconds, $\bar{t}_a$ = 1.2 seconds)	9.49	4.56	10.6	8.1	5.86	4.4
Revised schedule with reduced journey time allocation and revised boarding and alighting times (C = 2.5 seconds, $\bar{t}_b$ = 2.5 seconds, $\bar{t}_a$ = 1.2 seconds)	9.24	4.65	12.3	8.2	5.73	3.9

simple mathematical model of a bus service, which ignored passenger alighting, to show that the degree of bus bunching, caused by differences in bus-stopped times, depended on the ratio of the passenger arrival rates at the bus stops to the passenger loading rate, and that the lower the loading rate the greater the bunching.

An additional improvement in passenger waiting times can be achieved by rescheduling the bus service to take account of the decreased journey times resulting from the reductions in stopped times. On Route 9 the average saving per trip is over 2 minutes. If the allocated schedule journey times are cut by 2 minutes, thereby reducing the mean service headway still further, an overall improvement in mean passenger waiting time of 0.53 minutes (approximately 8 per cent) is observed, while the overall reduction in the number of passengers waiting more than fifteen minutes is 45 per cent.

Equation 1 gives the theoretical mean passenger waiting time for random arrivals, $\bar{t}_w$, as the sum of two components:–

(i) the mean bus headway component, $\frac{\bar{h}}{2}$

and (ii) the bus irregularity component, $\frac{\text{var } h}{2\bar{h}}$

Table 3 shows the changes in $\bar{t}_w$ and its two component terms (which will be denoted $\Delta\bar{t}_w$, $\Delta_{term 1}$ and $\Delta_{term\ 2}$ respectively) computed for a number of stops when the conditions of simulation changed from the existing Route 9 conditions to the revised boarding and alighting times and the revised schedule conditions described above.

TABLE 3

The effects of changes in boarding and alighting time parameters on the theorectical mean passenger waiting time for random arrivals, $\bar{t}_w$.
(The meaning of symbols is given in the text.)

Stop	$\Delta\bar{t}_w$ (minutes)	$\Delta_{term\ 1}$ (minutes)	$\Delta_{term\ 2}$ (minutes)
5	– 0.45	– 0.10	– 0.35
10	– 0.77	– 0.36	– 0.41
15	– 1.24	– 0.24	– 1.00
25	– 0.42	– 0.27	– 0.15
30	– 0.41	– 0.21	– 0.20
35	– 0.48	– 0.18	– 0.30

Such calculations, though subject to the limitations on absolute accuracy mentioned in Section 3, indicate that the major part of the improvement in waiting times comes from the improved bus regularity.

rather than the reduction in mean bus headway. In their analysis Cundill and Watts[5] estimated the community cost of additional passenger waiting brought about by increases in bus boarding time by equating it with the cost to the bus company of restoring the original mean bus headway. The observation made above suggests that this could underestimate the cost by more than 50 per cent. Since they calculated that the cost in central London alone was over £100,000 per annum, per second of bus-stopped time, this discrepancy is significant.

Decreases in bus-stopped times also lead to reductions in passenger journey times once they have boarded a bus. On the simulated Route 9, during the evening peak period, 15.30 to 18.00, the average stopping event involves approximately three people boarding and three people alighting from the bus. Thus from Equation 2 the changes considered in boarding and alighting parameters will lead to a reduction in mean bus-stopped time of 12 seconds. The origin-destination data collected during the TRRL surveys show that, on average, passengers pass 6.2 stops during the course of a journey, so that the mean reduction in travel time per passenger is 74 seconds, or approximately 10 per cent.

5. CANCELLED BUSES

5.1 The present situation

In recent years the reliability of many bus services has deteriorated because of staff shortages. Few bus operators have been able to achieve a full complement of staff, and the result has been that many trips have been cancelled, either because crews were not available or because lack of maintenance staff has caused a shortage of roadworthy vehicles. In some companies maintenance has been further hampered by shortages of spare parts.

Passengers waiting for a bus which has been cancelled will, in general, incur an enforced additional wait approximately equal to one scheduled headway. In peak periods, however, when the service is heavily loaded, the following bus may well be full and some passengers will then have to wait still longer.

Under conditions where there are persistent shortages it may be better to reschedule to a less frequent but operationally more reliable service, since this will result in less unforeseen 'excess' waiting on the part of bus travellers. This section reports a theoretical investigation of the effect on passenger waiting time of rescheduling to compensate for a shortage of buses.

5.2 The effect of bus cancellations in the off-peak period

During the 1972 TRRL survey in Bristol the mean passenger time measured on Route 9 during the off-peak period, with 12 minute headways, was 5.4 minutes. Consider what will happen to this waiting time when a bus is cancelled from the service.

In the absence of rescheduling, cancellation of one bus in eight from the original 12 minute service would, clearly, cause the waiting times of approximately 12.5 per cent of all passengers to be increased by about 12 minutes, or the average for all passengers to be increased by 1.5 minutes (28 per cent) to 6.9 minutes.

When the need for this cancellation persists there is an opportunity to reschedule the service. On most bus routes with intermediate-and long-headway services, the schedule is such that the headway is a rational fraction of an hour, particularly in off-peak periods, so that the bus timings at the various points on the route can be quoted in the form "and then at the following minutes past the hour". This enables passengers referring to the timetable to memorise easily the times of the buses. Consequently, if a service of 12 minute headway, which is presently operated by eight buses, is rescheduled for operation by seven buses, the headway of the revised service is likely to be 15 minutes. The relationship between mean passenger waiting time and mean bus headways has been studied by Holroyd and Scraggs[4] for bus stops in central London and by Seddon and Day[3] for bus stops in Manchester. The empirical formulae which they have developed to describe their results give values of 7.4 minutes and 5.4 minutes respectively for a 12 minute mean headway. In view of its agreement with the TRRL survey figure, the Seddon and Day formula will be taken to apply to the situation in Bristol: applying it now to a 15 minute service indicates a mean passenger waiting time of 6.2 minutes.

Thus, for the case considered, rescheduling for 7 buses instead of 8 might lead to a reduction in the mean passenger waiting time of approximately 10 per cent (from 6.9 to 6.2 minutes). Moreover, there should be a large decrease in the number of passengers experiencing long waiting times.

5.3 The effect of bus cancellations in the evening peak period

A similar exercise can be carried out much more rigidly for the evening peak period with the aid of the simulation model.

In peak periods the number of buses working the route increases to 11 and the mean scheduled headway drops to 9 minutes. The effects of a depleted service and of rescheduling are summarised in Table 4.

Since the effect of a cancellation on passenger waiting times is dependent on the position of the bus in the schedule, a fact which was not allowed for in the simple calculations given in the previous section, 4 different individual bus cancellations were considered in the simulation. It was found that the values of mean passenger waiting time varied between 7.82 and 7.16 minutes. The mean of the 4 means was 7.40 minutes, which represents an increase of 18 per cent over the value observed with a full service. The number of passengers waiting over 15 minutes is significantly raised, to about 13 per cent of the total, by the cancellation of a single bus.

If the service is rescheduled for 10 buses, so that the bus headways are as far as possible equalised, the mean passenger waiting time decreases to 6.83 minutes and the number of passengers waiting more than 15 minutes is significantly reduced. During the rescheduling the run-time and mean layover time allocations were left unchanged and the peak buses were introduced at approximately the same times as before. In the peak period scheduled bus headways were not required to be rational fractions of an hour; this is in accord with the existing schedule.

Results given in Table 4 for 2 bus cancellations are the mean of studies of 3 different pairs of cancellations. In each case the buses cancelled were chosen to be well separated in the service. Even so, the increase in mean passenger waiting time over the full service value was found to be 39 per cent, and one in 5 passengers had to wait more than 15 minutes. Rescheduling reduced the increase in mean waiting time to 23 per cent and substantially reduced the incidence of long individual waiting times.

5.4 Further work

In practice the number of cancellations necessary on a given route during a period of shortages is likely to vary from day to day. Under those circumstances rescheduling on a day to day basis would require

TABLE 4

The effects of bus cancellations

Conditions of simulation	BUS HEADWAYS		PASSENGER WAITING TIMES	
	Mean (minutes)	Standard deviation (minutes)	Mean (minutes)	Percentage greater than 15 minutes
Original schedule for 11 buses full service running	9.63	5.38	6.26	7.1
Original schedule for 11 buses one cancellation (Mean results from 4 sets of 12 runs,see text)	10.76	6.55	7.40	12.6
Revised schedule for 10 buses full service running	10.85	5.83	6.83	8.8
Original schedule for 11 buses two cancellations (Mean results from 3 sets of 12 runs, see text)	11.99	7.87	8.70	19.1
Revised schedule for 9 buses full service running	12.10	6.16	7.72	12.7

a rather more complex form of operational control than is available in most bus companies: in particular the problem of coordinating crew relief times is difficult to solve when the schedule is constantly changing. Nevertheless, where control is available, the more limited objective of equalising the headways of those buses in the vicinity of gaps caused by cancellations should be possible in many cases using existing systems of control and should yield worthwhile benefits for high frequency services.

Further work has been carried out at TRRL using an analytic model, less realistic than the simulation model used here, but able to take account of the day to day variations in the number of cancellations necessary[7]. The results suggest that the optimum policy is to reschedule for the mean number of buses available, to make failure to fulfil the schedule less probable, and to inject any spare buses which become available on a given day into service as appropriate. The benefits thereby gained with a variable number of cancellations are only marginally less than those evaluated in this work which assumes an essentially constant level of cancellations.

6. BUS SCHEDULING

6.1 Scheduling policies

In some bus operations the journey times allocated in the schedules remain more or less constant throughout the day and do not reflect variations observed on the road[8]. The allocations are often average values computed over the whole day, with perhaps a few minutes added during peak periods. This frequently results in off-peak buses having too much time and peak buses insufficient. One possible definition of bus service reliability is the extent to which the actual service on the road compares with the service described by the published schedule. It follows that the service can only be "reliable" if the journey times incorporated in the schedule accurately reflect the observed journey times on the road at all times of day, and that the scheduling policy just described may be a root cause of unreliability.

6.2 Service 9 scheduling in the afternoon off-peak period

In Figure 3 bus journey times measured on the three days of the 1972 survey are plotted against journey start time for the four quarters of the route lying between the termini and the city centre. In the evening peak period simulated journey times are also shown to demonstrate the correspondence. The journey times allocated in the existing schedule are indicated by the solid lines.

In the afternoon off-peak period, 12.00 to 15.30 the mean journey times remain more or less constant with time of day. The schedule allocations for journeys between the Winterstoke terminus and the city centre, in both directions of travel, appear to be satisfactory. Those for journeys between the Hanham terminus and the city centre, however, appear to be too long and this results in many buses running ahead of schedule on some sections of the route. Figure 4 shows that 19 per cent of the buses observed at the city centre travelling westwards (stop 32), 19 per cent of the buses observed arriving at the Winterstoke terminus and 27 per cent of the buses observed arriving at the Hanham terminus were more than 5 minutes ahead of schedule. This is most undesirable since, in a situation where a proportion of passengers time their arrivals at the bus stop, (as is likely to be the case, off-peak, on Route 9) buses which run ahead of schedule cause a greater increase in passenger waiting time than those which run late. Considering a hypothetical 12 minute headway service which is initially perfectly regular, the result, for passengers who arrive randomly at stops, of a bus running 5 minutes ahead of schedule is exactly the same as that of a bus falling 5 minutes behind it – in both cases there is one headway of 7 minutes and another of 17 minutes. But if it is supposed that some passengers time their arrivals so as to be at the bus stop 4 minutes before the scheduled bus departure times, there is a difference in the two cases – the effect of a bus falling 5 minutes behind schedule being merely an increase of waiting time of 5 minutes, whereas that of a bus running 5 minutes early is to cause them to miss it entirely, and to have to wait a further 12 minutes beyond the 4 they had anticipated. This is particularly frustrating example of the "excess" waiting time mentioned earlier in Section 3.

In the case of the off-peak Service 9 this could be avoided by making reductions of, say, 3 minutes in the time allocations for the Hanham-city centre and city centre-Hanham journeys. This would have the effect of moving the relevant adherence-to-schedule histograms, shown in Figure 4, 3 minutes to the right along the abscissa scale, thereby eliminating much of the extreme early running and improving the mean adherence to schedule.

It is not suggested that these reductions in the off-peak period be used to decrease the scheduled headway, since, as was stated in Section 5, there are good reasons for maintaining a headway which is a rational fraction of an hour in this period. The changes are merely suggested as a means of bringing the observed running into closer correspondence with the schedule.

6.3 Service 9 scheduling in the evening peak

Between 16.00 and 16.45 congestion builds up on the route between stops 5 and 11 in the eastbound direction and between stops 30 and 35 in the westbound direction, and following 17.15 it dies down. At the height of the congestion mean bus journey times have increased by almost 100 per cent on these sections. The only allowance made in the schedule for the changes are additions of a few minutes to the allocated run-times as shown in Figure 3.

With the existing schedule the rapidly changing bus journey times have several deleterious effects on the service. During the evening peak the overall flow of passenger traffic is from the city to the suburbs and so the majority of the heaviest loading points are at the centre of the route. It is important, therefore, for bus headways on this section over this brief period to be as short as possible in order to minimise the total passenger waiting time on the route. The existing schedule, which is shown in Figure 5 in the form of a time-distance plot, requires bus departures from the Winterstoke terminus, stop 1, to be regular with a headway of 9 minutes. However, the rapid increase in successive bus journey times over the section of the route between stops 5 and 10 causes large gaps, such as that denoted A in the the time-distance diagram given in Figure 6, to open up in the service by the time the buses reach the city centre, stop 10. Following 17.00 successive bus journey times begin to decrease and the service is bunched on arrival at the city centre. Thus, in the eastbound direction the mean service headway observed at the centre of the route is greatest during the period of peak passenger demand and shortest after the peak has died down. In the westbound direction the situation is not as bad because congestion is somewhat less and gaps in the service only open up when some of the heaviest loading stops have been passed. Nevertheless, problems do occur after 17.30 as a result of those gaps generated in the eastbound direction carrying through on to the return trip.

Another manifest feature in the peak, resulting directly from unrealistic run-time allocations, is the poor adherence to schedule. Histograms of adherence to schedule at various points on the route are shown in Figure 7. These histograms together with the details which have been taken from them and presented in Table 5 show that many buses do not run in accordance with the published schedule, particularly during the second halves of cross-town trips. Additionally, because some bus journeys take as much as 15 minutes longer than their schedule allocation, an appreciable number of buses are left behind schedule at the end of the peak period. On the three days of the 1972 survey the mean bus lateness at 18.00 was 4.6 minutes, and 31 per cent of the buses were observed to be 10 minutes or more behind schedule at that time. This degree of bus lateness inevitably disrupts the service in the subsequent off-peak period. Consideration of the survey results suggests that some of the poor time- keeping observed on departure from termini can be attributed to drivers deliberately leaving early in order to have time in hand when they reach the congested sections of the route, because experience has made them aware of the schedule inadequacies.

The simulation model, incorporating the original schedule, satisfactorily represented all the features described above. Time-distance diagrams given in Reference 2 showed that the occurrence of gaps in the simulated service corresponded closely to those observed in practice. Similarly Figure 7 and Table 5 show that the simulated adherence to schedule was also realistic. At 18.00 the simulated mean bus lateness was 5.7 minutes and 27 per cent of the buses were 10 or more minutes behind schedule at that time.

An attempt was made to devise a schedule incorporating more realistic run times; it was programmed into the model in order to evaluate the possible effects of its use. For this purpose it was felt that a simple step function, such as that incorporated in the existing schedule, could not accurately reflect the observed variations in mean bus journey times with time of day, and that continuously varying allocations might

TABLE 5

Details of adherence to schedule with the existing schedule and revised schedule described in Section 6.

LOCATION	Percentage of observations with a deviation from schedule of less than 2.5 minutes			Percentage of observations with a deviation from schedule greater than 8.5 minutes		
	Existing schedule, survey	Existing schedule, simulation	Revised schedule, simulation	Existing schedule, survey	Existing schedule, simulation	Revised schedule, simulation
Departure from Winterstoke	77.2	77.9	88.0	6.5	6.8	2.4
Arrival at city centre (stop 10)	39.1	38.0	50.0	27.3	34.0	12.6
Arrival at Hanham	39.1	36.7	56.1	23.0	21.8	12.0
Departure from Hanham	70.3	68.8	72.7	8.0	15.5	0.0
Arrival at city centre (stop 32)	36.6	31.9	63.9	4.6	4.6	2.1
Arrival at Winterstoke	41.2	38.0	52.3	13.4	26.2	9.2

effect an improvement in level of service. Consequently the revised schedule was constructed in the following way:—

(i) The city centre stops in each direction of travel were taken as reference points and the required bus timings at these points were determined throughout the period considered. (This had to be done bearing in mind the number of buses available, which was taken to be the existing number, and the total round trip time. These together serve to determine the mean service headway);

(ii) New journey time allocations were calculated and used, in conjunction with the city centre timings, to determine the corresponding arrival and departure times at the two termini. (The revised allocations used for the rescheduling are shown in Figure 3 by the dashed lines. These allocations were made to be as far as possible reasonable representations of the mean journey times over the various sections of the route);

(iii) Bus arrivals at the two termini were linked with suitable subsequent departures. (This was carried out bearing in mind that the allocated layovers must be in accord with those of the present schedule; that is to say, not less than 5 minutes and, whenever possible, not greater than 10 minutes. To achieve satisfactory linkings a number of minor adjustments had to be made to the individual bus timings determined in stages (i) and (ii) of the process).

This method of construction was designed to achieve, as far as is possible:

(i) a better service at the heavily loading city centre stops, with no large gaps as observed with the existing schedule, so that the overall mean passenger waiting time on the route is reduced;

(ii) a better adherence to schedule;

(iii) a reduction in the amount of bus lateness observed at the end of the peak period, 18.00.

The schedule which was evolved in this way is shown in Figure 8 in the form of a time-distance diagram.

The results of simulation runs incorporating the revised schedule, with perfect and imperfect time-keeping, are given in Table 6. These can be compared with the corresponding results obtained with the existing schedule given previously in Table 1. Details of the mean bus headways and regularity simulated for alternate stops on the route with the two schedules are given in Figures 9 and 10: the regularity, or that rather the irregularity, of the service is measured by the magnitude of the irregularity component of Equation 1, I, where

$$I = \frac{\text{var } h}{2\bar{h}} \qquad \text{.. (3)}$$

Figure 9 shows that, if time-keeping on departure from termini was perfect, rescheduling would lead to a more frequent and generally more regular service over the whole route in the time period considered. The consequent improvement in mean passenger waiting time would be 8 per cent. However, because the regularity of the rescheduled service is relatively more sensitive than the existing one to time-keeping errors, the simulation indicates that rescheduling of the type considered would, in practice, bring about a deterioration in service regularity at a number of stops on the route, as Figure 10 shows, and that the

TABLE 6

The effects of time-keeping errors with the revised schedule in operation

Conditions of simulation	BUS HEADWAYS		PASSENGER WAITING TIMES	
	Mean (minutes)	Standard deviation (minutes)	Mean (minutes)	Percentage greater than 15 minutes
Time-keeping errors on departure from termini as observed in 1972 survey	9.18	5.12	6.05	6.4
On-time departures from termini	9.29	4.64	5.53	4.1

overall improvement in mean passenger waiting time would be only 3 per cent. Consideration of time-distance plots of the sumlation runs suggested that in neither case was the problem of gaps opening up in the eastbound service overcome, although its magnitude was somewhat reduced.

Figure 11 indicates that even with imperfect time-keeping a marked improvement in adherence to schedule is brought about by the rescheduling. Nevertheless, the variability of individual journey times (ie the scatter about the mean value) meant that there were still many buses observed with deviations from schedule greater than 2.5 minutes. At the end of the period considered, 1800, the mean bus lateness with reference to schedule was only 1.0 minutes and only 3 per cent of the buses were observed to be more than ten minutes late.

It is conceivable that such improvements in adherence to schedule might encourage some passengers to use the published timetable to time their bus stop arrivals, and thereby enable them to reduce their waiting times. However, the magnitude of the benefits, which could be generated in this way in practice is uncertain. Passengers may be better able to aim for a particular bus on leaving home in the morning than they are after finishing work in the evening and such benefits might, therefore, be more realisable at that time of day.

Thus although reductions in the variability of headways, and hence passenger waiting times, can be produced by rescheduling for variable run times (especially when time-keeping is good), the effects are likely to be only modest. More effective means of reducing this kind of variability (which is fundamentally due to traffic congestion) may be found in traffic engineering and bus priority measures.

7. CONCLUSIONS

A computer simulation model of a bus route, and the results of TRRL surveys carried out on the route modelled (Route 9 of the Bristol Ombibus Company) have been used to quantify the improvements in level of service which could be made by changes in four factors which affect the operation of the service: the accuracy of time-keeping, bus boarding times, methods of dealing with staff and vehicle shortages, and bus scheduling. The conclusions are as follows:

1. Work with the simulation model suggested that improvements in regularity brought about by the elimination of time-keeping errors on departure could achieve a 5 per cent improvement in the mean passenger waiting time on the route during the evening peak period, 15.30 to 18.00. The major part of this improvement could be gained by reducing the magnitude of the errors to a minute or less.

2. Bus boarding times have a critical effect on bus service operations, and particularly on regularity. By decreasing the mean boarding time per passenger from 5.5 to 2.5 seconds and the dead time between the bus stopping and the first passenger boarding from 5.5 to 2.5 seconds (the lowest timings observed in the UK on one-man-operated, graduated-fare vehicles), reductions of 8 per cent in the mean waiting time and 10 per cent in the mean on-bus travel time could be achieved in the evening peak period.

3. The cancellation of one bus from the service would cause a 28 per cent increase in the mean off-peak waiting time and 18 per cent in the mean peak waiting time. Cancellation of two buses in the peak period would cause the mean waiting time to increase by 39 per cent. (The service is scheduled to be operated by 8 and 11 buses respectively in the off-peak and peak periods). During times of persistent shortages, when cancellations are frequently necessary, increases such as these could be cut by about a half by rescheduling designed to take account of the mean number of buses available.

4. In the off-peak period, 12.00 to 15.30, journey time allocations incorporated in the schedule for some sections of the route were too long. This results in a number of buses running ahead of schedule and can cause passengers timing their arrival at the bus stop on the basis of the schedule to miss their bus and experience a long frustrating wait. Adjustments of scheduled running times can ameliorate this effect.

5. In the peak period, 15.30 to 18.00, the journey time allocations incorporated in the schedule failed to take account of the large increase in journey times observed on some sections of the route: this was at least partially responsible for gaps opening up in the service at key points on the route, for poor adherence to schedule and for lateness at the end of the peak which disrupted the service in the subsequent period.

   A schedule was constructed which incorporated continuously varying journey time allocations that corresponded closely to the mean values observed in practice and which was designed to provide a better service at the heavily loading city centre stops. This schedule brought about a reduction of 8 per cent in the mean passenger waiting time for a service with perfect time-keeping. However, time-keeping errors reduced this improvement to 3 per cent. The adherence to schedule was considerably improved but the variability of journey times about the mean meant that there were still considerable numbers of buses observed to be running more than 2.5 minutes off schedule. Lateness in excess of 10 minutes at the end of the period considered, 18.00, was reduced from 30 per cent to 3 per cent. It is concluded that overall, sophisticated scheduling is unlikely to be a very effective way of combating the disruption caused by rapidly varying bus journey times during peak periods. It seems unlikely to be a satisfactory substitute for bus priority or traffic management schemes which reduce the causes of the variability.

8. ACKNOWLEDGEMENT

The work described in this report was carried out in the Public Transport Division of the Transport Operations Department of TRRL. The authors wish to acknowledge the cooperation of the Bristol Omnibus Company during the course of the various surveys carried out in Bristol.

9. REFERENCES

1. WEBSTER, F.V. Research and public transport. *Department of the Environment, TRRL Report* SR 76 UC. Crowthorne, 1974 (Transport and Road Research Laboratory).

2. BLY, P.H. and R. L. JACKSON. Evaluation of bus control strategies by simulation. *Department of the Environment, TRRL Report* LR 637. Crowthorne, 1974 (Transport and Road Research Laboratory)

3. SEDDON, P.A. and M.P. DAY. Bus passenger waiting times in Greater Manchester. *Traffic Engineering and Control,* 1974, 15, 442.

4. HOLROYD, E.M. and D.A. SCRAGGS. Waiting times for buses in Central London. *Traffic Engineering and Control,* 1966, 8, 158.

5. CUNDILL, M.A. and P. F. WATTS. Bus boarding and alighting times. *Department of the Environment, TRRL Report* LR 521. Crowthorne, 1973 (Transport and Road Research Laboratory).

6. NEWELL, G. F. and R.B. POTTS. Maintaining a bus schedule. *Proc. 2nd Conf., Australian Road Research Board,* 1964, 2 (1) 1.

7. BLY, P. H. and R. L. JACKSON. Scheduling for depleted bus services. Sixth Annual Symposium on Public Transport. Newcastle upon Tyne 1975 (University of Newcastle upon Tyne).

8. BUTCHER, E. W. A. Vehicle location and control systems – an operators view. Fourth Annual Seminar on Operational Research in the Bus Industry 1972 (University of Leeds).

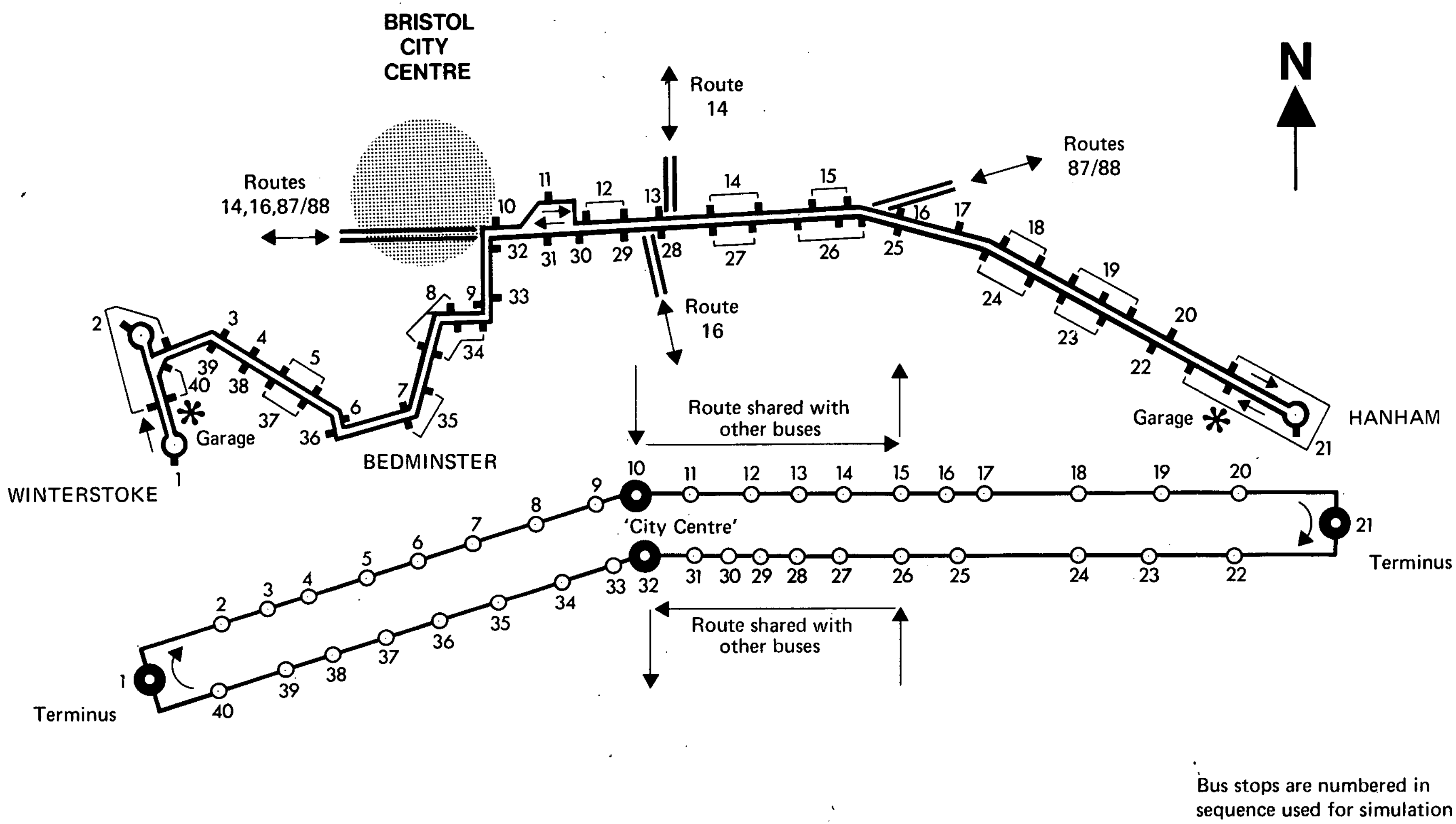


Fig. 1 SCHEMATIC PLAN OF ROUTE 9, BRISTOL AND LAYOUT OF SIMULATION ROUTE

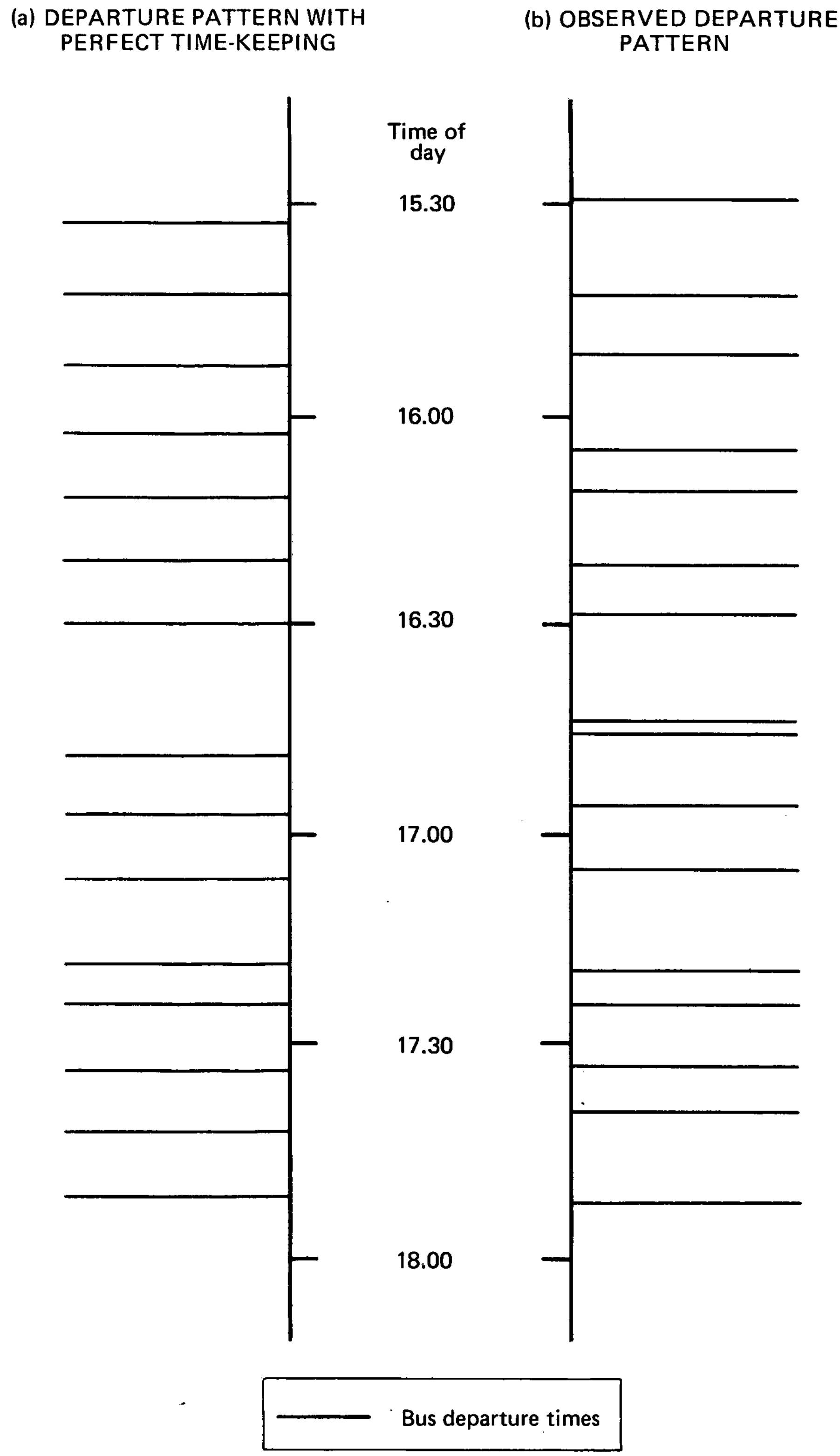


Fig. 2 A COMPARISON OF THE OBSERVED BUS DEPARTURE PATTERN FROM THE WINTERSTOKE TERMINUS ON ONE DAY OF THE 1972 SURVEY WITH THAT WHICH WOULD HAVE BEEN OBSERVED WITH PERFECT TIME–KEEPING

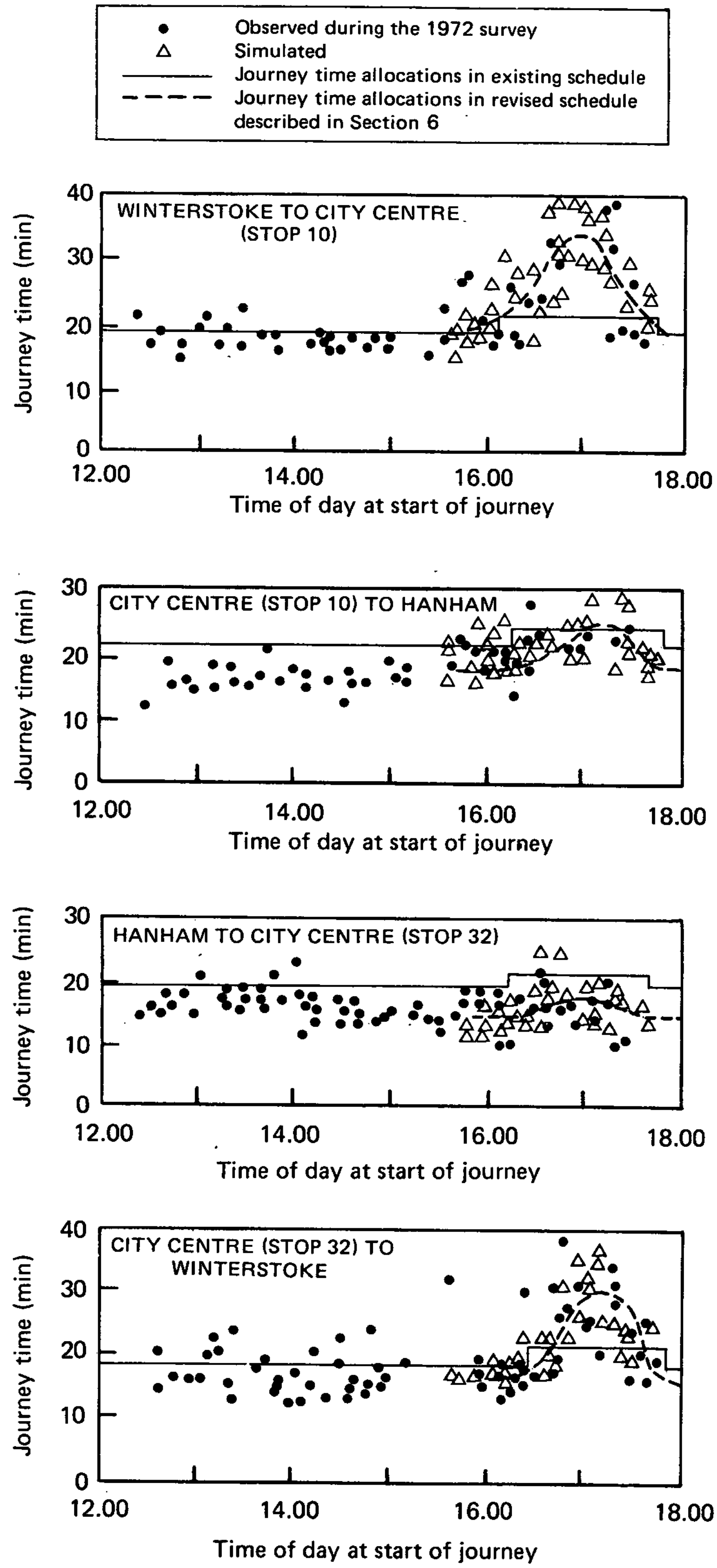


Fig. 3 OBSERVED AND SIMULATED BUS JOURNEY TIMES PLOTTED VERSUS JOURNEY START TIME FOR THE FOUR QUARTERS OF THE ROUTE

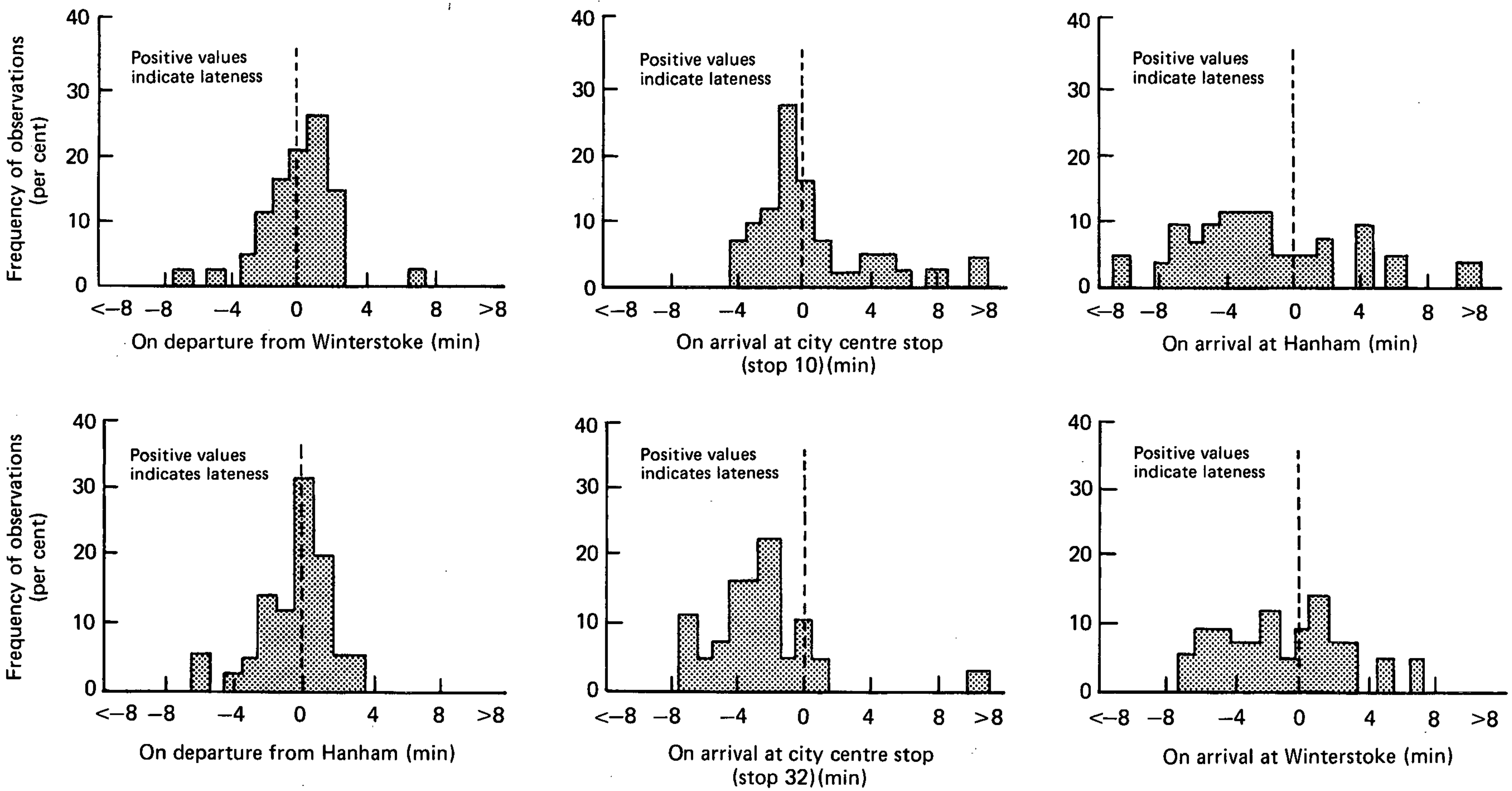
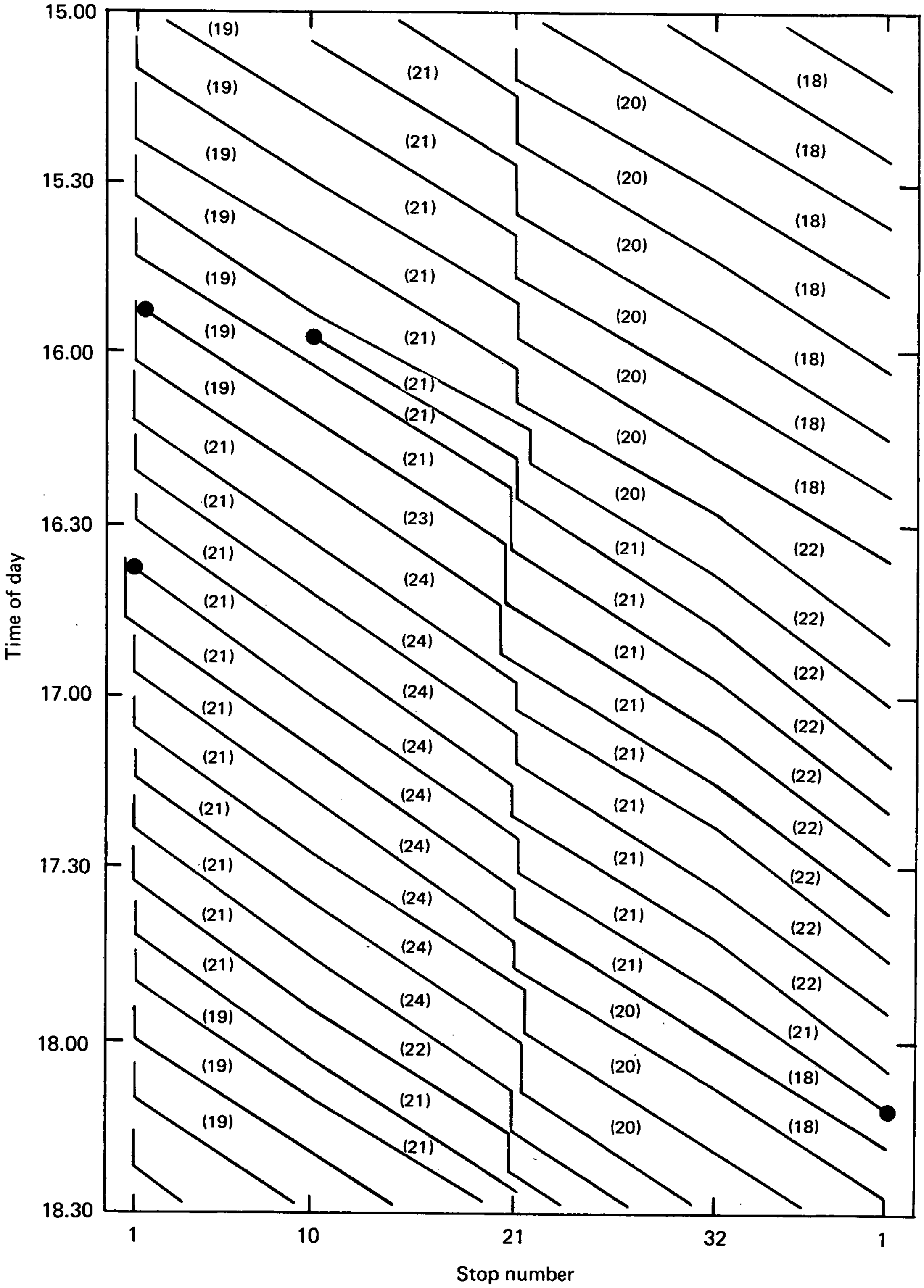


Fig. 4 HISTOGRAMS SHOWING OBSERVED ADHERENCE TO SCHEDULE AT VARIOUS POINTS ON THE ROUTE IN THE AFTERNOON OFF-PEAK PERIOD 12.00 to 15.30



The figures in brackets are the journey time allocations in minutes for the four quarters of the route.

Fig. 5 THE EXISTING SERVICE 9 SCHEDULE FOR THE PERIOD 15.00 to 18.30 SHOWN IN THE FORM OF A TIME–DISTANCE DIAGRAM.

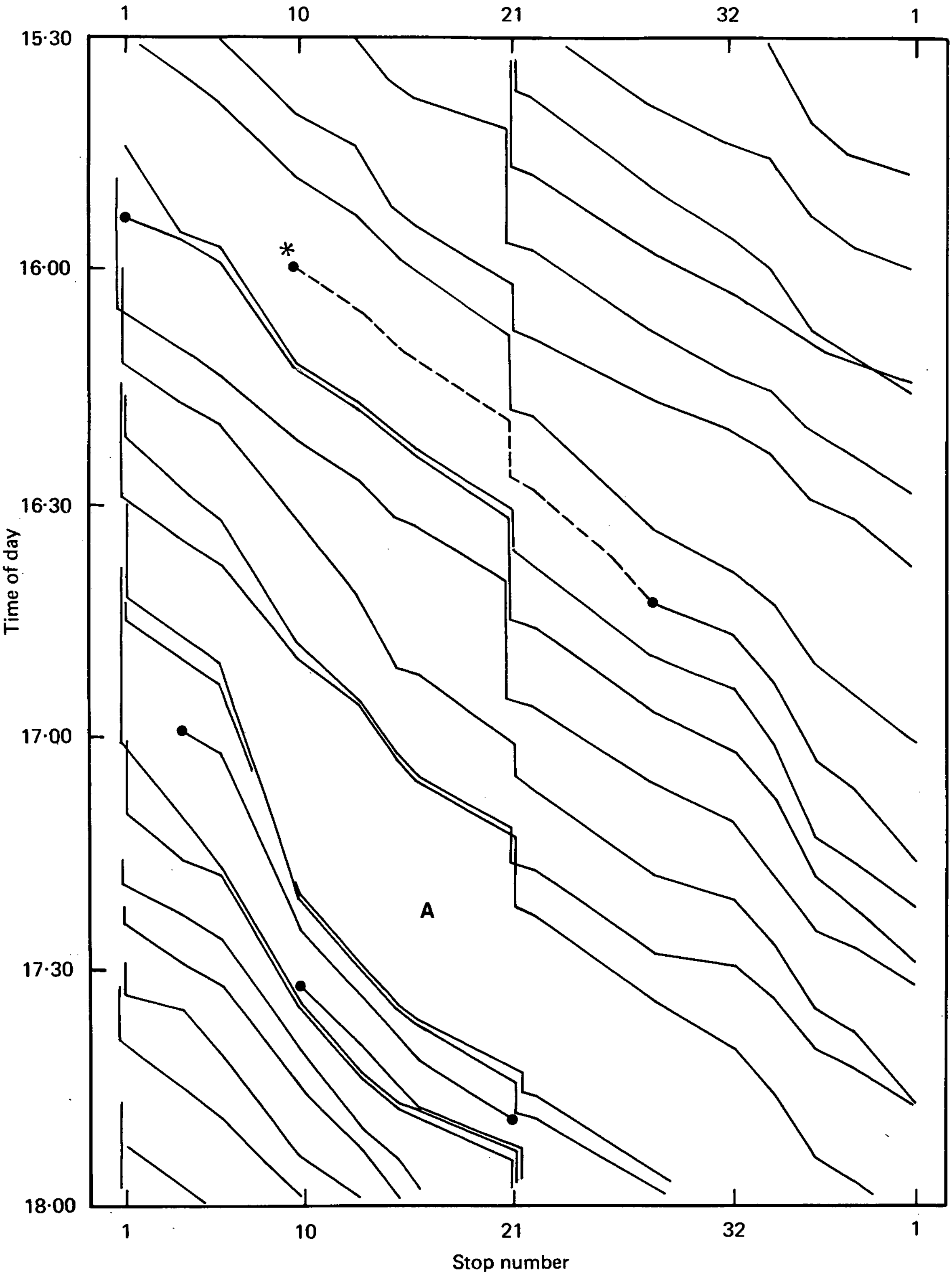


Fig. 6 TIME–DISTANCE DIAGRAM OF SERVICE 9 PLOTTED FROM THE SURVEY DATA. 'A' IS THE GAP REFERRED TO IN SECTION 6

***This particular bus started out late on the survey day in question. The dashed line represents that part of its schedule which it did not operate**

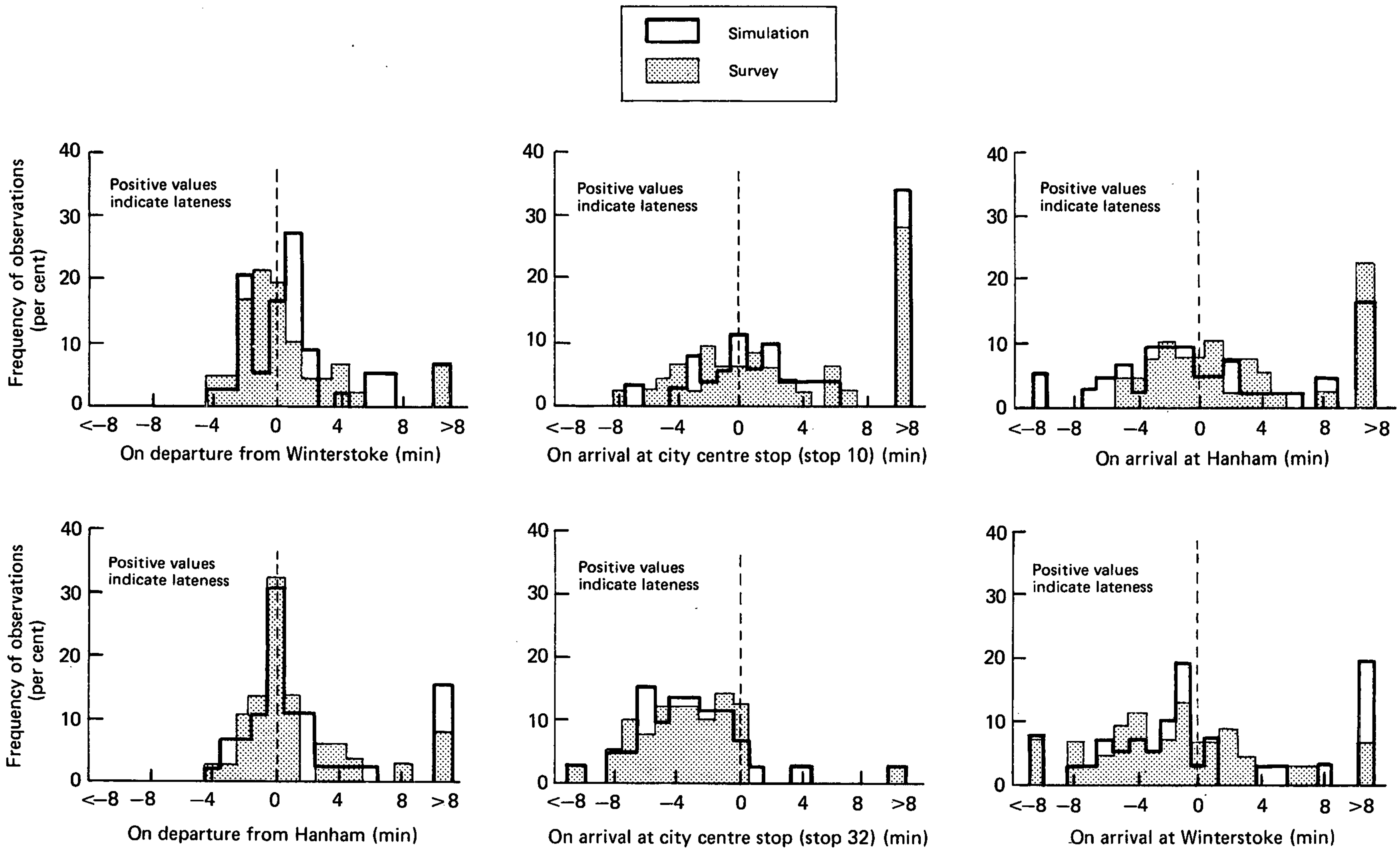


Fig. 7 HISTOGRAMS SHOWING OBSERVED AND SIMULATED ADHERENCE TO SCHEDULE AT VARIOUS POINTS ON THE ROUTE IN THE EVENING PEAK PERIOD, 15.30 TO 18.00

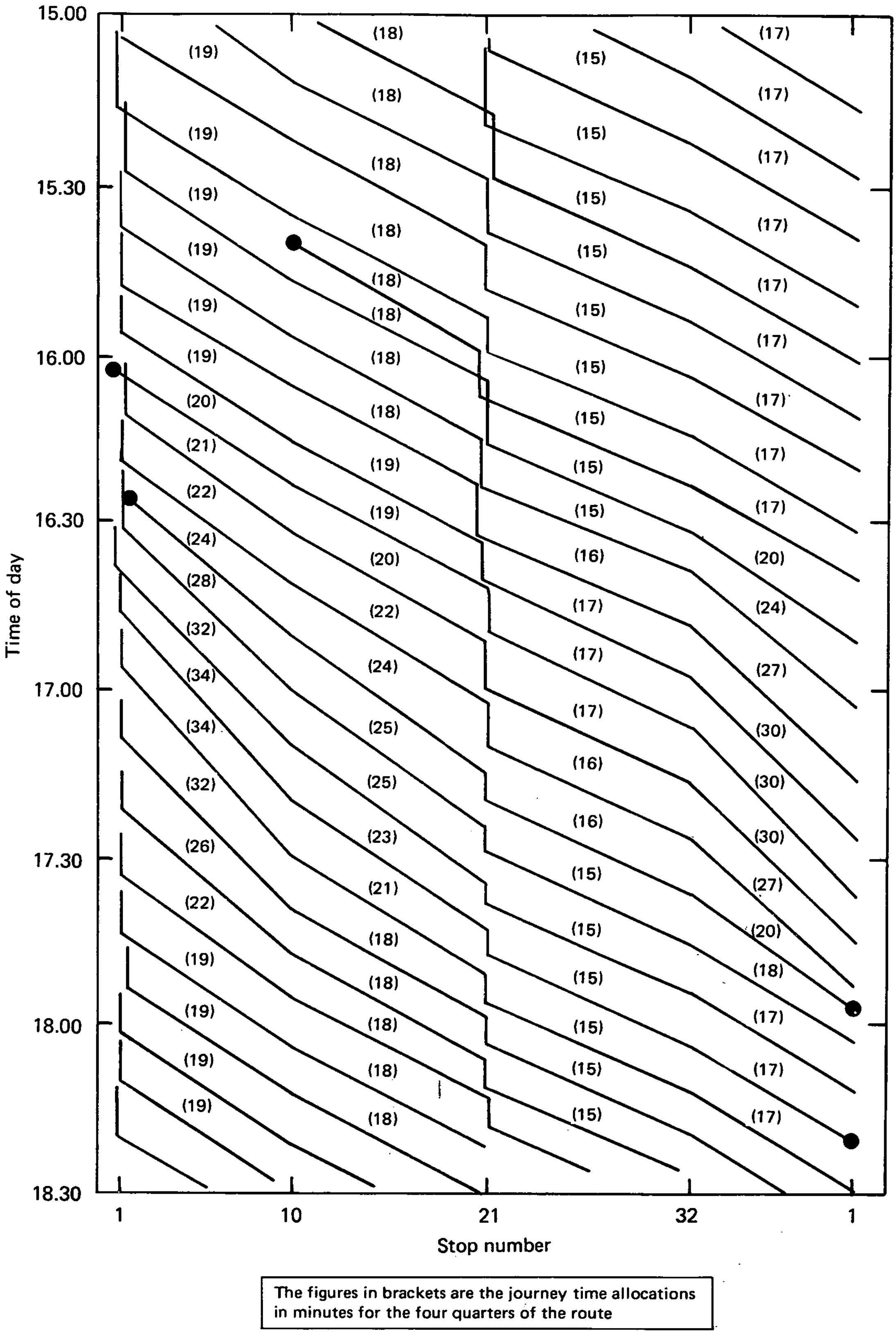


Fig. 8 THE REVISED SERVICE 9 SCHEDULE INCORPORATING MORE REALISTIC JOURNEY TIME ALLOCATIONS SHOWN IN THE FORM OF A TIME–DISTANCE DIAGRAM

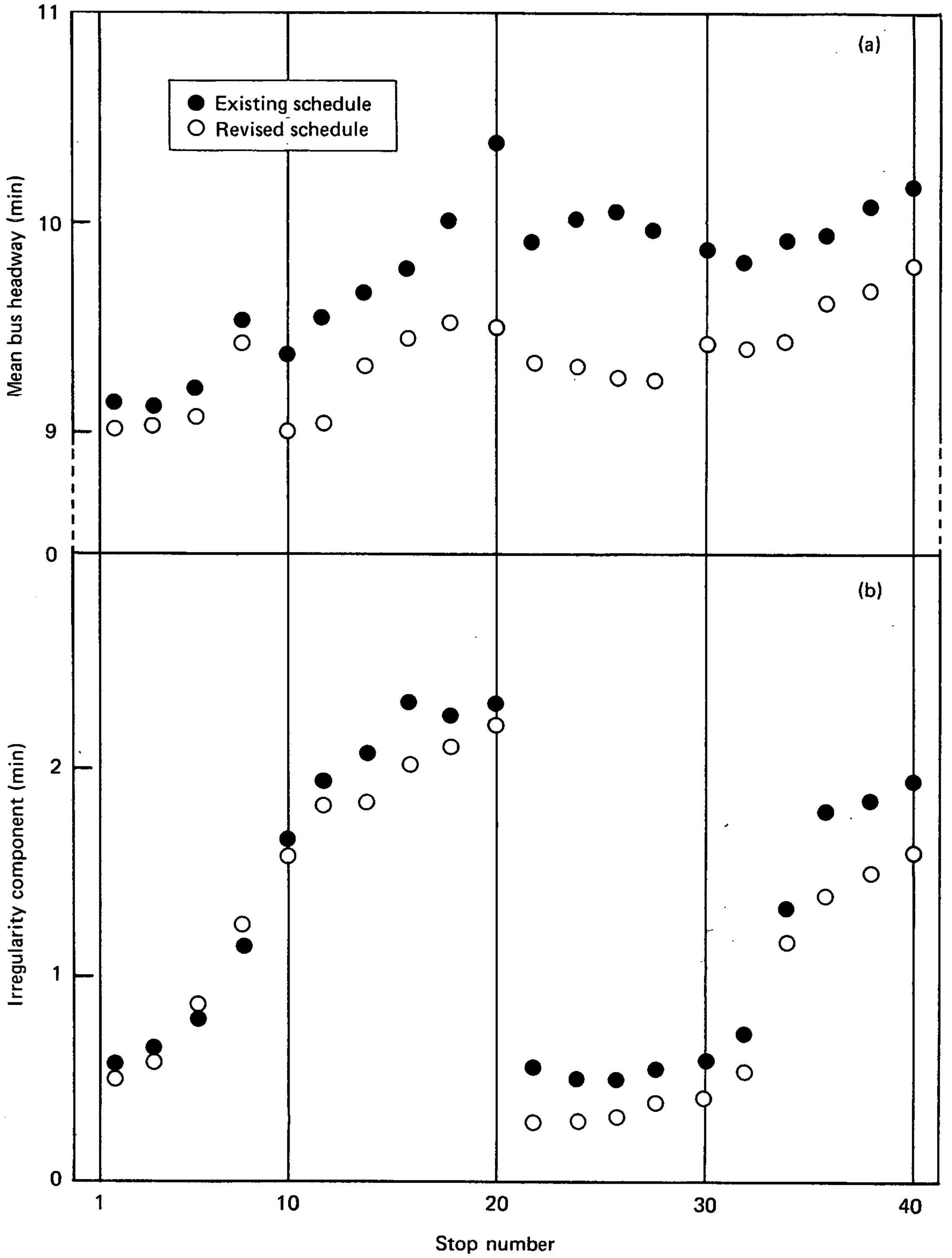


Fig. 9 VALUES OF (a) THE MEAN BUS HEADWAY AND (b) THE IRREGULARITY COMPONENT OF EQUATION 1 WITH THE EXISTING AND REVISED SCHEDULES AND WITH PERFECT TIME–KEEPING

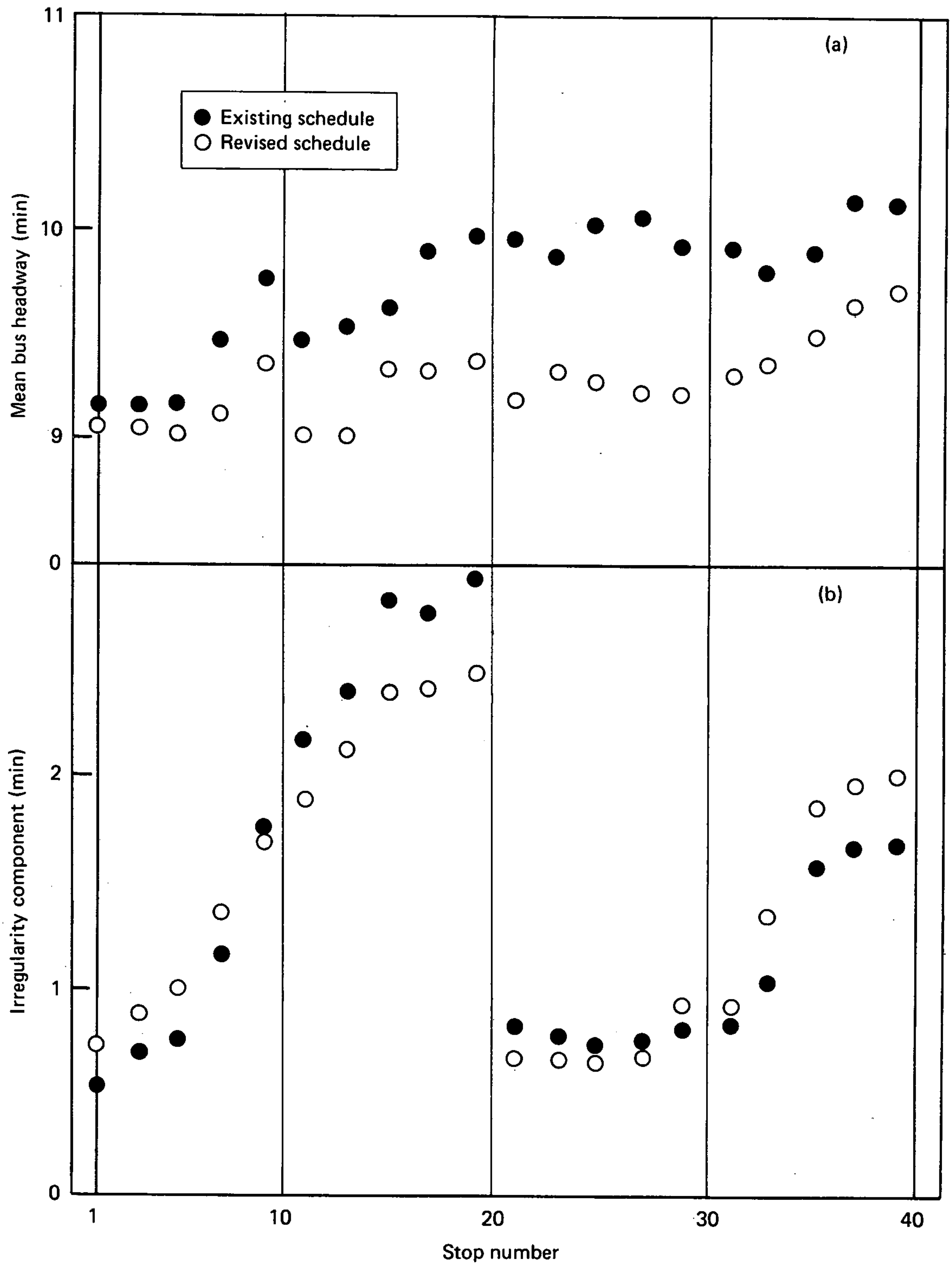


Fig. 10 VALUES OF (a) THE MEAN BUS HEADWAY AND (b) THE IRREGULARITY COMPONENT OF EQUATION 1 WITH THE EXISTING AND REVISED SCHEDULES AND WITH IMPERFECT TIME-KEEPING.

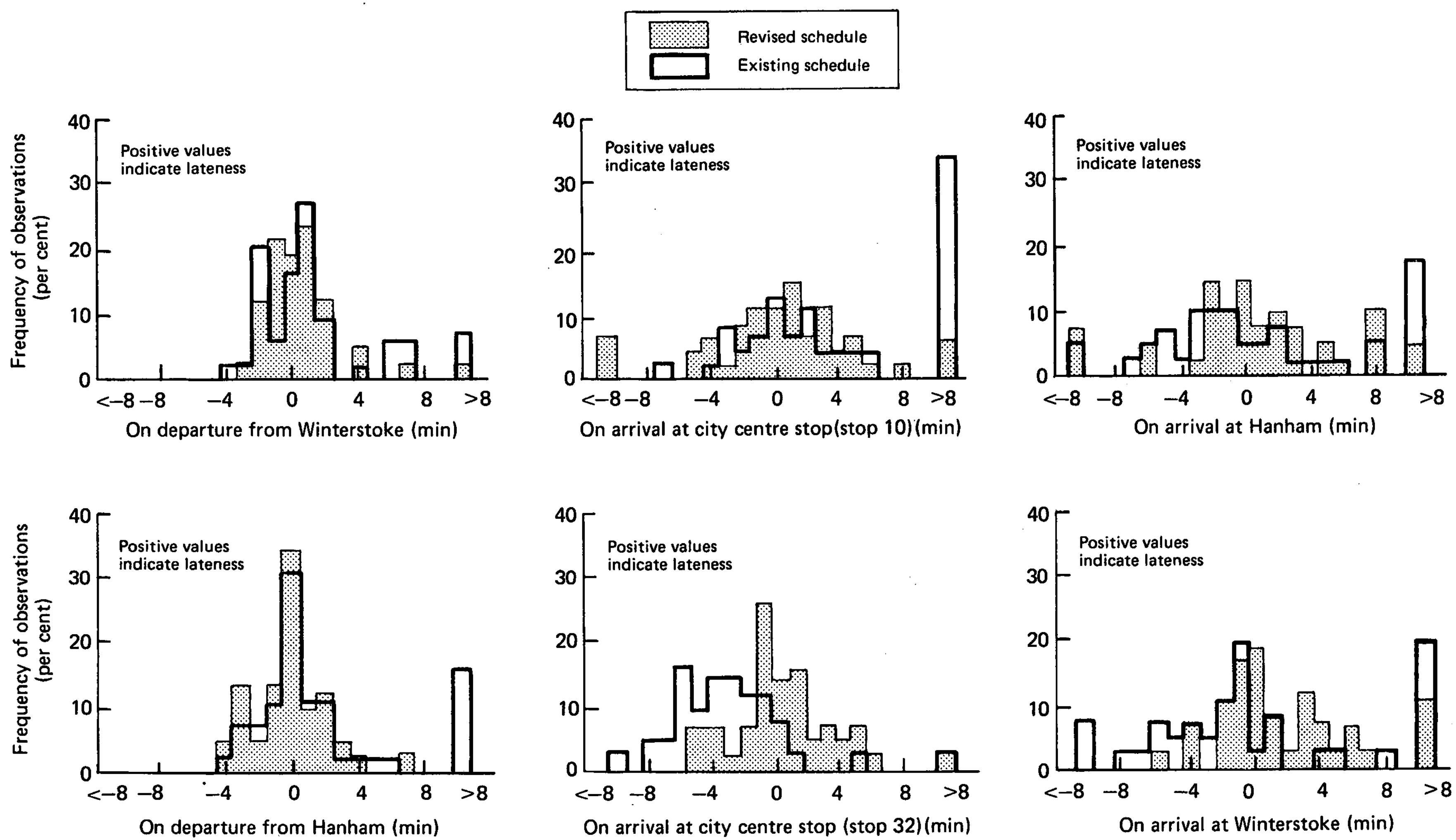


Fig. 11 HISTOGRAMS SHOWING SIMULATED ADHERENCE TO SCHEDULE AT VARIOUS POINTS ON THE ROUTE IN THE AFTERNOON PEAK PERIOD 15.30 TO 18.00 WITH THE EXISTING AND REVISED SCHEDULES IN OPERATION

(849) Dd443233 1,600 6/77 HPLtd So'ton G1915
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(ii) reducing bus-boarding times to the lowest values observed elsewhere in the United Kingdom could bring about reductions of 8 per cent in the mean waiting time and 10 per cent in the mean on-bus travel time in the evening peak period;

(iii) when there was a persistent need for cancellations, waiting times could be reduced by rescheduling designed to make the scheduled complement compatible with available resources: when an average of one bus was missing from the service considered, the reduction was estimated to be of the order 10 per cent of the waiting time for a full service, in both peak and off-peak periods;

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ISSN 0305–1293

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