Monograph:
May, A.D. and Montgomery, F.O. (1983) Work Journey Rescheduling: Results and Conclusions. Working Paper. Institute of Transport Studies, University of Leeds , Leeds, UK.

Working Paper 168

ITS

Institute of Transport Studies
University of Leeds

Published paper

May, A.D. and Mongtomery, F.O. (1983) Work Journey Rescheduling: Results and Conclusions. Institute of Transport Studies, University of Leeds, Working Paper 168

ITS INSTITUTE FOR TRANSPORT STUDIES
THE UNIVERSITY OF LEEDS

Working Paper 168

May 1983

WORK JOURNEY RESCHEDULING: RESULTS AND CONCLUSIONS

by

A.D. MAY and F.O. MONTGOMERY

Institute for Transport Studies, University of Leeds, Leeds LS2 9JT, England. Leeds (0532) 431751

CONTENTS

ABSTRACT

MAY, A.D. and F.O. MONTGOMERY (1983) Work journey rescheduling: results and conclusions. Leeds: University of Leeds, Inst. Transp. Studs., 168 (unpublished).

An assessment was made of the effects of changes in working hours on traffic conditions in the city centre of Wakefield. The study used survey data and modelling techniques which are described fully elsewhere, and summarised in section 2 of this report. This report concentrates on the results of the study and the conclusions to be drawn from them.

Assessments were made of traffic conditions had the current level of flexible and staggered hours operation not been introduced, and as the result of four different levels of increased rescheduling of work journeys. In all cases, results were presented in terms of changes in the temporal distribution of trip ends, cordon flows, and the network parameters of vehicle hours, vehicle kilometres, average speed and vehicle delay. In the peak 15 minutes car driver trip ends would have been 15% higher without current work hour arrangements, and 11% lower with further rescheduling. Changes in car driver trips entering the central area would have been about half as great as these changes in trip ends. Because the network is not operating at capacity, these changes would have had little effect on network performance generally, but time spent in queues, and delays on two congested approaches would have changed in the peak 15 minutes by ± 20%.

The report discusses the reasons for these relatively small changes and suggests criteria for identifying those cities in which work journey rescheduling could more successfully reduce congestion. It also recommends potential improvements in the analytical process adopted.

1. INTRODUCTION

1.1 Background

This paper presents the results and conclusions of a study carried out for the Department of Transport, the objectives of which were

(1) To study the present pattern and distribution of journeys to and from work in Wakefield, and the constraints imposed by employers, unions, domestic conditions, and

(2) To study the potential role of incentives in encouraging change in journey timing, and the possible costs and benefits which would arise.

Earlier papers have described the analysis method adopted (Montgomery and May, 1983) and the surveys on which the analysis was based (May, Montgomery and Wheatley, 1981).

The morning and evening peak in traffic levels in urban areas give rise to several problems. High levels of car use cause congestion and lead to increased delays and unreliability to car, bus and commercial vehicle users, and increased costs to their operators. They also encourage use of environmentally sensitive routes to avoid congestion.

High levels of bus and rail use increase the level of discomfort on public transport and the chance that waiting times will increase because buses or trains are full. Peak demands determine the level at which transport capacity is provided; new roads to alleviate congestion will often only be fully used during the peak periods; equally a large proportion of urban public transport vehicles and staff are required solely for the peak and are idle at other times.

The spreading of morning and evening peak travel demands is frequently advocated as a means of alleviating these problems and as an alternative to less palatable congestion reducing measures such as road construction or restraint. The most obvious way in which this can be achieved is by removing or modifying the requirement on individuals to travel at particular times. Since work journeys predominate in the peaks the emphasis has been on employees' hours, which have been modified by the introduction of both staggered and flexible working hours. There has also been some interest in modification of school and shop opening hours to reduce the peak. However, it is important to note that changes in the relative costs of peak and off peak travel can also affect the spreading of demand. Peak fare surcharges, reductions in peak public transport capacity and peak period restraint (as demonstrated in Singapore (Watson, 1978)) can all be expected to have some effect. So, as indicated by experience in York, can a reduction in highway capacity, since it inevitably causes more congestionin the peak than at other times (Dawson, 1979).

While spreading of peak demand can have obvious benefits, it is not without its drawbacks. Increased demand immediately outside the peak may add to delays and travel costs then, and may conflict with other travel requirements. It may also conflict with transport operators' need for some spare off peak capacity for such activities as road and vehicle maintenance. Choice of mode may also change; peak period bus users could conceivably be attracted to car use outside the peak because driving conditions were easier or cars more readily available and car sharing could perhaps be made more difficult if potential sharers' working hours change.

Perhaps the greatest drawback, however, is the lack of information on the scale of effects of different strategies for spreading the peak, without which it is difficult to predict the effects of transport authorities' actions or, equally importantly, to know how transport demands will change if employers introduce flexible working hours to an increasing extent. Some information is available on the changes resulting from the introduction of staggered working hours (Selinger, 1976), flexible working hours (Sefavian and McLean, 1975, Department of Transport, 1977), area licensing (Watson, 1978) and capacity reductions (Dawson, 1979) but this information is often incomplete and more importantly, there is no informaiton on the causal process by which travellers select any particular changed time to travel.

The current project was designed to cast more light on this issue by identifying the factors influencing time of travel (in terms of constraints at workplace and home, and costs of travel) estimating the changes in time of travel which would be made if these constraints or costs were modified and predicting the effects on the transport system of such changes.

1.2 The study approach

Early work on the development of the form of model necessary to cover the behavioural aspects of the objectives demonstrated that the requirements of such a model would be well beyond the resources of the project. The study objectives were therefore modified to concentrate on the effects on traffic of given work journey rescheduling strategies.

Rather than attempt to simulate the response of firms and their employees to different types of work journey rescheduling strategy, the study makes the simplifying assumption that employees' responses to different strategies will be similar in similar types of firm, and uses the patterns of response to existing arrangements in Wakefield to estimate these responses. It then considers six strategies

(i) a base strategy representing current conditions

(ii) a 'backwards looking' strategy in which all firms work fixed hours, to test the effects of the level of rescheduling which has already occurred

(iii) a 'realistic flexible hours' strategy in which half the firms for whom flexible or internal staggered hours are feasible, but which are currently on fixed hours, reschedule their activities

(iv) a 'realistic external staggering' strategy in which half the firms on fixed hours who are unable to introduce flexible hours, but have start times near the peak, have their start times rescheduled

(v) a 'realistic rescheduling' strategy representing a combination of (iii) and (iv)

(vi) a 'maximum effect' strategy in which all firms in (iii) and (iv) reschedule their operations.

The effects on traffic patterns are then modelled in detail to provide four different levels of response of the highway system. The question of which level of response is most likely is not answered, but the results serve to indicate the importance to be placed on obtaining a clearer understanding of the behavioural processes which would determine the response.

1.3 The study area

It was decided to base the study on Wakefield, which has been identified as likely to benefit from peak spreading (Wytconsult, 1976). It was further decided to concentrate on morning peak period work trips by private car, because

(1) origin destination data was available for the study area for the a.m. peak period only
(2) work trips predominate in the a.m. peak and appear to be more amenable to spreading than education trips (Wytconsult, 1977)
(3) unlike most cities, the level of public transport provision in Wakefield is rather uniform throughout the day, so that public transport effects would have been somewhat atypical.

1.4 Report outline

Chapter 2 summarises briefly the modelling approach adopted and the surveys conducted, which are described in more detail in Montgomery and May (1983) and May, Montgomery and Wheatley (1981) respectively. Chapter 3 presents and compares results for the six strategies listed in 1.2 above. Chapter 4 draws conclusions from the results, and suggests areas in which further study is required.

2. STUDY METHOD

2.1 The basis of the study

As noted in 1.2 above, the study approach was modified in its early stages to concentrate on the effects on traffic of current levels of work journey rescheduling (by comparing strategy (ii) with the base strategy (i) and of four levels of introduction of further rescheduling (by comparing strategies (iii) to (vi) with the base strategy (i)).
The prime emphasis was on the effect on peak period traffic conditions, and in particular on the level and distribution of the following parameters throughout the peak period

(i) trip ends for selected purposes
(ii) flows across selected cordons
(iii) vehicle-km per hour in the area
(iv) vehicle-hours per hour in the area
(v) vehicle-hours per hour spent delayed and in queues in the area
(vi) average speed in the area
(vii) delays on selected parts of the area network.

In order to determine these values for existing conditions (strategy (i)), to estimate them for past conditions (strategy (ii)) and to predict them for future ones (strategies (iii)-(vi)) a study methodology was developed; this is perhaps best explained by working backwards from the required output. In this order the stages were

(a) the use of a temporally disaggregated assignment-simulation model to produce the outputs listed above
(b) production of a series of temporally disaggregated demand matrices for each of the strategies as input to (a)
(c) determination of employee arrival profiles for different types of firm and work hours arrangement as a basis for temporal disaggregation of the journey to work matrices for individual strategies
(d) conduct of surveys of employers and employees to provide the input to (c)
(e) collection of information on the supply side of the network (which was assumed fixed for all strategies) for input to the model in (a).

The following sections describe the study area and time periods used for the analysis, and then outline in turn stages (a)-(e) above.

2.2 The study area

The area in which it was assumed that rescheduling strategies would be applied was the central area of Wakefield, as defined in Figure 1. However, information was also obtained for some firms in an intermediate area, which is also shown in Figure 1.

2.3 Time periods

All network analysis was conducted on a $1\frac{1}{2}$ hour morning peak period (0745-0915) which was divided into six 15-minute periods. Employee arrivals were recorded and modelled over the period 0700-1015, but that part of the arrivals between 0745-0915 was treated as a fixed total; it was assumed that there would be no transfer of work journeys outside this period. Strategy (i) (the base strategy) was determined for spring 1981 conditions, and the same conditions in terms of overall demand and network operation were used for other strategies. This strategy (ii) represented conditions in spring 1981 if the amount of rescheduling which had by then taken place had not been implemented; strategies (iii)-(vi) represented conditions if the higher levels of rescheduling had been implemented by spring 1981. In particular all calculations were based on network conditions prior to work starting on the Chantry Bridge traffic management scheme in mid 1981, which on completion greatly reduced congestion on the southern approaches to Wakefield.

2.4 The traffic model

The model used was the Institute's simulation-assignment model, SATURN, which had been developed as an aid to the design of traffic management schemes (Van Vliet, 1982). As originally designed SATURN simply described conditions during an assumed stable peak period, and it was necessary to modify it to describe individual 15 minute periods, and to transfer conditions at the end of one period to the beginning of the next. The method for doing this is described in Chapter 4 of WP 167 (Montgomery and May, 1983).

2.5 Demand matrices

32 zones were used to cover the area modelled by SATURN; 12 of these represented the central area, 9 the intermediate area, and 11 were 'route' zones representing those trips entering or leaving the intermediate area on a particular route (see Figure 1). Vehicle trip matrices were available for the morning peak period (0745-0915) from the 1975 WYTCONSULT surveys. These matrices described trips for six separate purposes (home based work, home based other, non home based, education,

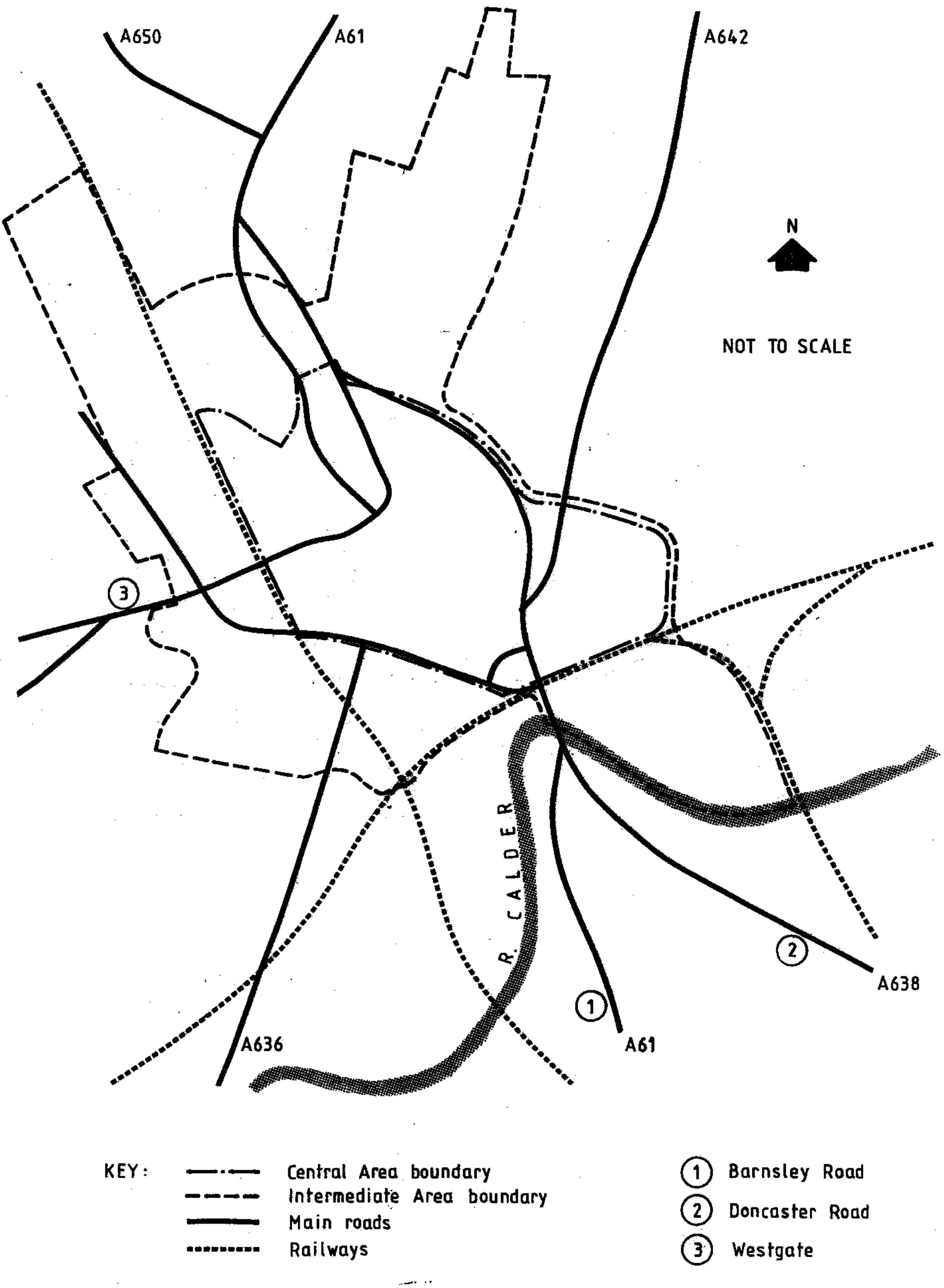


Fig. 1 The Wakefield Study Area

heavy goods vehicles and light goods vehicles) for a 129 zone system. For use in the study they first required to be aggregated to the trip purposes which were of importance to the study. Only work trips were to be rescheduled, and the home based work matrix was therefore kept separate. The other matrices were aggregated into a commercial vehicle and an 'other' matrix. The matrices were then reduced to a 32 zone system, using a cordon isolation procedure to identify trips to and from the 'route' zones and to omit those which were wholly external to the smaller study area. The matrices then required updating to 1981 and disaggregating to sets of six 15 minute trip matrices. This was predominantly carried out using a series of cordon and screenline counts conducted in 1980 (May, Montgomery and Wheatley, 1981) and the counts available from earlier years, and the matrix estimation procedure incorporated in SATURN (Willumsen, 1982). It was for this purpose that the commercial vehicle matrix was kept separate, since these were readily identifiable from traffic count data and could be expected to have a different temporal distribution from the 'other' matrix. The procedure for this complex process is fully described in Chapter 3 of WP 167 (Montgomery and May, 1983).

A different procedure was used, however, for temporal disaggregation of that part of the home based work matrix with destinations in the central and intermediate areas since variations in this disaggregation for the central area were to be the input variable to the series of test strategies. For the central area in the base strategy this was done by determining an arrival profile for each firm in each zone, aggregating these, weighted by the number of car driver work trips to each firm, to produce an overall car trip arrival profile for each zone, and using this to disaggregate the trip ends in that zone. For the intermediate area one overall profile was used for the whole area.

2.6 Employee arrival profiles

Rather than attempt to describe precisely the distribution of arrivals over time for each firm, it was decided to model these using a curve-fitting procedure which simplified data manipulation, enabled profiles for unsurveyed firms to be estimated, and provided the basis for predicting the effects of rescheduling strategies. The curve fitted was a logit function of the form

$$y = 100/(1 + e^{-\beta(x-\alpha)})$$

where x = time in minutes after midnight

y = estimated cumulative % arrived by time x

e = base of natural logarithms

α β are parameters to be calibrated.

The parameter α is closely related to the mean arrival time (in minutes after midnight) and β to the peakiness of the arrival pattern, as can be seen in the examples in Figure 2.

The α and β values obtained from individual firms were classified, and it was found that there was a clear relationship between α and type of firm (in terms of standard industrial classification) and between β and type of work hours (defined at this stage as flexible, staggered β (internally) or fixed). Table 1 summarises this evidence. For firms which were fully surveyed, their calibrated α and β parameters were used to describe the base strategy. For the others, α and β parameters were determined as follows:-

(i) SIC and type of work hours known:-

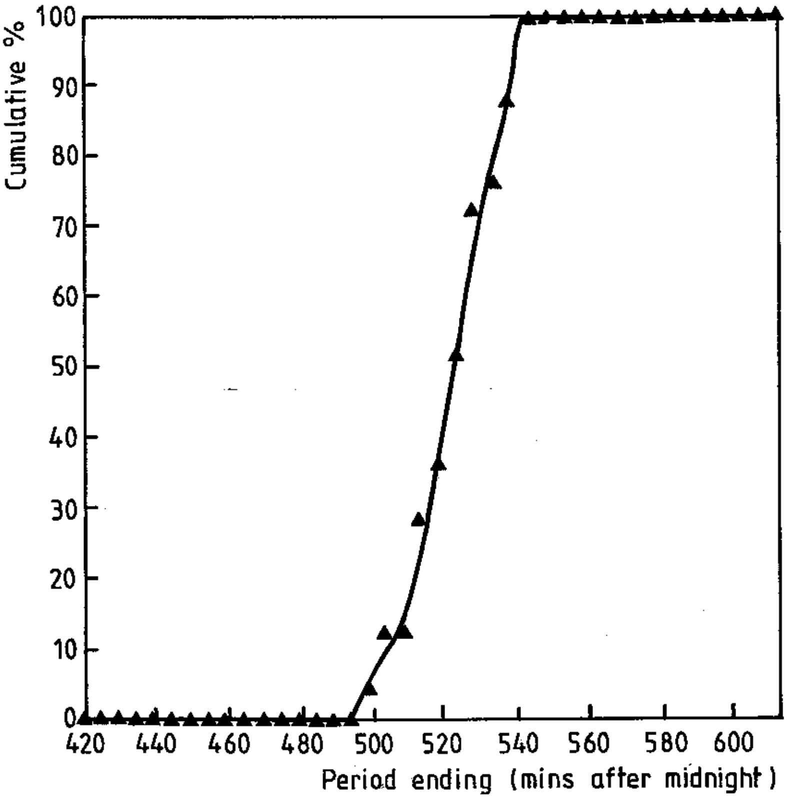
- α from firm's stated average arrival time
- β selected randomly from distribution recorded for that work hour type

(ii) SIC known, work hours type unknown:-

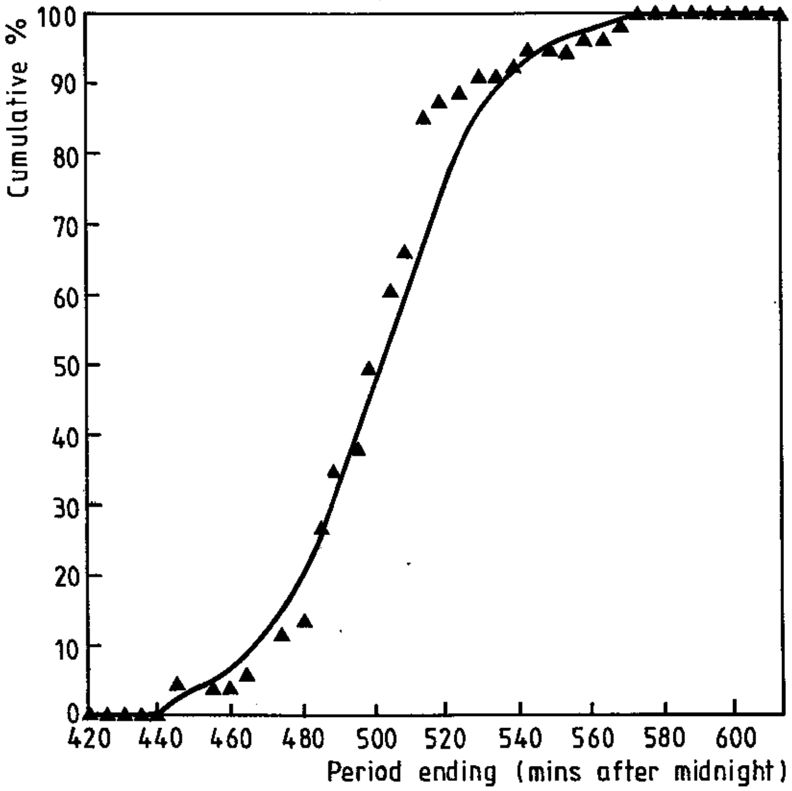
- α selected randomly from distribution recorded for that SIC type
- β by assigning a work hour type where this seemed probable from the SIC or otherwise by sampling randomly from the distribution of work hour types; then proceeding as in (i).

The procedures summarised above are fully described in Chapter 2 of WP 167 (Montgomery and May, 1983).

In order to produce modified disaggregated work matrices for the other strategies, the α and β parameters of selected firms in the central area were modified. The adjustments made were as follows:-



(a) Firm 86: $\alpha = 525.7$, $\beta = 0.1535$



(b) Firm 88a: $\alpha = 500.6$, $\beta = 0.0784$

Fig. 2 Examples of arrival profiles

TABLE 1: α and β values for surveyed firms by dominant work hour type (car arrivals only).

FIXED HOURS			FLEXIBLE/INTERNAL STAGGERED HOURS		
FIRM NO.	α	β	FIRM NO.	α	β
18	527.2	.0794	22	500.8	.0471
66	503.5	.1073	30	554.8	.0565
83	519.7	.0934	44a	496.2	.0860
86	525.7	.1535	64	514.5	.0592
113b	506.1	.0823	67a	510.8	.0697
114b	500.2	.1395	88a	500.6	.0784
121	509.0	.1366	113a	504.9	.0758
127	506.7	.1386	114a	499.6	.0674
136	506.7	.1077	67b	507.7	.0890
UNWEIGHTED AVERAGE		.1154	UNWEIGHTED AVERAGE		.0699

Strategy (ii): all firms currently on flexible or internally staggered hours were returned to fixed hours by increasing β by 0.0455 (the difference between the unweighted mean values of β for fixed hour firms and other firms: Table 1).

Strategy (iii): an assessment was made of firms for which flexible or staggered hours were feasible; half of these were selected randomly as being cooperative and their β value reduced by 0.0455.

Strategy (iv): those firms for which flexible or staggered hours were considered infeasible in (iii) were identified; half of these were selected randomly as being cooperative to external staggering, and their α values were increased by between 5 and 15 minutes, to enable their arrival times, which were all after the overall average arrival time, to be suitably spread.

Strategy (v): was simply a combination of strategies (ii) and (iv).

Strategy (vi): the procedures in strategies (iii) and (iv) were applied to all firms (with no allowance for lack of cooperation).

The basis for these adjustments is described more fully in Chapter 5 of WP 167 (Montgomery and May, 1983).

2.7 Employer and employee surveys

A two stage process was used to obtain information from firms in Wakefield. The first was a questionnaire distributed to all known firms with 15 or more employees in the central area of Wakefield, and a limited number of firms in the intermediate area. The questionnaire sought information on the numbers of staff, by employment category, working fixed, internally staggered and flexible hours, and the hours of operation of the various work hour arrangements. The numbers of firms and employees in the central area had initially to be estimated from the 1976 census of employment, but were later adjusted in the light of questionnaire returns. Only 42% of the estimated 112 employers completed the questionnaire, but these represented 64% of the estimated 5432 employees. All but four of the 12 SICs in central Wakefield were well represented in the survey, and the intermediate area firms surveyed were selected in an attempt to fill these gaps, as well as to provide overall information for work hour patterns in the intermediate area. After expanding the data by SIC to represent conditions for all central area employees, the result indicated that, in the base strategy:-

38% worked fixed hours
43% worked internally staggered hours
18% worked flexible hours
1% worked rotating shifts.

57% of the responding employers agreed to a survey of their employees, which formed the second stage of the survey process and involved a questionnaire to determine the characteristics of the journey to work on the survey day, and the times of arrival at, and departure from work on the previous five weekdays. A 36% response rate was obtained, and of the respondents:-

67% arrived by car
20% arrived by bus
8% arrived before 0800
23% arrived between 0800 and 0815
26% arrived between 0815 and 0830
20% arrived between 0830 and 0845
12% arrived between 0845 and 0900
7% arrived after 0900
4% were not at work during the survey period.

The arrival patterns for individual firms were input directly into the curve-fitting procedure described in Section 2.6 above, and these results were applied to the firms for which no employee survey was conducted.

A fuller discussion of the survey methods, results and implications of the response rate is given in WP 150 (May, Montgomery and Wheatley, 1981).

2.8 Network data

In order to calibrate SATURN and to disaggregate the trip matrices, traffic surveys were conducted in November 1980 to obtain

- classified counts of inbound and outbound traffic crossing two cordons, one surrounding the central area and the other surrounding the intermediate area.
- travel times and delays by fifteen minute time period on selected links in the network, using registration number matching surveys on three corridors.

The results of the first of these are presented in WP 150 (May, Montgomery and Wheatley, 1981) and of the second in WP 167 (Montgomery and May, 1983).

3. STUDY RESULTS

3.1 Form of the results

As noted in 2.1 above, the following information was produced for each of the six strategies for the six 15-minute time periods between 0745 and 0915:

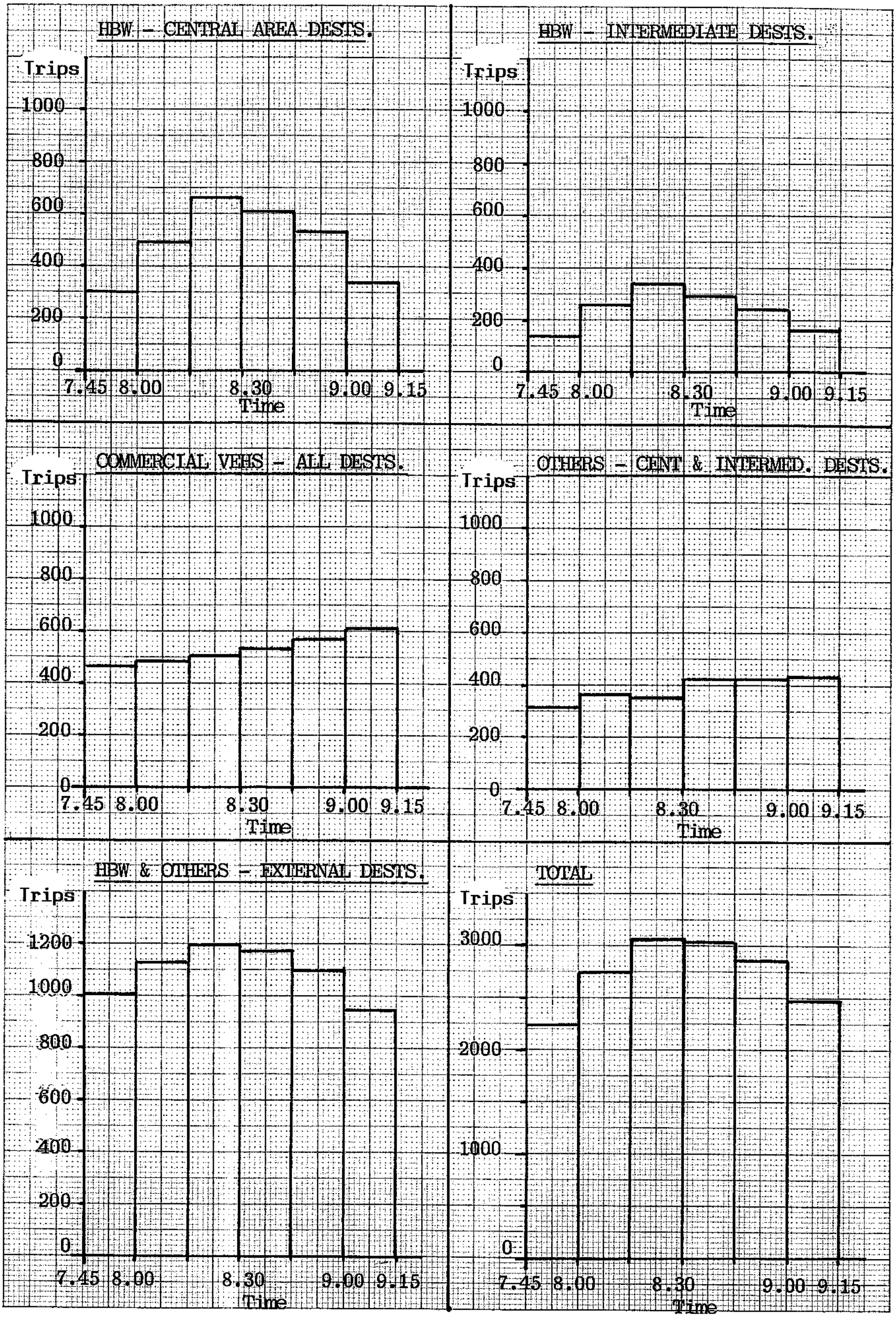
(i) trip ends for selected purposes
(ii) flows across selected cordons
(iii) vehicle km. per hour in the area
(iv) vehicle hours per hour in the area
(v) vehicle hours per hour spent delayed and in queues in the area
(vi) average speed in the area
(vii) delays on selected parts of the network.

The following sections present these results in turn.

3.2 Trip ends

Figure 3 indicates the size of the total car-driver trip matrix for each of the six time periods in the base strategy ((i)), and the main components of those matrices. The number of trips in the total matrix is highest between 0815 and 0845 at just over 3000 trips per 15-minute period. The two adjacent periods have 5% and 8% fewer trips, and the two 'shoulder' periods 17% and 25% fewer trips, providing considerable opportunities for peak spreading. The pattern is more marked with the

FIGURE 3. STRATEGY (i): CAR DRIVER TRIP PROFILES BY PURPOSE



home based work trips to central area destinations which are the target of rescheduling strategies. These have a 15 minute peak of 660 trips between 0815 and 0830, and 'shoulder' periods 48% and 55% lower. However, they are a relatively small part of the total trip matrix; even in the peak 15 minutes they only represent 22% of all trips, and trips to external destinations, most of them through trips, predominate at 40%. This clearly limits the ability of peak spreading strategies to improve conditions in the city.

Figure 4 and Table 2 present for all six strategies the trip profiles for home based car driver trips to work in the central area; it is the variations in these which provide the input to the model for each strategy. Comparison of strategies (i) and (ii) demonstrates the effect of rescheduling strategies to date.

Without the current level of flexible and internally staggered work hours, the 15 minute peak would have been 15% higher than it now is; most of this has been transferred to periods 5 and 6, from 0845 to 0915.

Strategy (iii) (cooperative flexible hours) only reduces the peak 15-minute trips by 3%, and produces similar small reductions in the subsequent two periods (0830-0900). Most of the increase takes place in the final period, which increases by 14%.

Strategy (iv) (cooperative external staggering) has a slightly smaller effect on the peak 15-minute period, but reduces the two subsequent periods (0830-0900) by 7% and 10% respectively. All the increase occurs in the final period, which experiences a 33% trip increase. This apparently uneven effect is a result of the current timings of those firms which are required to work fixed hours.

Strategy (v) is the combined effects of strategies (iii) and (iv). Strategy (vi) extends the changes to all firms (excluding retail and educational establishments) and hence produces the largest response. Trips in the peak 15-minute period fall by 11% and in the subsequent two

FIGURE 4. CAR DRIVER TRIP PROFILES: HOME BASED WORK TRIPS TO THE CENTRAL AREA

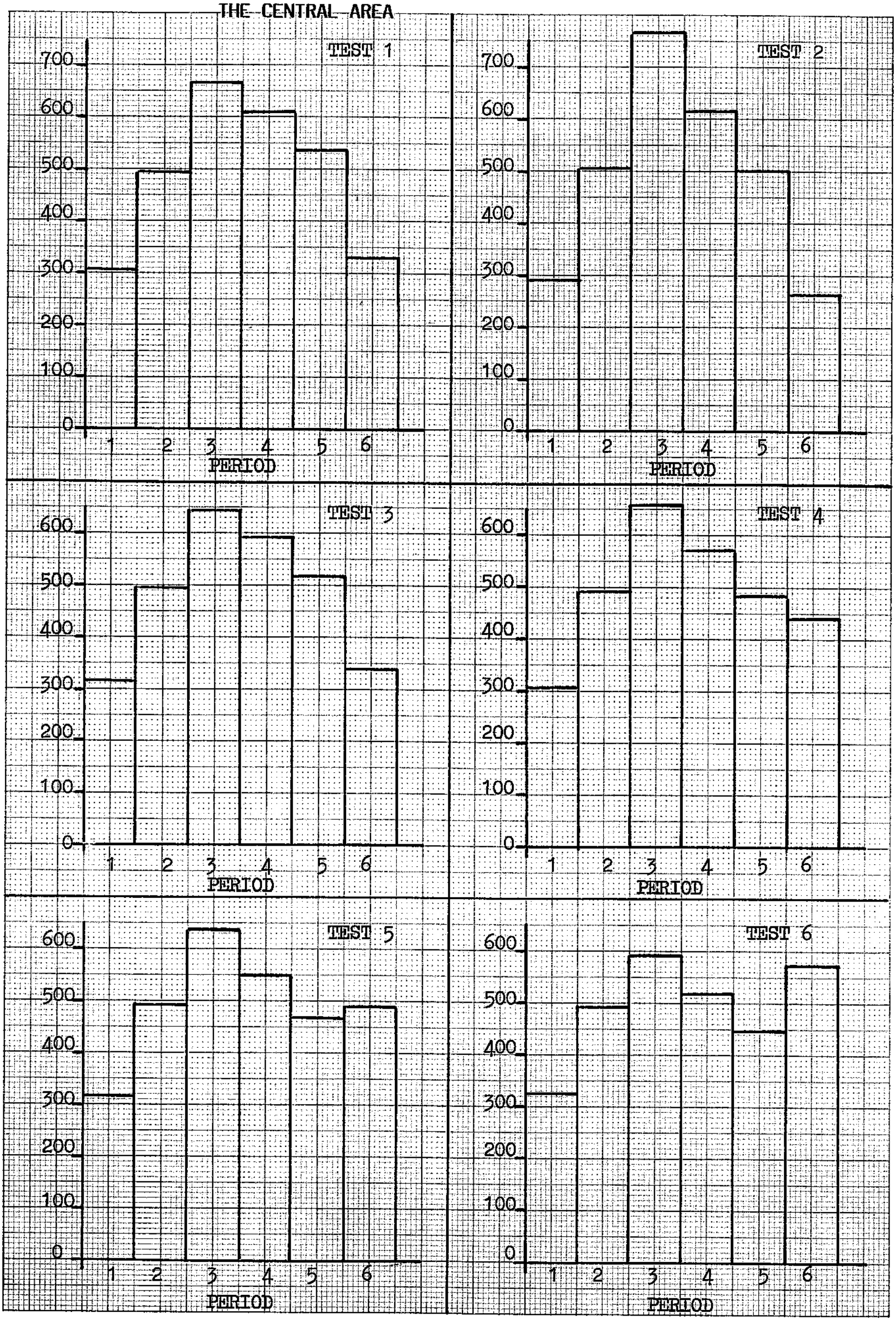


TABLE 2. Home based car driver work trips to the central area by time period and strategy.

Strategy	(i)		(ii)		(iii)		(iv)		(v)		(vi)	
	Trips	% of (i)	Trips	% of (i)	Trips	% of (i)	Trips	% of (i)	Trips	% of (i)	Trips	% of (i)
0745 - 0800	305	100	289	95	315	103	305	100	314	100	323	106
0800 - 0815	494	100	508	103	493	100	491	99	490	99	489	99
0815 - 0830	664	100	763	115	645	97	653	98	634	95	593	89
0830 - 0845	610	100	613	100	591	97	567	93	549	90	516	85
0845 - 0900	533	100	502	94	516	97	481	90	464	87	445	83
0900 - 0915	331	100	262	79	377	114	439	133	485	147	572	173
TOTAL	2937	-	2937	-	2937	-	2937	-	2937	-	2937	-

periods by 15% and 17%. They increase by 73% in the final period and by 6% in the first period. As a result periods 3 and 6 have very similar numbers of trips, but the profile is still very peaked. This result appears largely to be the effect of the emphasis on flexible hours, which themselves give greater freedom to the employee to continue travelling at the height of the peak. A strategy based on a higher proportion of external staggering might have provided a useful theoretical test of a greater degree of peak spreading; however such a policy would almost certainly be less acceptable to the employers and employees concerned.

Figure 5 presents the effects of the strategies on the total trip matrix; since central area work trips are never more than a quarter of the total the effects are necessarily small. The highest 15-minute trip matrix is increased by 3% in strategy (ii) and reduced by 2% in strategy (vi). It is also noticeable that although the trip matrix in the final period (0900-0915) is increased by almost 10%, the total trip profile has only one peak (0815-0830) as opposed to the two in Figure 4.

3.3 Cordon flows

The most interesting cordon crossing flows to study are those inbound across the inner (central area) cordon. The results are shown in Figure 6 and Table 3.

The base strategy (i) has two virtually identical peak 15 minute periods between 0815 and 0845, each taking 19% of the total 1½ hour flow. Without the current level of flexible working and internal staggering (strategy (ii)), it is estimated that flows in the first of these periods (0815-0830) would have been 6% higher; in the previous period (0800-0815) there would have been a 9% increase.

The results for the other strategies are similar in form to, but not as marked as the effects of those strategies on central area work trip ends. Strategy (iv) (external staggering) is slightly more effective than strategy (iii) in reducing the peak 15-minute flow, though neither achieves more than a 3% reduction. Strategy (v) which combines them

FIGURE 5. CAR DRIVER TRIP PROFILES: TOTAL TRIPS

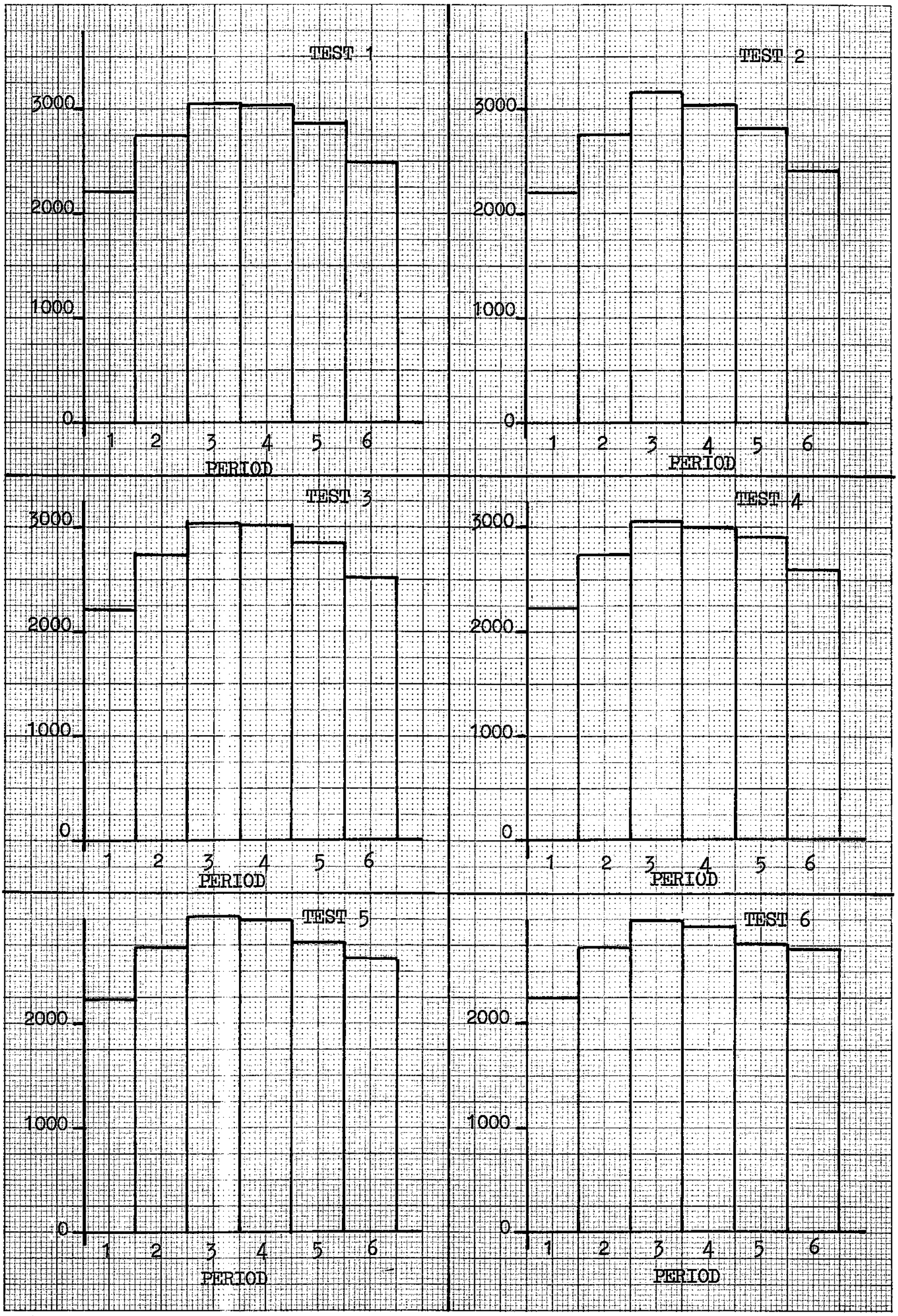


FIGURE 6. CAR DRIVER TRIP PROFILES: INBOUND MOVEMENTS ACROSS THE INNER CORDON

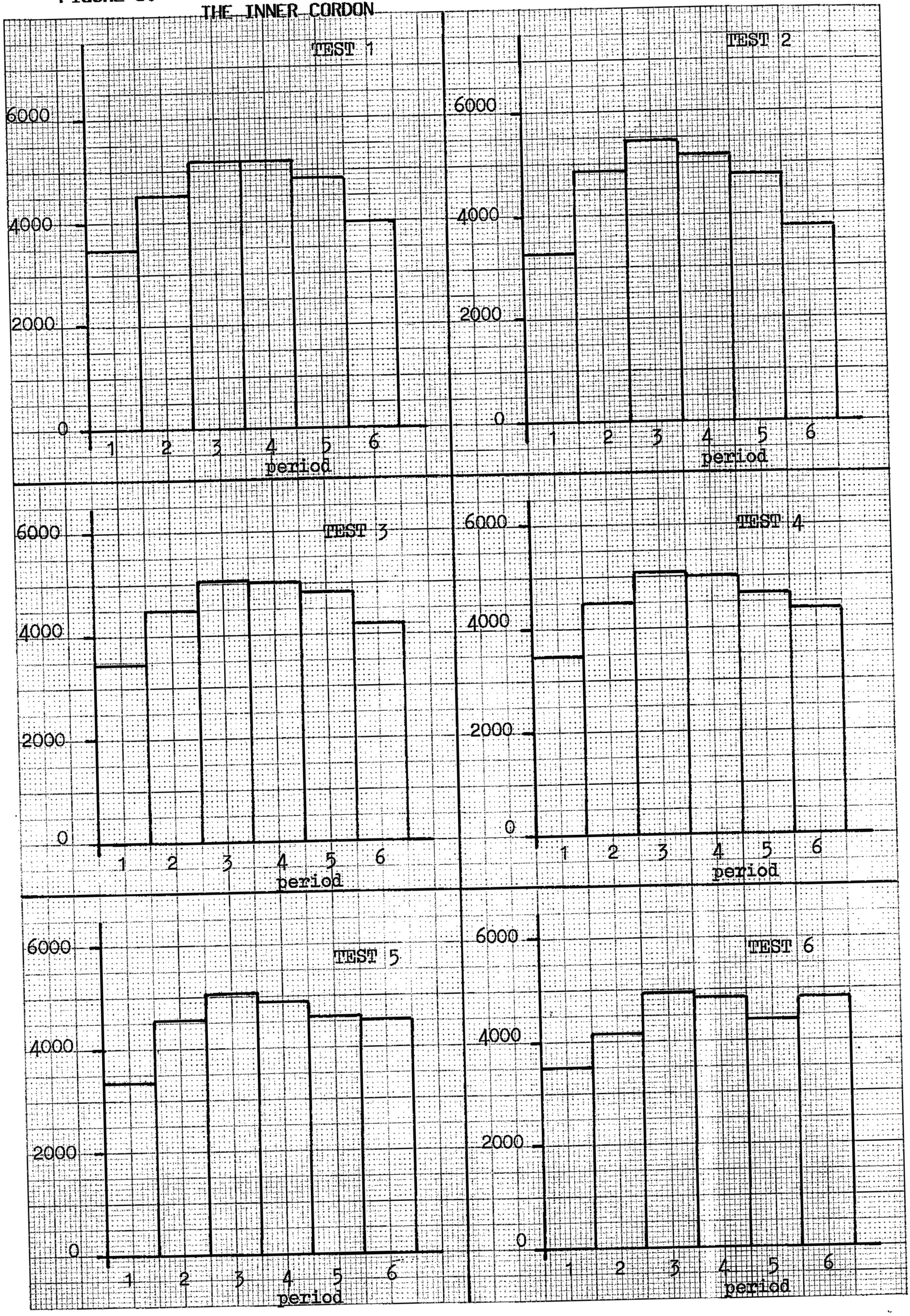


TABLE 3. Car driver trips crossing the inner cordon inbound, by time period and strategy.

Strategy	(i)		(ii)		(iii)		(iv)		(v)		(vi)	
	Trips	% of (i)	Trips	% of (i)	Trips	% of (i)	Trips	% of (i)	Trips	% of (i)	Trips	% of (i)
Time Period												
0745 - 0800	3463	100	3283	95	3465	100	3457	100	3352	97	3532	102
0800 - 0815	4506	100	4888	109	4525	100	4534	101	4555	101	4167	92
0815 - 0830	5175	100	5482	106	5096	98	5084	98	5051	98	4944	95
0830 - 0845	5192	100	5161	99	5068	98	5013	97	4924	95	4826	93
0845 - 0900	4877	100	4775	98	4816	99	4680	96	4622	95	4474	92
0900 - 0915	3979	100	3727	94	4213	106	4370	110	4529	114	4816	121
TOTAL	27192	100	27316	100	27183	100	27138	100	27033	99	26759	98

produces a 5% reduction. Strategy (vi) which applies flexible hours or external staggering to all firms reduces the peak 15 minute period by 7% and the other periods between 0800 and 0900 by up to 8.3%. The flow in the first period is increased by 2.0% and that in the last by 21.0% providing a second peak in the flow profile. Once again more emphasis on external staggering might have produced a more even distribution, though it would be a less popular option.

Comparison of these results with those to Figure 4 and Table 2 emphasises the point that the effects of work journey rescheduling become progressively less pronounced further from the workplace. The percentage changes in peak 15-minute cordon flow (Table 3) are typically only 40% to 50% of the percentage changes in peak 15-minute central area work trips.

3.4 Vehicle-kilometres per hour

Since a fixed total matrix is being assigned in the six strategies, vehicle kilometres will only change to the extent that longer routes are taken to avoid congested locations. Tables 4 to 9 present the vehicle kilometres per hour by time period for each of the six strategies, and Table 10 the summary statistics for the 1½ hour period for all strategies. It can be seen from Table 10 that all the vehicle-kilometre per hour figures are well within one percent of each other, although surprisingly vehicle kilometres per hour increase as the peak is spread. Comparing the peak 15-minute values, vehicle-kilometres per hour are 2½% higher in strategy (ii) than strategy (i), and 1% lower in strategy (vi). These small changes, of course, mask larger changes within the central area.

3.5 Vehicle-hours per hour

While vehicle-kilometres are unlikely to change much, work journey rescheduling might be expected to reduce total time spent in the network, if drivers are as a result able to avoid travelling in congested conditions. The results are again presented in Table 4-10. These show, surprisingly, an even smaller effect than that for vehicle-kilometres. Strategy (ii) has a 1% increase over strategy (i); strategy (vi) a ½% reduction.

TABLE 4. Network performance statistics: strategy (i)

STATISTIC	TIME PERIOD						
	1 0745-0800	2 0800-0815	3 0815-0830	4 0830-0845	5 0845-0900	6 0900-0915	TOTAL 0745-0915
DELAYED TIME (VEH-HRS/HR)	62	83	105	102	91	68	85
QUEUED TIME (VEH-HRS/HR)	4	59	132	122	87	5	68
FREE RUN TIME (VEH-HRS/HR)	324	389	424	421	398	353	385
TRAVEL TIME (VEH-HRS/HR)	390	531	660	645	575	426	538
TRAVEL DISTANCE (VEH-KMS/HR)	10693	12862	13978	13832	13084	11631	12680
AVERAGE SPEED (KM/HR)	27.4	24.2	21.2	21.5	22.8	27.3	23.6

TABLE 5. Network performance statistics: strategy (ii)

STATISTIC	TIME PERIOD						
	1 0745-0800	2 0800-0815	3 0815-0830	4 0830-0845	5 0845-0900	6 0900-0915	TOTAL 0745-0915
DELAYED TIME (VEH-HRS/HR)	61	84	112	102	90	66	86
QUEUED TIME (VEH-HRS/HR)	4	58	158	123	84	4	72
FREE RUN TIME (VEH-HRS/HR)	323	391	435	421	395	345	385
TRAVEL TIME (VEH-HRS/HR)	388	533	705	647	569	415	543
TRAVEL DISTANCE (VEH-KMS/HR)	10638	12936	14311	13829	12971	11363	12675
AVERAGE SPEED (KM/HR)	27.4	24.3	20.3	21.4	22.8	27.4	23.3

TABLE 6. Network performance statistics: strategy (iii)

STATISTIC	TIME PERIOD						
	1 0745-0800	2 0800-0815	3 0815-0830	4 0830-0845	5 0845-0900	6 0900-0915	TOTAL 0745-0915
DELAYED TIME (VEH-HRS/HR)	62	83	103	100	89	70	85
QUEUED TIME (VEH-HRS/HR)	4	60	125	114	79	14	66
FREE RUN TIME (VEH-HRS/HR)	325	390	423	418	397	358	385
TRAVEL TIME (VEH-HRS/HR)	391	533	651	633	565	443	536
TRAVEL DISTANCE (VEH-KMS/HR)	10736	12872	13935	13751	13033	11805	12689
AVERAGE SPEED (KM/HR)	27.4	24.2	21.4	21.7	23.1	26.7	23.7

TABLE 7. Network performance statistics: strategy (iv)

STATISTIC	TIME PERIOD						
	1 0745-0800	2 0800-0815	3 0815-0830	4 0830-0845	5 0845-0900	6 0900-0915	TOTAL 0745-0915
DELAYED TIME (VEH-HRS/HR)	62	83	105	100	88	73	85
QUEUED TIME (VEH-HRS/HR)	4	56	137	118	77	24	69
FREE RUN TIME (VEH-HRS/HR)	324	390	422	416	394	364	385
TRAVEL TIME (VEH-HRS/HR)	389	529	663	634	559	461	539
TRAVEL DISTANCE (VEH-KMS/HR)	10689	12881	13897	13691	12972	12000	12688
AVERAGE SPEED (KM/HR)	27.5	24.4	21.0	21.6	23.2	26.0	23.5

TABLE 8. Network performance statistics: strategy (v)

STATISTIC	TIME PERIOD						
	1 0745-0800	2 0800-0815	3 0815-0830	4 0830-0845	5 0845-0900	6 0900-0915	TOTAL 0745-0915
DELAYED TIME (VEH-HRS/HR)	62	83	103	99	86	76	85
QUEUED TIME (VEH-HRS/HR)	4	59	125	114	69	33	68
FREE RUN TIME (VEH-HRS/HR)	325	389	422	415	393	369	385
TRAVEL TIME (VEH-HRS/HR)	391	531	649	628	548	478	538
TRAVEL DISTANCE (VEH-KMS/HR)	10734	12842	13883	13667	12935	12130	12698
AVERAGE SPEED (KM/HR)	27.4	24.2	21.4	21.8	23.6	25.4	23.6

TABLE 9. Network performance statistics: strategy (vi)

STATISTIC	TIME PERIOD						
	1 0745-0800	2 0800-0815	3 0815-0830	4 0830-0845	5 0845-0900	6 0900-0915	TOTAL 0745-0915
DELAYED TIME (VEH-HRS/HR)	62	83	99	97	85	81	85
QUEUED TIME (VEH-HRS/HR)	4	56	108	103	65	55	65
FREE RUN TIME (VEH-HRS/HR)	326	389	420	413	391	378	386
TRAVEL TIME (VEH-HRS/HR)	392	528	627	612	541	514	536
TRAVEL DISTANCE (VEH-KMS/HR)	10781	12848	13836	13579	12853	12433	12722
AVERAGE SPEED (KM/HR)	27.5	24.3	22.1	22.2	23.7	24.2	23.7

TABLE 10. Summary network performance statistics, 0745-0915.

STATISTIC	STRATEGY					
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
DELAYED TIME (VEH-HRS/HR)	85	86	85	85	85	85
QUEUED TIME (VEH-HRS/HR)	68	72	66	69	68	65
FREE RUN TIME (VEH-HRS/HR)	385	385	385	385	385	386
TRAVEL TIME (VEH-HRS/HR)	538	543	536	539	538	536
TRAVEL DISTANCE (VEH-KMS/HR)	12680	12675	12689	12688	12698	12722
AVERAGE SPEED (KM/HR)	23.6	23.3	23.7	23.5	23.6	23.7

The SATURN model does, however, also permit the vehicle-hours to be categorised as time spent delayed, in queues, and travelling freely. Delay is defined as time spent moving at less than the free running speed for the link and queued time is defined as time spent stopped.

Again the results are presented in Tables 4-10. Changes in delay are as small as those in total travel time, but the results for time spent in queues show a more marked effect. Strategy (ii) involves a 5½% increase over strategy (i) in time spent in queues, while strategy (vi) produces a 4% reduction. For the peak 15-minute period, time spent in queues rises by 20% in strategy (ii) and falls by 18% in strategy (vi). Strategy (vi) also produces a much more even distribution of time spent in queues throughout the peak, with 14% of the queued time in the final 15-minute period, as compared with 1½% in strategy (i) and 1% in strategy (ii). These results suggest that the beneficial effects on energy consumption and environmental intrusion might be more marked than those on travel time.

3.6 Average speed

The final statistic provided in Tables 4-10 is average speed, determined as the ratio of vehicle-kilometres per hour to vehicle-hours per hour. Since neither of these parameters changed significantly, neither does average speed, which for the 1½ hour period as a whole ranges from 23.3 km/h in strategy (ii) to 23.7 km/h in strategy (vi). Again strategy (vi) produces far greater uniformity; in the final five periods the range in average speed is only 2.1 km/h as opposed to 6.1 km/h in strategy (i) and 7.1 km/h in strategy (ii). The main cause of this is the substantial rescheduling into the final period, as a result of which its speed in strategy (vi) is 11% lower than in strategy (i).

3.7 A network performance curve

Finally it is interesting to plot the values for vehicle-hours and vehicle-km for each time period in each strategy as an indication of network performance. These points need not necessarily lie on one curve, because they represent different trip matrices, and hence distributions of demand. However as Figure 7 indicates, they do appear to lie on one curve, with the possible exception of the first time period, which appears to have a lower speed than might be expected. The expected shape of such a network performance curve is concave upwards, up to the point at which network capacity in vehicle-kilometres per hour is reached, at which the curve has a vertical tangent and becomes backward sloping. It is clear that the network as a whole is operating at considerably below capacity. Indeed the part of the curve through the range of data is virtually linear, and as a result redistribution of a fixed number of vehicle-kilometres over time has little effect on vehicle-hours. Further weight is given to this analysis by an earlier test conducted in the model development stage of the project, in which the base 1½ hour matrix was factored by between 0.90 and 1.15 and assigned to the network. No temporal disaggregation was used, and the network performance curves are therefore not comparable. However Figure 8 presents the results of these tests, in which the more rapid increase in travel time at factors in excess of 1.10 can be clearly seen. This suggests that demand in vehicle-kilometres per hour on the Wakefield network might need to increase by about 10% before peak spreading could have a significant effect in reducing vehicle hours per hour on the network.

3.8 Delays at specific locations

While the effect of rescheduling over the network as a whole is limited, it could be expected that the effect on those locations operating most closely to capacity would be greater. By far the most congested locations at the time of the study were the Barnsley Road and Doncaster Road approaches to Chantry Bridge (Figure 1) where a major traffic management scheme has since relieved conditions. Another less serious congestion point was the Westgate corridor (Figure 1). The SATURN model was used to produce estimates of average delay, in seconds per vehicle on each of these approaches. The average delays, calcualted for the last cycle of each period, are presented in Tables 11-13. While the delays on Westgate scarcely vary from period to period or strategy to strategy (Table 13), those on Doncaster Road and Barnsley Road vary markedly, and in broadly the same way. Figures 9 and 10 present these variations for the two routes for strategies (i) (ii) and (vi). Without the existing level of peak

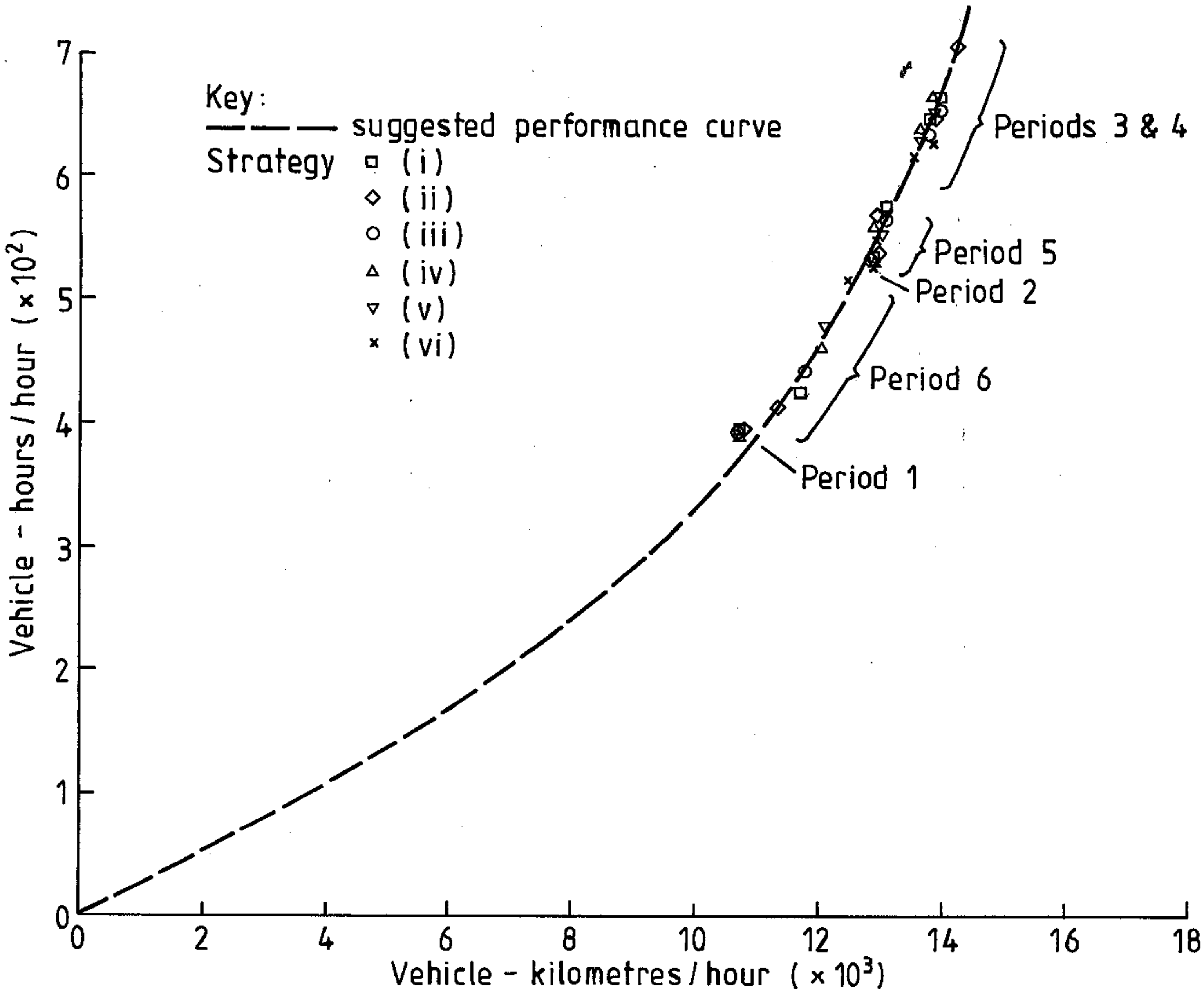


Fig. 7 A network performance curve for Wakefield

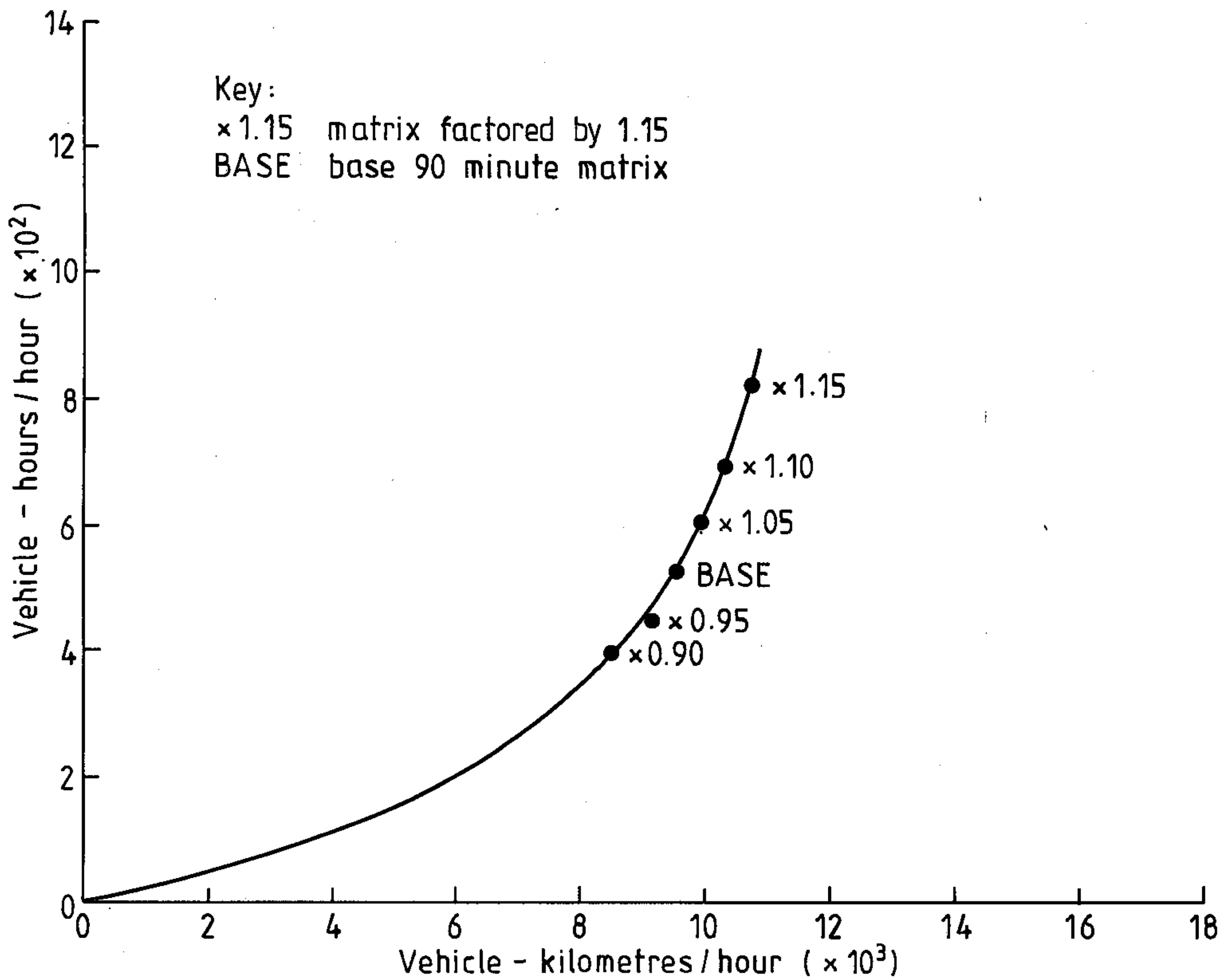


Fig. 8 Network performance curve: the effect of matrix factoring

TABLE 11. Average delays (in seconds per vehicle) on Doncaster Road.

Strategy	(i)	(ii)	(iii)	(iv)	(v)	(vi)
0745 - 0800	23	23	23	23	23	23
0800 - 0815	95	95	94	95	93	94
0815 - 0830	235	262	225	232	221	192
0830 - 0845	206	201	192	190	177	160
0845 - 0900	132	122	119	113	100	92
0900 - 0915	23	23	23	23	28	73

TABLE 12. Average delays (in seconds per vehicle) on Barnsley Road.

Strategy	(i)	(ii)	(iii)	(iv)	(v)	(vi)
0745 - 0800	26	26	26	26	26	26
0800 - 0815	82	82	79	80	78	79
0815 - 0830	205	238	195	200	190	176
0830 - 0845	189	188	184	170	164	146
0845 - 0900	121	111	117	97	93	80
0900 - 0915	26	26	26	27	27	65

TABLE 13. Average delays (in seconds per vehicle) on Westgate

Strategy	(i)	(ii)	(iii)	(iv)	(v)	(vi)
0745 - 0800	22	22	22	20	22	22
0800 - 0815	24	24	24	24	24	24
0815 - 0830	27	28	27	26	26	26
0830 - 0845	27	27	26	26	26	25
0845 - 0900	25	25	25	25	25	25
0900 - 0915	23	23	24	24	24	25

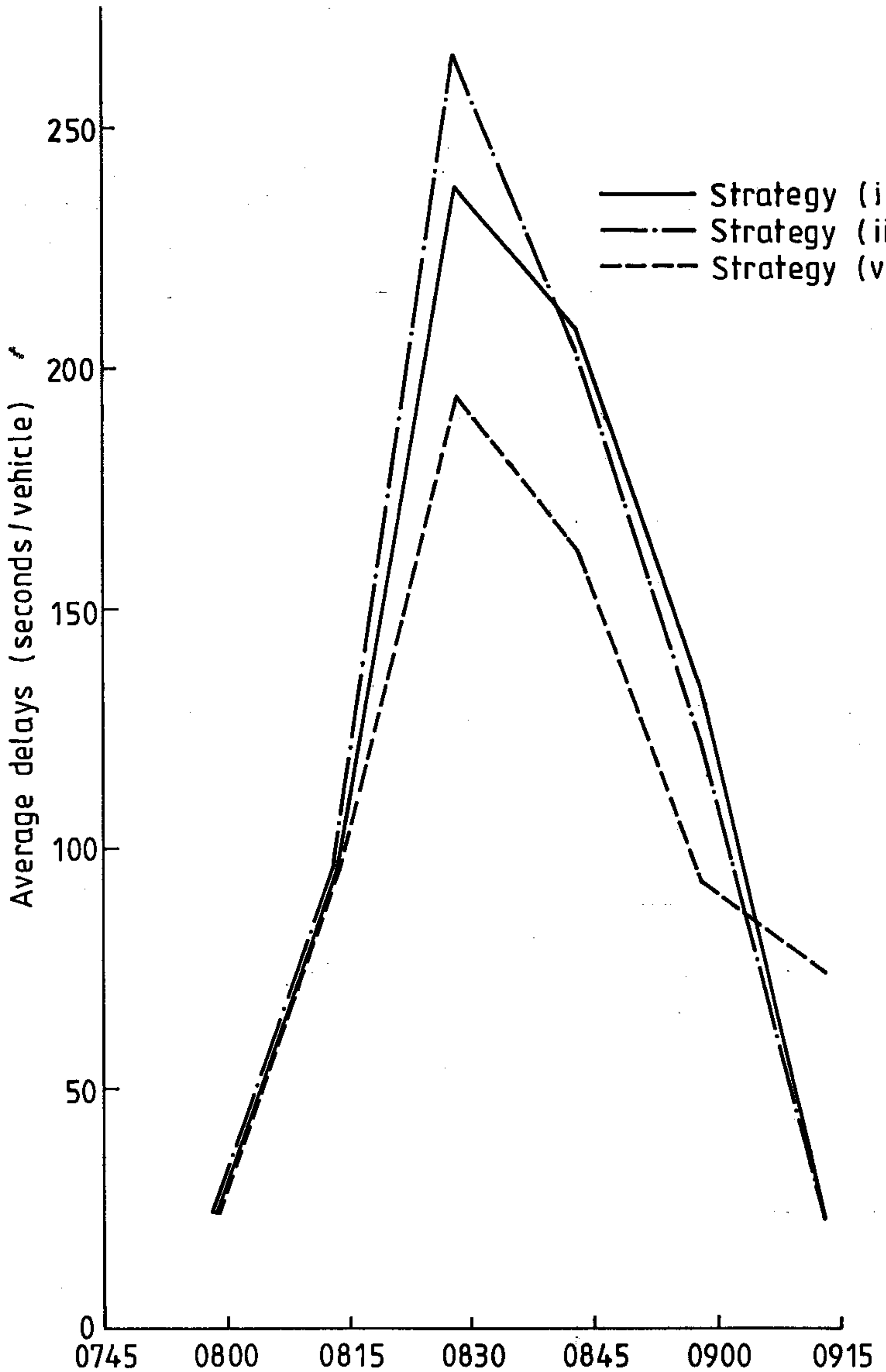


Fig. 9 Average delays on Doncaster Road

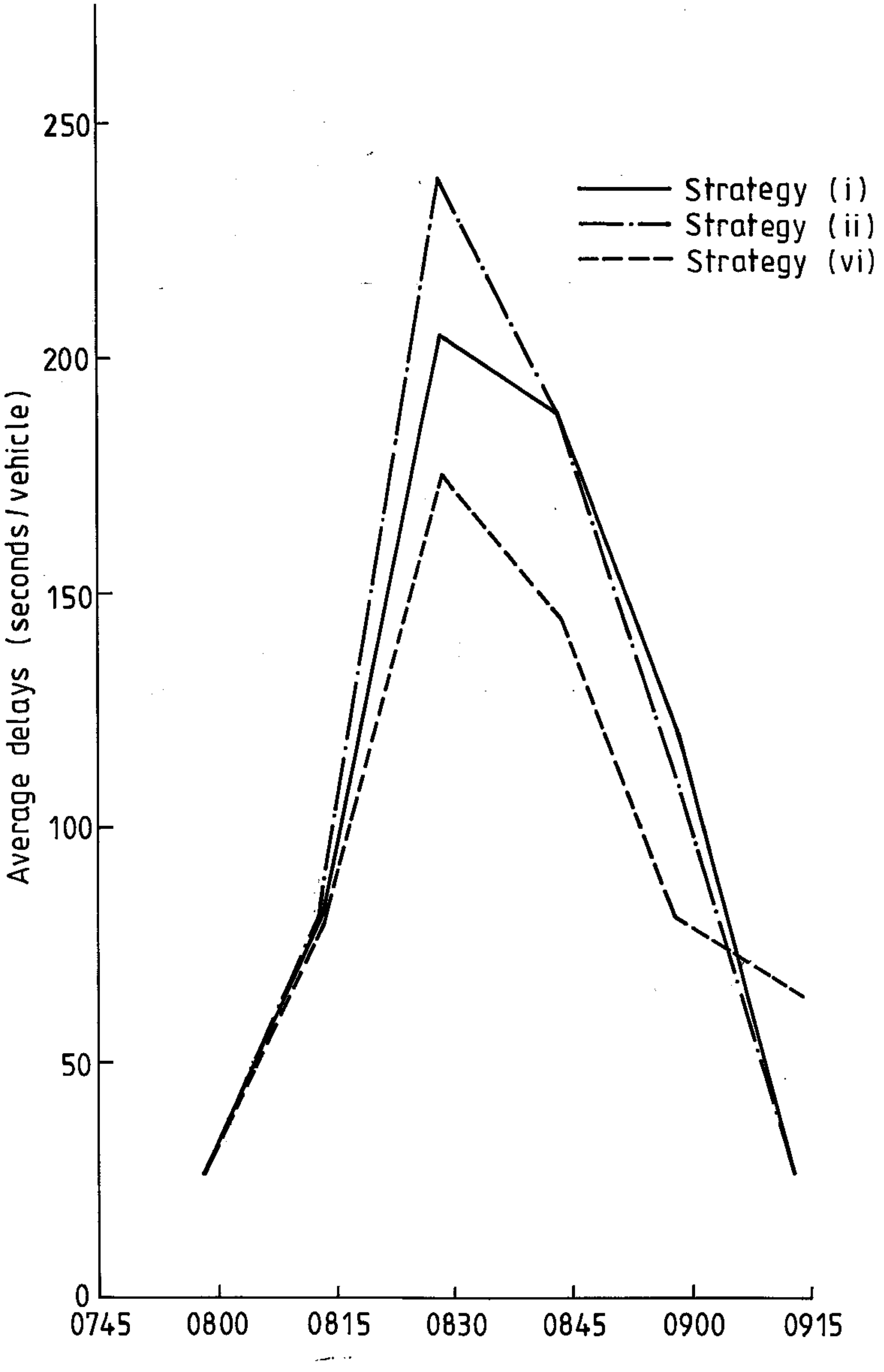


Fig. 10 Average delays on Barnsley Road

spreading (strategy (ii)) the average delay at 0830 would have been 11% higher on Doncaster Road and 16% higher on Barnsley Road, but delays at other times would have been little different from the base situation (strategy (i)). Of the rescheduling strategies, the flexible hours one (strategy (iii)) is better able to reduce the peak delay, while the external staggering one (strategy (vi)) has more effect on the subsequent two periods. Their combined effect (strategy (v)) produces reductions of average delays on the two approaches of around 7% at 0830, 14% at 0845 and 24% at 0900. The most extensive rescheduling strategy (strategy (vi)) produces reductions at the above times on the two approaches of 16%, 22% and 32% respectively, but increases the delay at the end of the final period.

4. CONCLUSIONS

4.1 Introduction

This section summarises the results of the study, and draws conclusions from them. Section 4.2 presents the conclusions for the policy of peak spreading, some of which are specific to Wakefield, and others of which can be drawn more generally. For completeness, Section 4.3 reproduces the conclusions for analysis methodology which are drawn in and based on the Working Paper on study methodology (Montgomery and May, 1983).

4.2 Policy conclusions

4.2.1 At the time of the survey in Wakefield, 18% of employees worked flexible hours, and a further 42% worked internally staggered hours. As indicated below, this existing level of variation in work hours has already had some impact on peak period travel conditions. This seems likely to be the case in most larger urban areas.

4.2.2 The opportunities for further rescheduling of work journeys are therefore limited. It was estimated that of the 38% of employees currently working fixed hours in Wakefield, 60 % could in theory work flexible or internally staggered hours; for the remainder any change would have to be made at the level of the firm as a whole. In practice, of course, the level of further rescheduling will be less than this, unless means can be found to require changes of those employers who are not prepared voluntarily to change their working arrangements.

4.2.3 Despite this, there is still room for considerable rescheduling of work trips to Wakefield's central area. The peak 15 minute period there accounts for 22% of the 1½ hour peak's work trips, and these trips are around double the work trip flows in the shoulders of the peak. Unfortunately, though, the effect of a flattening of this peak would to a large extent be lost in the overall trip matrix, which is over four times the size of the central area work trip matrix. These results are likely to be mirrored in many medium sized urban areas.

4.2.4 The combined effect of the conclusions in 4.2.2 and 4.2.3 was seen in the effect of the proposed rescheduling strategies on the trip matrices. Were the current level of peak spreading to be removed, the peak 15 minute work trips to the central area would increase by 15%, and the total trips in Wakefield by 3%. Were the most extensive rescheduling strategy to be introduced, reductions of 11% and 2% respectively would be achieved.

4.2.5 It is particularly interesting to note (Figure 4) that even this most extensive policy does not produce an even distribution of work trips across the peak period. The main reason for this appears to be the existence of flexible hours schemes, which enable employees to continue travelling at the height of the peak if they wish. However, this result must be treated with caution, since the study is based on the assumptions that current flexible hours workers' choices of travel time will be maintained even if the time of the peak changes. This clearly is an issue which merits further study. Meanwhile, it can at least be deduced that a more certain way of achieving a higher amount of peak spreading would be to introduce a series of more rigid internal and external staggering schemes. These however would be less likely to be popular with employees.

4.2.6 Inevitably the effects of rescheduling become less pronounced further from the workplace. This is demonstrated in a comparison of the effects on central area work trips (Figure 4 and Table 2) and on traffic entering the central area (Figure 6 and Table 3). The changes in the latter follow those of the former, but are typically only 40% to 50% as great.

4.2.7 Most network performance parameters (vehicle-km/hr, vehicle-hours/hr, delayed vehicle hours/hr and average speed)are affected to an insignificant extent by any of the rescheduling strategies (or by the amount of peak spreading which has already taken place). The only exception is vehicle-hours spent in queues per hour. In the peak 15 minute period these would have been 20% higher without the existing level of peak spreading, and would fall by 18% with the highest level of rescheduling. The figures for the 90 minute peak period as a whole were 5½% and 4% respectively. The most extensive rescheduling strategy would have produced a much more uniform distribution of queueing throughout the peak, which suggests in turn more beneficial effects on energy consumption and environmental intrusion.

4.2.7 On two particularly congested approaches (which have since been relieved by a traffic management scheme) the effect on delay was greater; average delay per vehicle in the most extensive rescheduling option would fall by 16% at the height of the peak and by 32% half an hour later.

4.2.8 The key to the small effect of rescheduling can be seen in Figure 7, which demonstrates that the Wakefield network as a whole was operating at well below capacity. In this situation, with a virtually linear relationship between vehicle-hours per hour and vehile-kilometres per hour, rescheduling simply redistributes the vehicle hours travelled over time rather than reducing them. Once the curve becomes more concave reduction of the vehicle kilometres per hour in the peak time period can have significant effects on time spent in the network.

4.2.9 In summary the predicted effects of rescheduling in Wakefield are small on all but a couple of severely congested approaches because

- a significant amount of rescheduling has already taken place
- the opportunities for further rescheduling are small
- flexible working hours, which are more popular with employees, do not ensure that employees avoid the peak (although their effect requires further study)
- work trips to the central area are a small proportion of all trips in Wakefield
- the road network generally is operating at significantly below capacity.

4.2.10 However, even these small effects may be worth seeking in terms of energy and environmental savings, and of reductions in time spent in queues and in delay on particularly congested approaches. More generally, peak spreading could have important implications for public transport, which have not been studied here.

4.2.11 The list in 4.2.9 above suggests a set of criteria for checking the appropriateness of work journey rescheduling as a policy in a given urban area. To be effective, the area should have

- a limited amount of rescheduling already introduced
- a large proportion of firms amenable to rescheduling
- less emphasis on flexible hours than on staggered hours (although this conclusion merits further study)
- a high proportion of total peak period trips terminating in areas where rescheduling can readily be introduced
- a network operating at close to capacity.

A simple analysis of vehicle hours and vehicle kilometres in the network, using SATURN results as in Figure 7, will provide a useful check on this last point.

4.3 Methodological conclusions

4.3.1 As already mentioned in para. 4.2.5, the modelling method adopted was not designed to predict the precise response of employees to the introduction of flexible work hours schemes, nor does it attempt to model any 'feedback' effect whereby changes in traffic congestion consequent on new work hours schemes may induce employees to make further changes in their times of travel. A model capable of doing this would be more complex than adopted here, and require considerable development work. (Appendix B of WP.167 puts forward our ideas on the content and requirements of such a model.) Development of such a model would be a valuable contribution to our understanding of the response to flexible work hours.

4.3.2 The method adopted here assumes that when a firm adopts flexible or staggered work hours, the arrival pattern of its employees will be similar to that currently shown by other firms of a similar type already on flexible or staggered hours. This assumption seems to be supported by the data from the high proportion of firms in the study area which were already on flexible or staggered hours, and could readily be tested by conducting surveys of firms which do change their work hours. The main problem is likely to be lack of information on such changes.

4.3.3 Logit curves were fitted to the cumulative percentage of employees arriving at each firm (by car and by all modes). It was found that this class of curves fitted the data well in most cases, with the notable exception of one firm (no. 96), where the provision of a works bus meant that the great bulk of employees arrived at one time. As we were principally concerned with employees arriving by car, this was not a serious problem, but would merit further attention if all modes were being modelled.

4.3.4 The method used for temporally disaggregating the base O-D matrices was somewhat complex, and was specific to the study area in that it relied on the existence of a car-tight cordon just inside the inner ring road. The method would therefore not be transferable to other locations without careful survey planning.

4.3.5 An enhanced version of SATURN was used to assign the temporally disaggregated O-D matrices to the road network. Difficulties were encountered in calibrating the base data, due in part to the preponderance of roundabouts in Wakefield, (whereas SATURN is principally designed for networks with a high density of signalised junctions); and partly to the fact that SATURN was in the process of development during the course of our study, so that the version used for updating the O-D matrices was different in some respects from that used in assigning the disaggregated matrices.

4.3.6 Other drawbacks to the use of SATURN in this particular project were the method adopted for passing queues formed at the end of one time period to the next and the fact that flows within each time period are assumed to be uniform. The first of these required the use of manual adjustments to the output in order to correct for under-reporting of delays in queues, while the second meant that, as vehicles were not considered individually, all vehicles coming onto the network during the period modelled would be loaded on to their respective links for the whole of that period, irrespective of whether their origin was at the edge of the network or close to the centre. This would lead to difficulties in a large network if the travel time across the network were greater than the time period being modelled, however, in the case of Wakefield the network was sufficiently small for the problem to be ignored. While the first of these problems could readily be overcome, the second would need a different approach to the detailed modelling of traffic movements.

5. REFERENCES

DAWSON, J.A.L. (1979) Comprehensive traffic management in York: the monitoring and modelling. Traffic Engineering and Control. 20(11).

DEPARTMENT OF TRANSPORT (1977) Some effects of flexible working hours on traffic conditions at a large office complex. D.Tp. Traffic Advisory Unit.

MAY, A.D., F.O. MONTGOMERY and M.D. WHEATLEY (1981) Work journey rescheduling: report of surveys. WP.150. Leeds: Institute for Transport Studies.

MONTGOMERY, F.O. and A.D. MAY (1983) Work journey rescheduling: model development and analysis. WP.167. Leeds: Institute for Transport Studies.

SAFAVIAN, R. and K.G. McLEAN (1975) Variable working hours: who benefits? Traffic Engineering, March 1975.

SELINGER, C.S. (1976) Managing transportation demand by alternative work schedule techniques. Special Report 172. Washington: Transportation Research Board.

VAN VLIET, D. (1982) SATURN: A modern assignment model. Traffic Engineering and Control. 23(12).

WATSON, P.L. and E.P. HOLLAND (1978) Relieving traffic congestion: the Singapore Area Licence Scheme. World Bank Staff Working Paper 281. Washington: The World Bank.

WILLUMSEN, L.G. (1982) Estimation of trip matrices from volume counts. P.T.R.C. Summer Annual Meeting. London: P.T.R.C.

WYTCONSULT (1976) Free standing towns studies: Interim report on Wakefield. Document 417. Wakefield: West Yorkshire M.C.C.

WYTCONSULT (1977) Staggering hours in Leeds and Bradford. Document 320. Wakefield: West Yorkshire M.C.C.