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WORK JOURNEY RESCHEDULING
MODEL DEVELOPMENT AND ANALYSIS

F. O. Montgomery and A. D. May

ABSTRACT

F. O. Montgomery and A. D. May (1983) Work journey rescheduling: model development and analysis. Leeds: University of Leeds, Inst. Transp. Stud., WP 167 (unpublished).

Using Wakefield as a case study, a method was developed of testing the effects on traffic of several different work journey rescheduling strategies. The method consisted essentially of assigning a series of six O-D matrices to the Wakefield network, each matrix representing the trips for consecutive 15 minute periods over the morning peak. The six matrices were obtained by firstly disaggregating the $1\frac{1}{2}$ hr peak matrix by purpose (into home-based work, commercial vehicle, and other trips) and then disaggregating each of these three matrices by time. This temporal disaggregation was based, for the home based work trips, on employee arrival profiles by zone, and for the CV and other trips on cordon crossing profiles. The different strategies were modelled by making adjustments to the parameters of the employee arrival profiles.

Other relevant papers in this series are WP 150 Work Journey Rescheduling : Report of Surveys, and WP 168 Work Journey Rescheduling : Results and conclusions.

CONTENTS

Cont/d.,

1. INTRODUCTION

1.1 Background

This paper presents the analysis method adopted for 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 rôle of incentives in encouraging change on journey timing, and the possible costs and benefits which would arise.

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 congestion in 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 (Safavian 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 information 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 (as outlined in Appendix B) 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 (May et al 1981) 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 Model outline

Perhaps the easiest way to understand the model is to consider the process in reverse. The required final output (flows on links, journey times, overall network performance measures) is produced by means of a modified version of SATURN (SATURNQ) which is an assignment-simulation model designed for testing the effects of traffic management schemes on urban networks. The basic inputs to the modified version of SATURN are the network coding, and a set of origin-destination matrices one for each of six quarter hour periods covering the $1\frac{1}{2}$ hour morning peak.

These matrices are not simply scaled down versions of the total peak period matrix, because the distribution of trip purposes changes over the peak. Rather they were produced by firstly disaggregating the total peak period matrix into purpose groups, and then factoring each purpose-matrix into its quarter-hour components. The factors for work trips were obtained by calibrating curves (or profiles) to the arrival patterns of employees, and for other groups of trips by using a combination of these work trip factors, and factors obtained from cordon counts.

1.5 Report outline

Chapter 2 describes in detail how the arrival profiles of employees were obtained and Chapter 3 describes how these and other profiles were used to disaggregate the O-D matrices. Subsequent chapters then describe the modification and application of SATURN, the calibration and validation of its output.

2. EMPLOYEE ARRIVAL PROFILES

2.1 Introduction

This chapter describes the process by which the distributions of employee arrival times were obtained for different types of firm with different types of work schedules. These 'arrival profiles' were used to disaggregate the peak period trip matrix for the 'base' strategy and were assumed to be transferable to similar types of firm when they were required, in any of the other strategies, to change their work schedules. Thus the arrival profile for a firm in Standard Industrial Classification (SIC) 27 which transferred to flexible hours in the 'realistic rescheduling' strategy was assumed to be the average profile of those SIC 27 firms already working flexible hours (Appendix A lists the SICs used).

2.2 Data

WP 150 (Report of Surveys) gives full details of the relevant surveys. Briefly, questionnaire surveys were carried out among employers (Stage 1) and employees (Stage 2) over a range of firms in the central and intermediate areas of Wakefield. The primary aim was to obtain as much information as possible about the arrival patterns of firms in the central area (Zones 1-11 & 16) (Fig. 1). However poor response among some employment categories led us to survey some intermediate area firms as a proxy for their central area counterparts.

Stage 1 data consists of details of the firms' location, SIC group, and the number of persons working in the firm, classified by type of work hours (fixed, flexible, rotating shifts or staggered hours). The start and finish times of each shift are also given (ranges in the case of flexible hours).

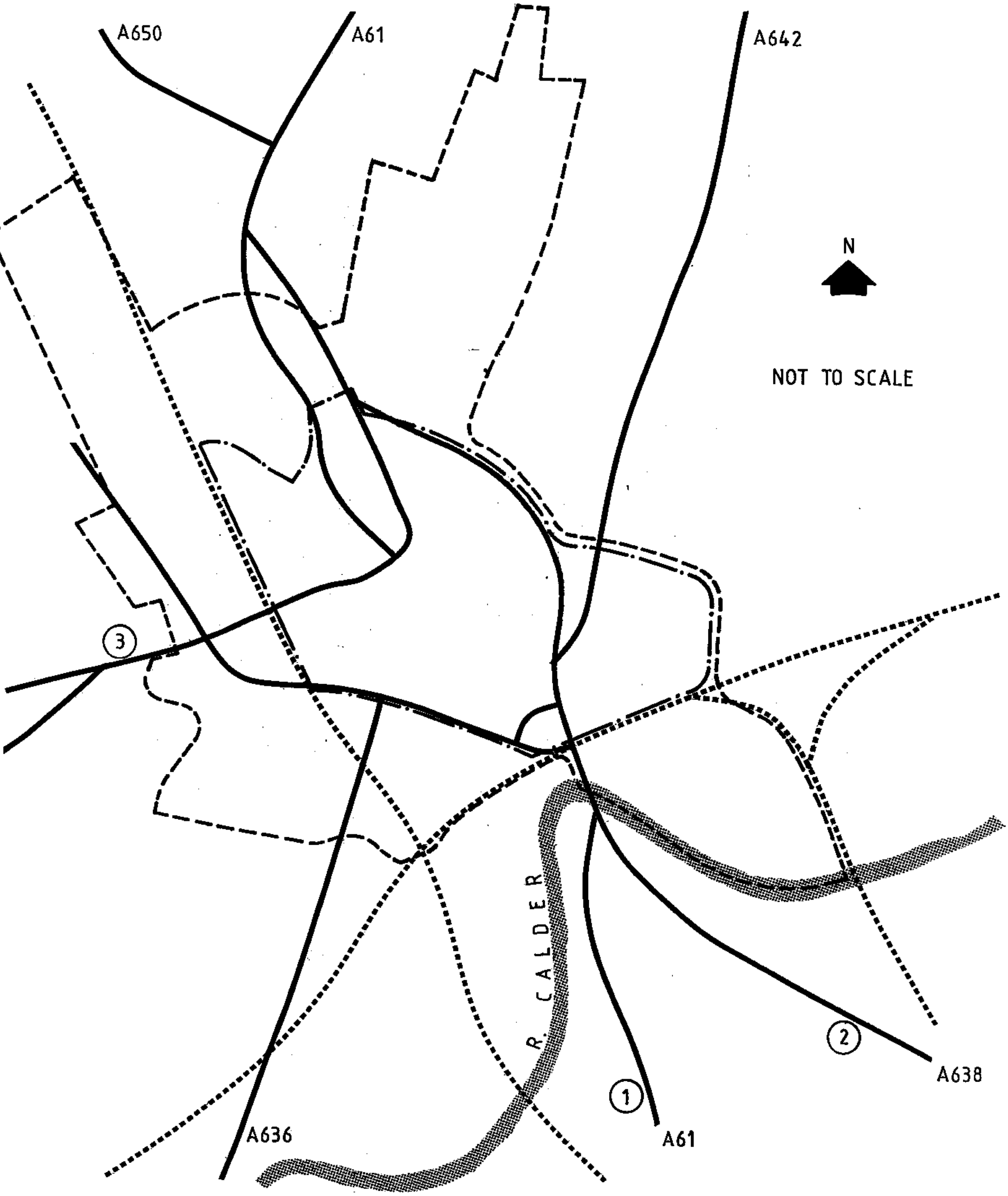
Stage 2 data, which is available for only a proportion of the Stage 1 firms, consists of details of the employee's journey to work, including modes used, journey times, times of arrival over a week, and whether the respondent is able to vary his/her arrival time from day to day.

The main input to the modelling process described here consisted of tabulations of the Stage 2 data using SPSS. Tabulations were produced of the number of respondents arriving by firm by 5-minute period (within the range 7.00 a.m. - 10.15 a.m.). The tabulations were run for those able to vary their work hours from day to day, and (separately) for those not able to do so; and for those arriving as car driver as well as all modes.

2.3 Need for a model

Even if data had been available on the arrival times of all employees in all firms, it would still have been useful to construct a model rather than use the actual data as input for the following reasons:

1) Reported arrival times are often clustered around easily remembered times such as 8.30, 8.45 etc., giving the illusion of little peaks within the main peak. A suitable model fitted to the data smooths out these peaks.
2) The use of an analytical function in the model enables the arrival patterns to be represented much more succinctly - by 2 parameters rather than one per time slice.
3) Defining each pattern by only 2 parameters makes it much easier to



KEY:
- Central Area boundary
- Intermediate Area boundary
- Main roads
- Railways

1. Barnsley Road
2. Doncaster Road
3. Westgate

Fig. 1 The Wakefield Study Area

examine and alter individual firms' patterns when testing strategies.

Data is available for only a proportion of firms however, so that the model must also be used to estimate the arrival patterns of those firms for which no data is available. This process entailed examining the parameters of the fixed arrival patterns to see whether and how they were related to potential classificatory variables such as SIC. The results of this process are described later.

2.4 Form of the model

Firstly, rather than model the actual numbers arriving in each time period, it was decided to model the cumulative pattern, i.e. the proportion arrived by a given time, expressed as a percentage of the total arrivals in the period modelled (7.00 - 10.15 a.m.), See Fig. 2.

The modelling process then resolves itself into a curve-fitting exercise. That is, the form of curve to be used is decided simply on the basis of how well it fits the data and conforms to the constraints presently set out, and is not based on any behavioural assumptions. There is indeed scope for future research to develop such a behavioural model.

There is only one constraint on the fitted curve, and that is that it must be non-decreasing (i.e. it is impossible for less people to have arrived at time t + 1 than at time t).

Various forms of curve were attempted including polynomials, cubic splines and logit, and the latter was chosen because 1) it was the only one consistently to satisfy the forementioned constraint; 2) it is defined by only two parameters as opposed to 4 or 5 for the other forms; 3) the function is easily calculable by computer.

(Note that the cumulative normal curve could have been used and would satisfy 1 and 2 above, but is not so easily calculable).

The form of the function chosen is thus

$$y = 100/\left(1 + e^{-\beta(x-\alpha)}\right) \qquad \ldots \quad \ldots \quad (1)$$

where
x = time in minutes after midnight
y = estimated % arrived by time x
e = base of natural logs
α, β are parameters to be calibrated.

(Note: α is closely related to the mean arrival time, and β to the peakiness of the arrival pattern.)

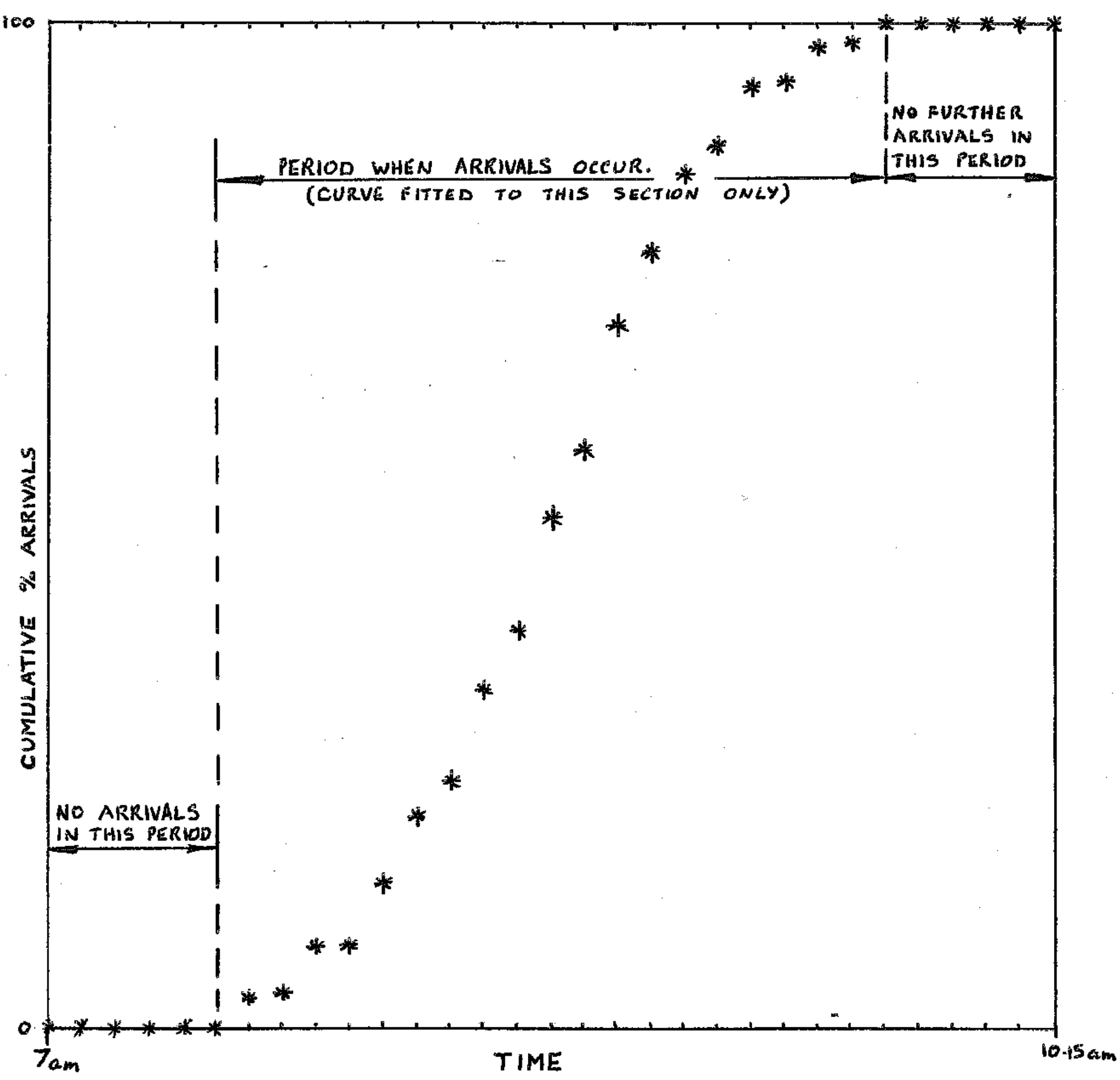


FIG 2 GENERAL FORM OF CUMULATIVE ARRIVAL DATA

2.5 Calibration

The parameters α & β were determined for each set of data points as follows:

$$\text{eqn (1) becomes} \qquad e^{-\beta(x-\alpha)} = \frac{100 - y}{y}$$

$$\text{Taking logs;} \quad -\beta(x-\alpha) = \ln((100 - y)/y)$$

$$\text{Or:} \quad \ln((100 - y)/y) = -\beta x + \beta\alpha \qquad \ldots \quad \ldots \quad (2)$$

Eqn (2) is a linear equation with abscissa = x and ordinate = $\ln((100-y)/y)$. Thus the best straight line fitted through the transformed data points has slope = $-\beta$ and intercept = $\beta\alpha$.

(Note that only those values of y greater than 0 and less than 100 are used in the calibration.)

The advantage of this method of calibration is its simplicity and robustness. However it suffers from the disadvantages that 1) a goodness of fit statistic is available only for the transformed data, and cannot be transferred to the original data; 2) data points close to y = 0 or y = 100 tend to exert a stronger influence than they should on the result.

2.6 Results of calibration

A program was written to carry out the calibration for each data set and also to plot the data and the fitted curve. Examples of the output are shown in Figs. 3 and 4. It will be seen that the form of the data consists of a flat section (during which there are no arrivals) followed by a curved section (representing the arrivals), followed by another flat section (during which there are no further arrivals). The program automatically fits a logit curve to those points where $(0 < y < 100)$, and gives as output the calibrated range and coefficients of the curve.

Examination of the graphical output for each data set greatly aided the decision whether to accept or reject the fitted curve as being representative of the data. In a few cases the data was too sparse to enable a curve to be fitted at all but otherwise the curves approximated the data very well. One exception worth noting was firm 96, where the use of a works bus results in a very peaky arrival pattern for the bus users, followed by a more spread-out pattern for the rest. Thus the cumulative arrival pattern as in Fig. 5 cannot be represented properly by a logistic curve.

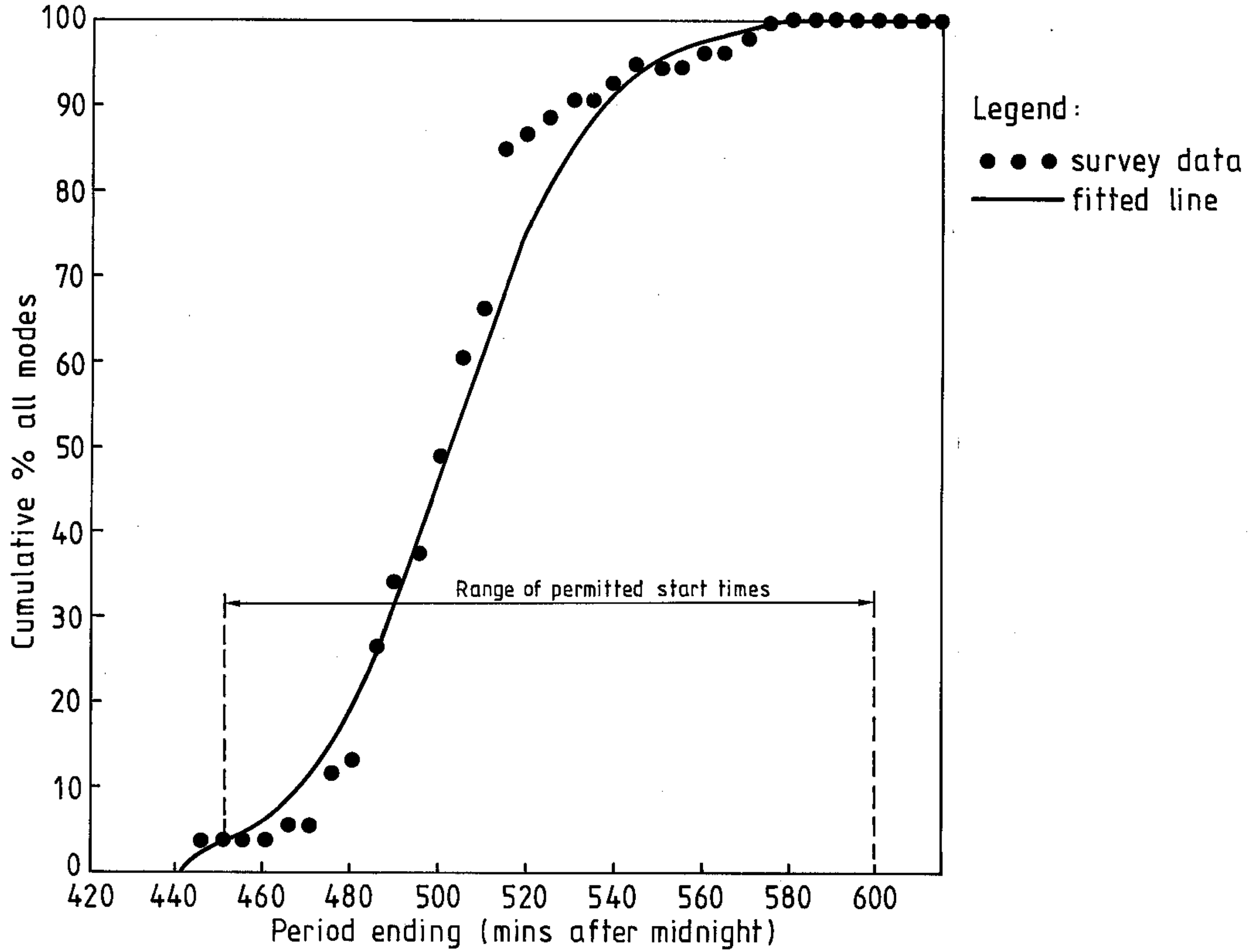


Fig. 3 Typical arrival pattern of firm with flexible work hours

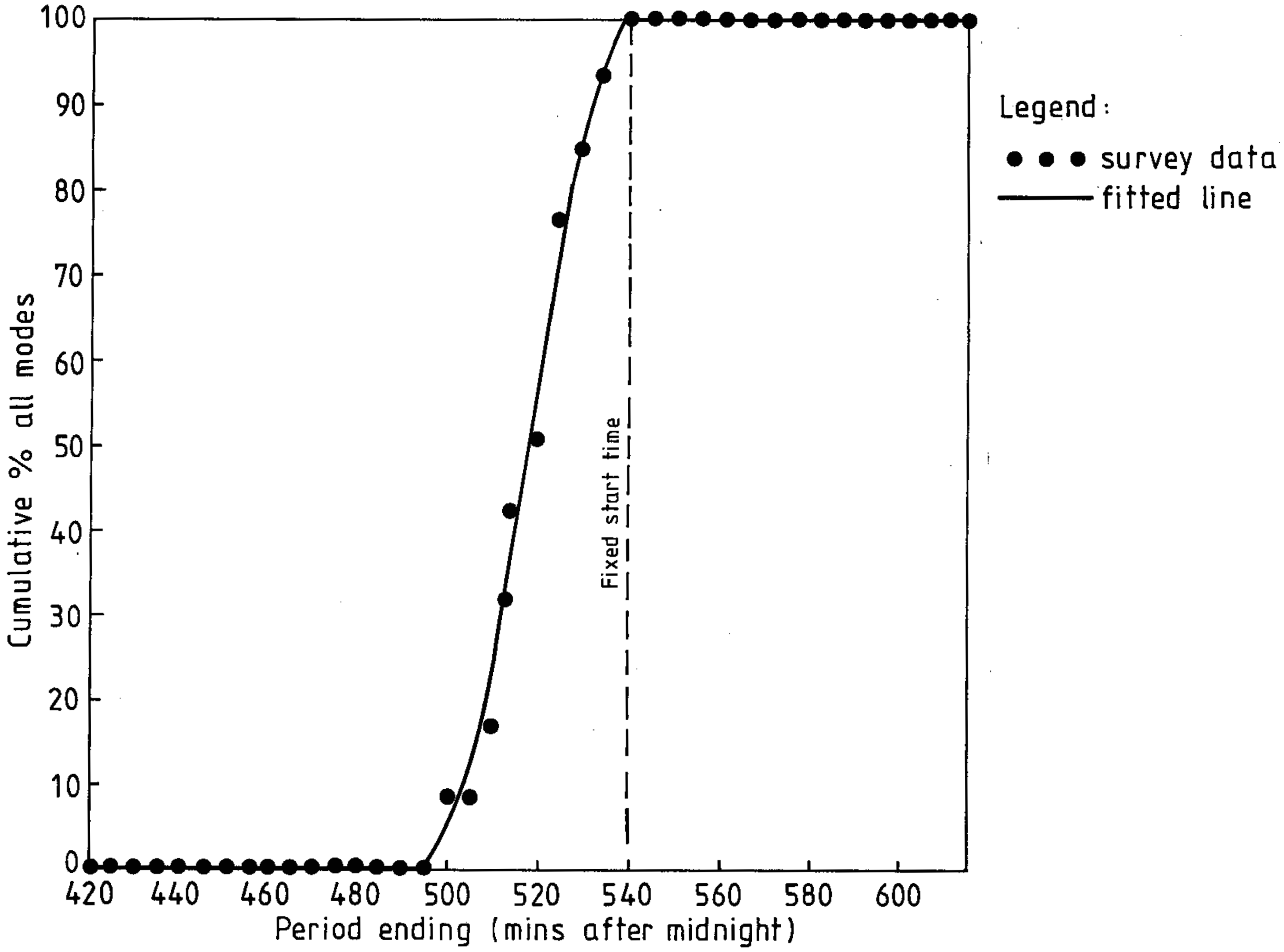


Fig. 4 Typical arrival pattern of firm with fixed start time

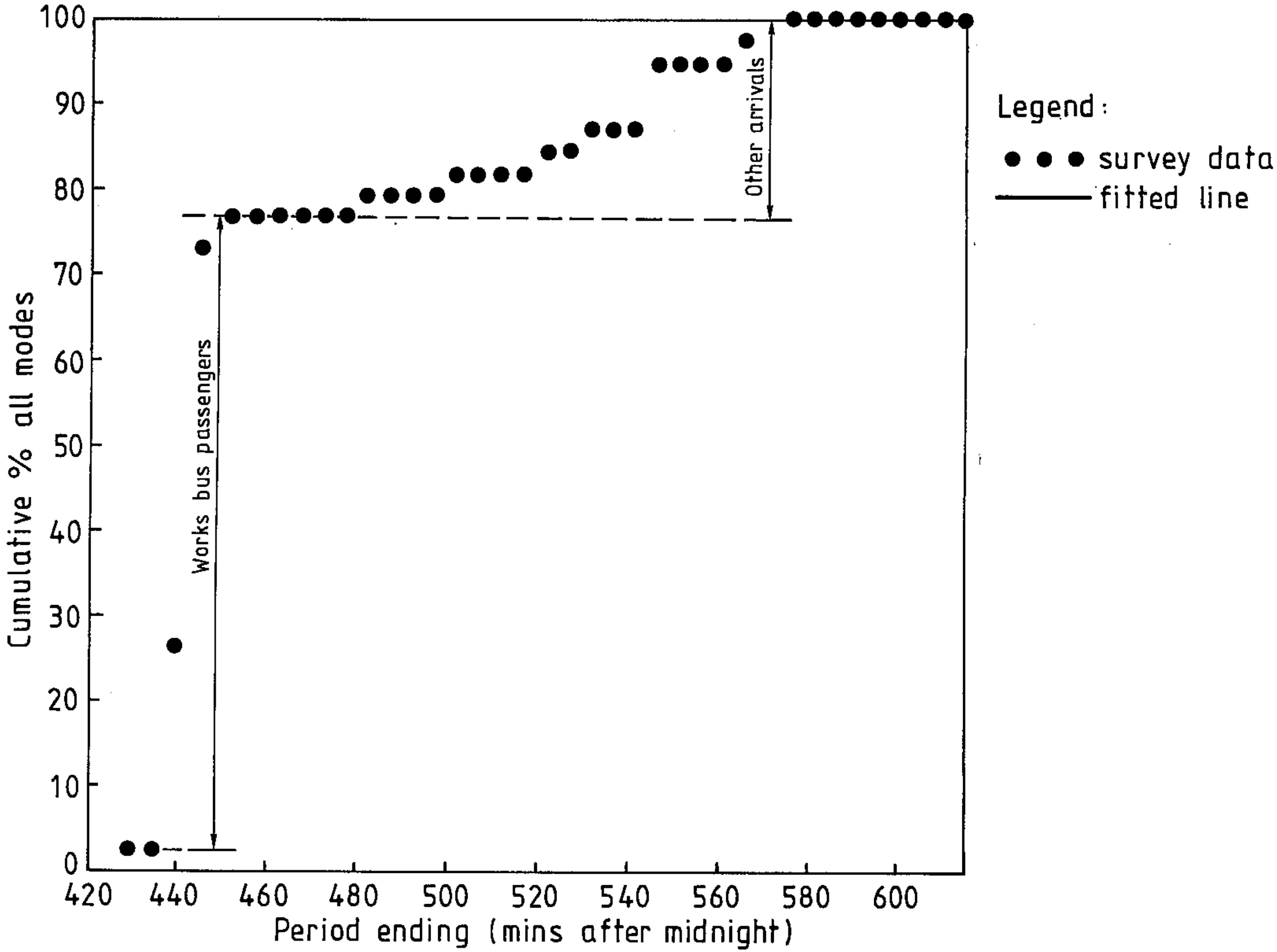


Fig. 5 Unusual arrival pattern of firm 96 due to use of works bus

The problem of how to represent this type of arrival pattern is worthy of further investigation, but as in this study we are concerned primarily with arrivals by car the problem need not concern us further.

Tables 1 and 2 then, show the results of calibrating the curves. Table 1 shows the results for each firm, both for car arrivals and for all modes. Table 2 refers to those firms where the proportion of employees able to vary their work hours is not close to 0 or 1. Table 2a shows for these firms, the results of calibrating curves against only the arrival times of those employees who can vary their hours. Table 2b shows the results for employees who cannot vary their hours.

2.7 Classification of curves

2.7.1 In classifying the curves into types, there are two attributes to be considered, corresponding to the two parameters β & α. The first attribute is the maximum slope of the curve, which is determined by β and is inversely proportional to the standard deviation of the arrival time data. The second attribute is the position of the curve on the time axis, which is determined by α and is directly related to the mean of the arrival times.

2.7.2 Classification by SIC It had been thought from the start that there would be some correlation between the type of the curve and the SIC of the firm, and this was therefore the first relationship to be examined.

Fig. 6 then, shows the distribution of β with SIC, for all modes and for cars only. It is obvious from this that the variation within SIC's is as much as or greater than the variation between them, i.e. there is no detectable relationship between SIC and β.

The next stage was to look at the correlation between SIC and α. In fact rather than α we examined the mean arrival time, determined from Stage 1 surveys for firms on fixed or staggered hours, or Stage 2 surveys for those on flexible hours. (The reason for examining mean arrival times rather than α was to increase the amount of data for comparison - α & β parameters were only obtainable for those data sets where sufficient Stage 2 responses had been obtained to calibrate a curve).

Fig. 7 therefore shows the relationship between SIC and mean arrival time, and from this it can be seen that there is in fact a degree of correspondence, with the mean starting times of most SIC's tending to cluster around different positions.

TABLE 1.

Results of fitting LOGIT curves to firms' arrival profiles

NB. Curve formula is $y = 100/(1 + e^{-\beta(x-\alpha)})$; x = time
y = % arrived

	Firm no.	SIC	Calibr. Range From x =	To	β	α	No. in sample Can vary	Cannot vary
Cars only			505	540	0.0794	527.2	1	5
All modes	18	20	505	545	0.1147	529.7	2	11
			470	565	0.0471	500.8	2	7
	22	23	470	565	0.0682	502.4	3	19
			515	585	0.0565	554.8	8	1
	30	24	515	600	0.0526	551.0	11	3
			475	520	0.0845	497.8	12	3
	44	27	475	540	0.0845	497.8	21	3
			-	-	-	-	-	2
	50	26	465	530	0.0274	504.7	-	3
			-	-	-	-	-	3
	62	27	500	540	0.0664	510.9	1	6
			-	-	-	-	-	2
	63	27	485	540	0.0650	503.7	2	6
			500	530	0.0592	514.5	1	5
	64	27	485	530	0.0779	511.4	2	9
			490	530	0.1073	503.5	-	17
	66	27	490	530	0.1148	502.0	-	23
			450	580	0.0891	509.1	14	122
	67	27	450	580	0.0926	511.2	31	238
			495	555	0.0934	519.7	3	13
	83	24	495	555	0.1206	519.6	5	28
			505	540	0.1535	525.7	-	15
	86	24	500	540	0.1233	524.1	1	24
			445	555	0.0793	500.4	29	-
	88	27	445	570	0.0636	502.7	51	1
			-	-	-	-	1	1
	96	15	430	565	0.0312	456.6	2	37
			465	545	0.0843	505.4	31	17
	113	22	455	585	0.0731	509.6	83	38
			475	570	0.0798	500.5	27	19
	114	21	470	570	0.0884	501.4	61	20
			495	530	0.1366	509.0	1	8
	121	21	495	530	0.1484	507.8	1	11
			500	510	0.1386	506.7	1	2
	127	23	500	535	0.1478	518.9	2	10
			485	530	0.1077	506.7	-	25
	136	27	485	530	0.1165	507.1	1	34
			-	-	-	-	-	-
	214	7	420	567	0.0517	473.6	215	-
	All		445	585	0.0848	511.4		
	firms	-	430	600	0.0726	506.3		

TABLE 2.

Results of fitting LOGIT curves to firms' arrival profiles - split according to employee's ability to vary hours or not

NB Curve formula is $y = 100/(1 + e^{-\beta(x-\alpha)})$; x = time
y = % arrived

	Firm no.	SIC	Calibr. Range From x =	To	β	α	No. in sample
Cars only			475	520	0.0860	496.2	12
All modes	44	27	475	540	0.0805	497.3	21
(a)			-	-	-	-	1
Employees	64	27	-	-	-	-	2
able to			495	555	0.0697	510.8	14
vary	67	27	485	580	0.0648	511.1	31
work			445	555	0.0784	500.6	29
hours	88	27	445	565	0.0687	500.4	51
from			465	540	0.0758	504.9	31
day	113	22	455	585	0.0665	509.8	83
to			475	570	0.0674	499.6	27
day	114	21	470	570	0.0818	501.0	61
			445	570	0.0852	505.6	
	Total		445	585	0.0741	508.1	
Cars only			485	520	0.0495	499.0	3
All modes	44	27	485	520	0.0495	499.0	3
(b)			500	525	0.0371	508.9	5
Employees	64	27	485	525	0.0725	507.8	9
not			450	580	0.0890	507.7	122
able to	67	27	450	580	0.0959	509.4	238
vary			-	-	-	-	-
work	88	27	-	-	-	-	1
hours			480	545	0.0823	506.1	17
	113	22	475	545	0.0986	504.0	38
			485	515	0.1395	500.2	19
	114	21	485	515	0.1436	500.4	20
			450	580	0.0935	507.8	
	Total		450	580	0.0965	509.7	

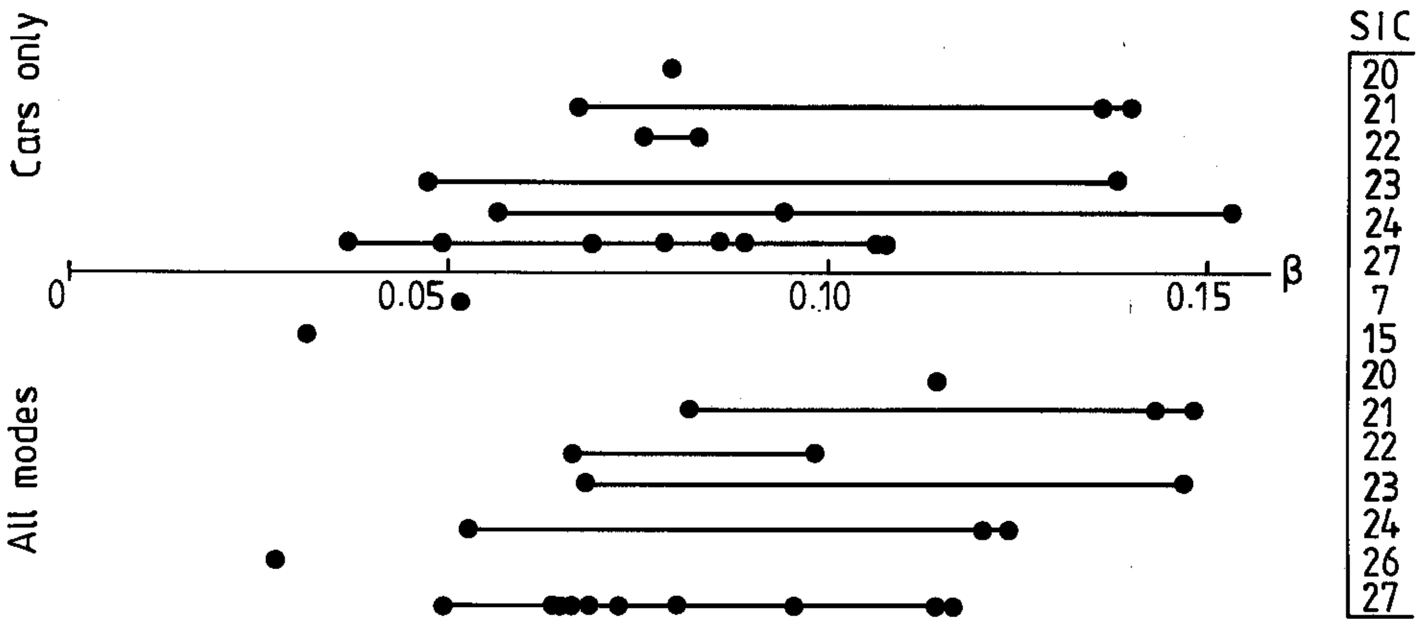
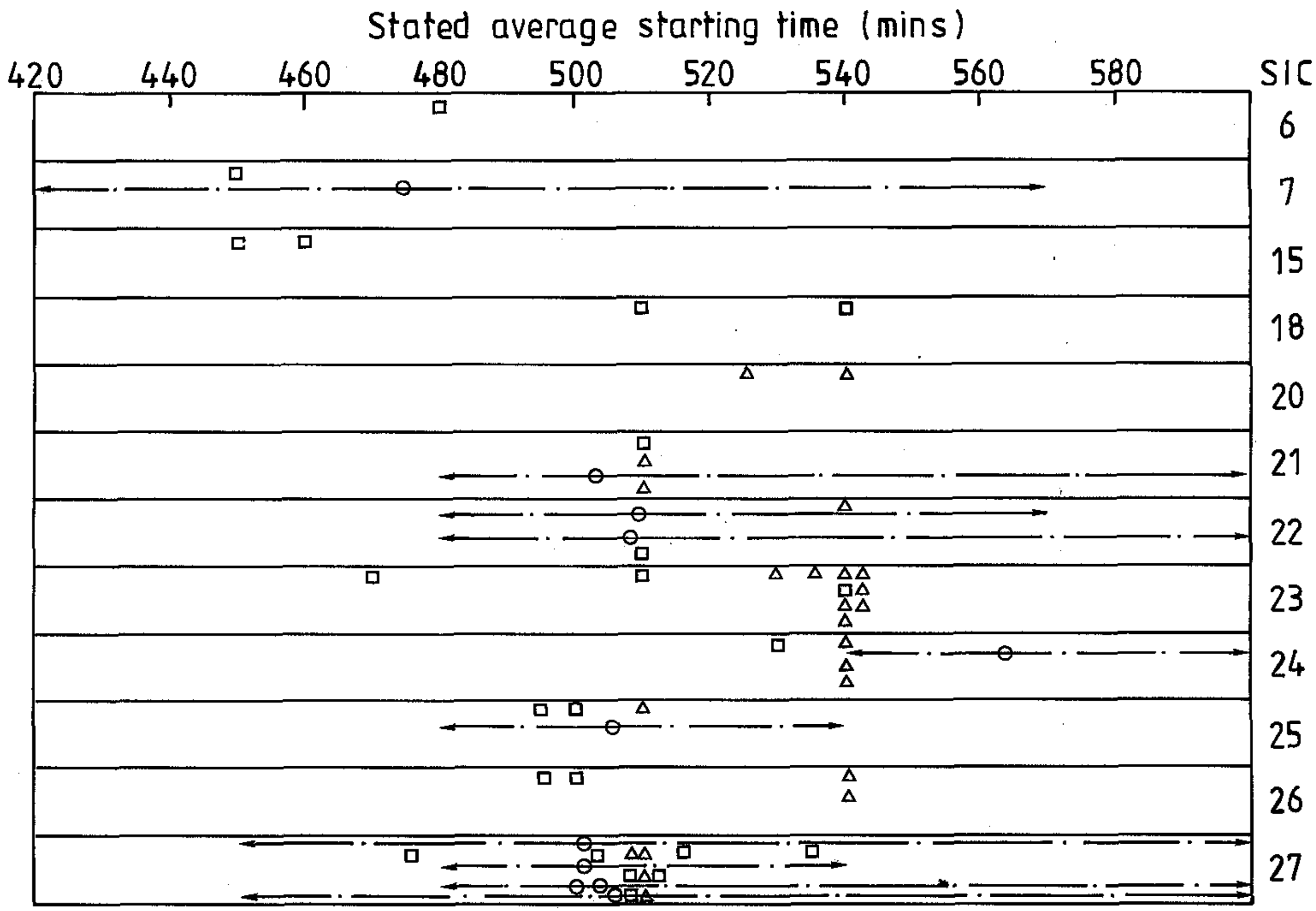


Fig. 6 Distribution of β with SIC



Key: □ Average start time of firm on staggered hours
△ Stated start time - fixed hours
←·○·→ Range and average start time for flexible hours

Fig. 7 Distribution of stated average arrival times (all modes) by SIC

Hence, although there is no evidence of a relationship between SIC and β (the shape of the curve) there does appear to be a correspondence with the mean arrival time (hence α, the position of the curve).

2.7.3 Classification by stated work hour type It was therefore still necessary to find a classificatory variable for β, and this was found in the "type of work hours" as stated by the firms in the Stage 1 surveys. Work hours types included Fixed hours, Flexible hours, and Staggered hours (the latter including rotating shifts, a category occurring in only 5 firms). Fig. 8 is a scattergraph showing the calibrated α & β for each firm (all modes). The symbols denote the dominant work hour type in each firm. (Note that for those firms where no one type is dominant, i.e. those listed on Table 2, the results for both types are plotted).

Fig. 9 shows the same but for car arrivals only.

It can be seen that in both graphs the points fall into two groups, with fixed hour firms tending to have β values in a higher range than either flexible or staggered work hours firms.

Thus for all modes (Fig. 8) the β value for flexible/staggered hours firms lies between ∿ 0.05 and 0.10 whereas the value for fixed hour firms is between 0.10 and 0.15. Similarly for car arrivals, flexible/staggered hours firms have a β from ∿ 0.05 to 0.09, with fixed hours ranging from ∿ 0.08 to 0.16.

The relationship between stated work hours and α is not so distinct, but there does appear to be a tendency for the average start time of employees on flexible hours to be earlier than those on staggered, and for the latter to be earlier than those on fixed hours. This is a further topic which would benefit from further study.

Hence it would appear that the type of work hours, as stated by the firms in the Stage 1 surveys, can be used to classify the β values.

2.7.4 Difference between car arrivals and all modes Referring back to Table 1, an examination of the α parameter firm by firm shows that in 8 cases α is lower for 'cars only' than for 'all modes', and in 6 cases it is higher.

Looking at the β parameter, it can be seen to be lower for 'cars only' in 10 cases, and higher in 4 cases. Application of the 'sign' test gives probabilities of 39.5% and 9.0% respectively for these or more extreme outcomes. Thus there is no significant difference between the arrival patterns of cars and all modes.

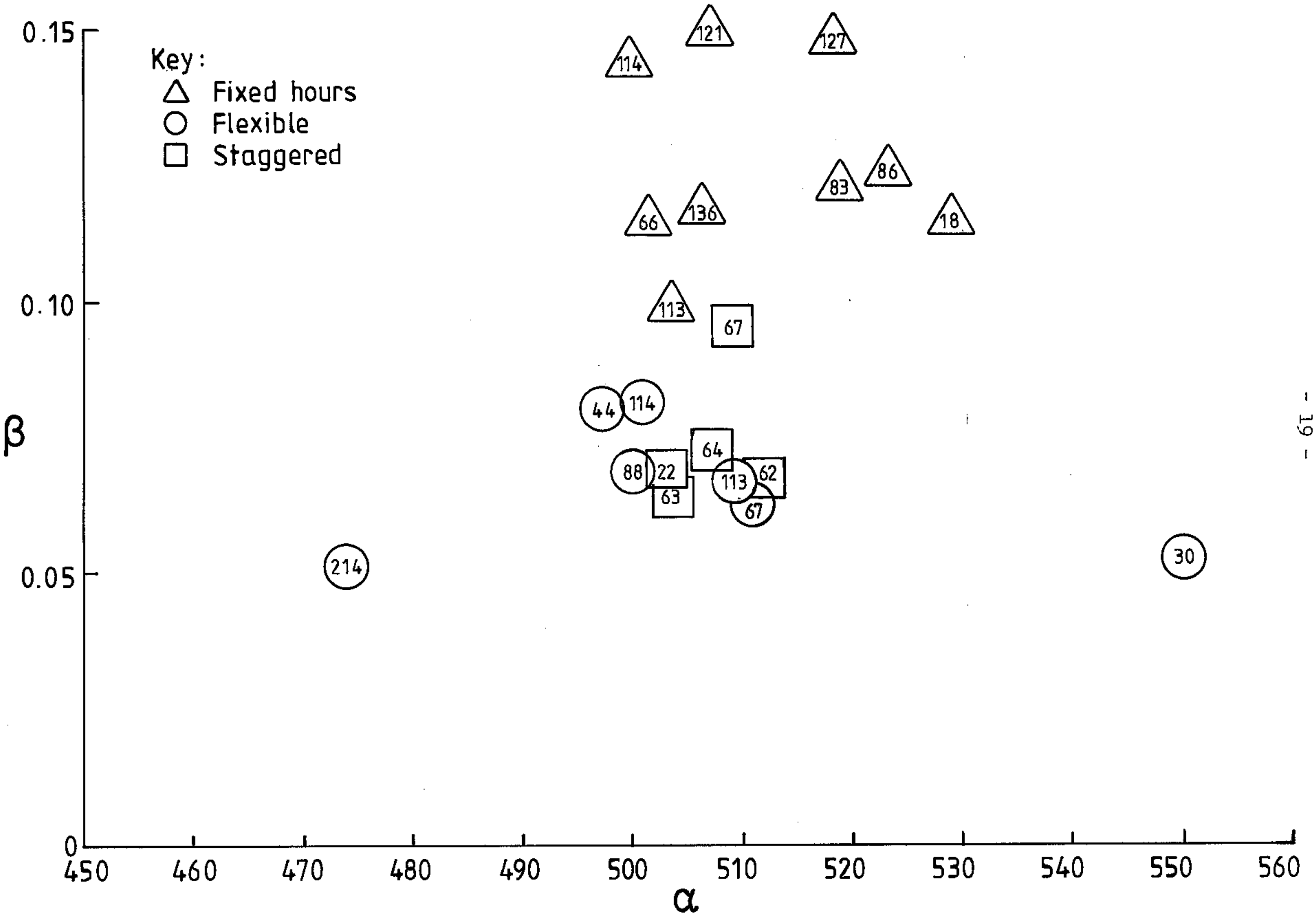


Fig. 8   Scattergraph showing distribution of α and β by firm for arrivals by all modes

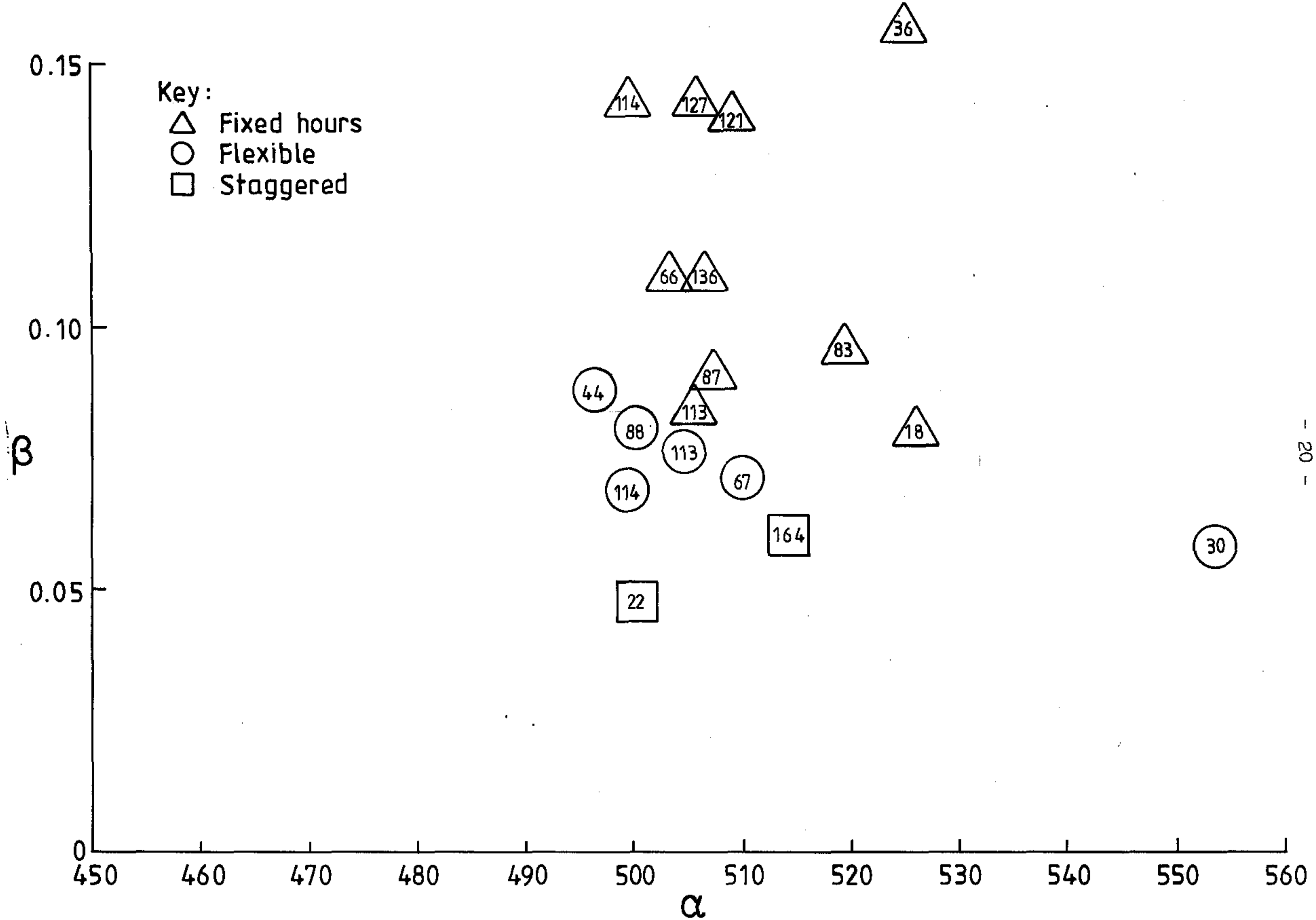


Fig. 9 Scattergraph showing distribution of α and β by firm for arrivals by car

This being the case, it becomes justifiable to utilise the patterns for 'all modes' in the model where insufficient data had resulted in unreliable or non-existent 'cars only' patterns.

2.8 Extension to firms not surveyed in Stage 2

The purpose of classifying the curves as described above is of course so that reasonable estimates can be made of the arrival patterns of those firms not surveyed. For those firms which have been surveyed in Stage 2, and for which profiles are therefore available, the parameters calibrated for 'cars only' were used where available, otherwise those for 'all modes' were used.

For those firms not surveyed in Stage 2, the following procedures were adopted.

1) Firms surveyed in Stage 1

   For these firms details of the work hours were known, and α could therefore be determined by reference to the stated average arrival time. The possible range of β for each firm was determined on the basis of the stated work hours type, and within that range the actual choice of β was taken randomly from the observed distribution of β's.

2) Firms not surveyed in Stage 1, within the central area

   The SIC's of these firms is known, and this was therefore used to determine the possible range of α. Again the actual choice was made randomly from the observed distribution of α within the range.

   The choice of β for firms in this group is more of a problem as their work hour types are not known. The procedure adopted was to go through the list examining each firm individually, and firstly allocate a work hour type to each firm for which the choice is fairly straightforward (e.g. fixed hours for small shops, schools, flexible/staggered hours for local government offices); and then to allocate the remainder by randomly sampling the observed distribution of work hour types. (This ensures that the final estimated distribution of work hour types among firms is approximately the same as that surveyed.)

   Having thus allocated a work hour type to each firm, the choice of β was made in the same manner as in (1) above.

3) Firms not surveyed in Stage 1, intermediate area

It is not necessary to have individual profiles for firms in the intermediate area, as the test strategies affect only central area firms. It is sufficient therefore to have only one overall profile for the whole intermediate area, and in the absence of contrary information it was assumed that the overall arrival profiles of the central and intermediate areas are similar. Thus the overall arrival profile for the central area as obtained in 1 & 2 above was applied to the intermediate area as a whole.

3. MATRIX DISAGGREGATION

3.1 Introduction

This chapter describes the methods by which the morning peak origin destination matrices obtained from the WYTCONSULT Surveys of 1975 were updated and disaggregated by purpose and by time. The process is summarised in Fig. 10.

3.2 O-D data available

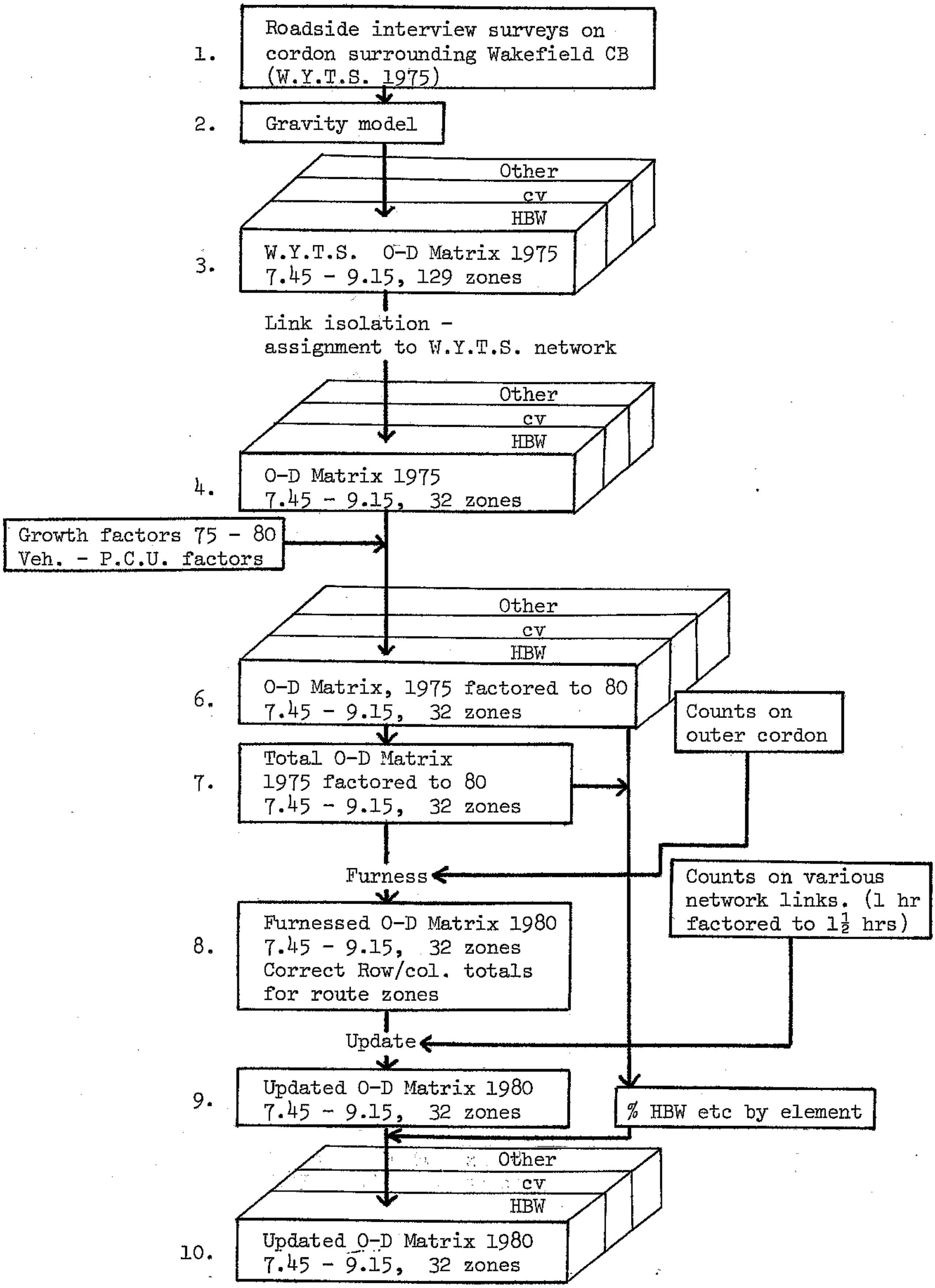
The basic source of origin-destination data is the WYTCONSULT surveys of 1975. O-D matrices were produced for Wakefield by calibrating a gravity model against trips observed at roadside interview stations, on a cordon drawn round the former Wakefield CB area. These matrices are for the morning peak period (7.45 - 9.15 a.m.) in 1975, disaggregated by purpose (HBW, HBO, NHB, EDUC, HGV & LGV) on a 129 zone zoning system.

3.3 Zoning, network and cordons

3.3.1 Zoning The 129 zone system used in WYTCONSULT is too fine in the outer zones for our purposes, as we only require to know by which routes traffic approaches the central area. For this reason, a 32 "zone" system was used, consisting of 21 WYTCONSULT zones covering the central area of Wakefield, and 11 "route zones" by which all external traffic enters the network. It should be noted that these "route zones" are not simply aggregations of WYTCONSULT zones, but rather the trips to/from them were obtained by a cordon isolation procedure, i.e. by running an assignment on the 129 zone system and recording those trips passing through each "route zone".

Thus a 32 x 32 zone O-D matrix was obtained in which only those trips which would use the SATURN network are included. (If the route zones

Fig. 10 Production of 1980 updated peak period O-D matrices



had simply been aggregations of the original zones, then trips from say 10 miles north of Wakefield to say 5 miles south, would have been included and hence assigned to the SATURN network, whereas in fact they would most probably avoid the Wakefield area altogether by using the M1.)

3.3.2 Network The network used for this study is based on, but different from, the WYTCONSULT network. It covers the central area of Wakefield from Leeds Road/Bradford Road in the North to Chantry Bridge in the South, and from Westgate End in the West to Peterson Road/Jacob's Well Lane in the East. Link lengths and speeds were provided by WYCC and the network was coded by a postgraduate student in the Institute as part of his M.Sc. dissertation project (Yip 1980).

3.3.3 Cordons There are two cordons pertaining to this model as shown in Fig. 11. The first is the outer cordon mentioned in 3.3.1 above, defined by the limits of the SATURN network which encloses zones 1-21. The second or inner cordon defines the CBD or town centre of Wakefield, where the bulk of office workers are employed, and which is the most likely area within which Work Journey Rescheduling (WJR) strategies could be implemented.

In locating the precise position of the inner cordon, the following points were considered important.

1) As far as possible trips should pass around rather than through this cordon. This feature makes the profiles obtained from cross-cordon flows more useful, and was achieved by keeping the cordon just inside the main inner relief roads.
2) The number of roads crossing the cordon should be as few as possible to reduce data collection time and cost. There are eleven crossing points here.
3) The cordon should be car-tight, i.e. there should be no uncounted minor roads, back lanes etc.
4) The area enclosed by the inner cordon should, as far as possible, contain the majority of workplaces amenable to WJR, and exclude as far as possible those workplaces which are not so amenable, and also non-workplaces. The chosen cordon therefore excludes the heavy industrial area south of Ings Road and the River Calder (zones 19, 20, 21) and the predominantly residential areas to the north, east and west of the central area.

The two cordons thus define three areas; central, intermediate and external.

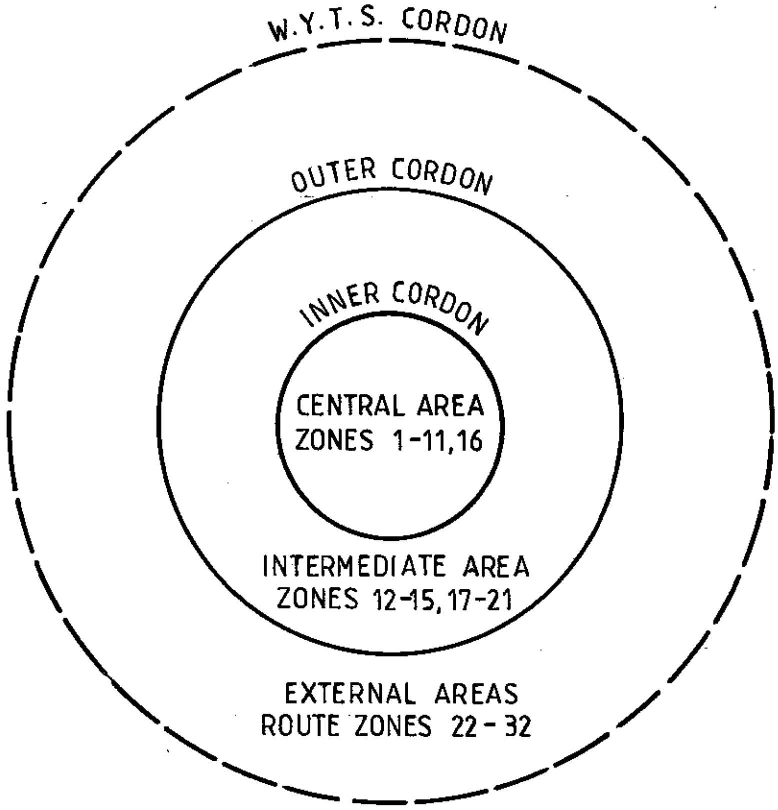


Fig. 11 Relationship of cordons to zoning system

The following paragraphs describe the relationship of each of these areas to the network and consequently to the survey methods required to model the effect that work journeys to these areas have on congestion in the network.

3.3.3.1 Central area   Because the central area is subject to WJR strategies, it is necessary to model with reasonable accuracy the present work journey arrival patterns in that area, in order to make sensible comparisons between base and test conditions. Thus it was attempted to carry out surveys of every employer in the central area employing more than 15 people, to obtain up-to-date details of the number and type of employees, and current work schedule arrangements. Additionally, a sample of firms was circulated with employee questionnaires, in order to obtain the current modal split and times of arrival. The information obtained from the employee surveys was expanded by means of the employer surveys and other data to produce a histogram or profile of arrival times by car for each firm. These profiles were then added (weighted by the number of employees) to obtain arrival profiles by zone (see Chapter 2).

3.3.3.2 Intermediate area   The intermediate area between the two cordons would not be subject to WJR strategies, but traffic generated/attracted there does have a strong influence on congestion in the network. Hence it was thought useful to carry out some employer/employee surveys in this area, but a lower sample fraction than in the central area was used.

3.3.3.3 External area   Because of the extent of the external area, its contribution to network congestion is likely to be much more evenly spread over time than the central and intermediate areas. It is not intended nor indeed would it be practicable, to survey the arrival times of firms in this area, and in any case as will be seen later the profiles of traffic attracted to external zones can be obtained from traffic counts alone.

3.4 Modifying the initial O-D matrices

Referring again to Fig.10, the derivation of the initial 32 zone matrix ((4) in Fig.10) has already been described. There are in fact 3 such matrices, for HBW private vehicles, CV's and all other (non-bus) vehicles. All these matrices of course refer to 1975 AM peak period flows, and it is therefore necessary to modify them to 1980 flows before they can be used in the model along with 1980 employment surveys, traffic counts etc.

This modification is accomplished in three stages as follows:

1) The application of overall growth factors to each matrix to account for overall traffic growth from 1975 to 1980 and to convert from vehicles to PCUs ((6) Fig. 10).
2) After adding the three matrices to form a total PCU matrix, the application of the Furness technique to make the row and column totals for the route zones agree with the measured 1980 flows on those routes ((8) Fig. 10).
3) The application of the UPDATE program associated with SATURN, which modifies the matrix elements within the given row and column totals so that, when assigned to the network, the resulting flows agree with measured link flows ((9) Fig. 10).

The outer cordon counts applied in (2) were for the $1\frac{1}{2}$ hour period 7.45 - 9.15 (i.e. the period covered by the O-D matrix). These counts were aggregations of the 5 minute counts conducted in November 1980.

The counts used in the UPDATE process were obtained mainly from WYCC. These counts were carried out in various months and years, and factored to 1980 by reference to long-term automatic count data. They each refer to the peak hour, so that before they could be used in the UPDATE program the matrices had to be factored down to 1 hour values and subsequently factored back to a $1\frac{1}{2}$ hour matrix using the 1980 ratio of $1\frac{1}{2}$ hour flow/1 hour flow at the internal cordon.

The UPDATE process can be carried out at present only on the <u>total</u> O-D matrix, and not on selected purpose sub-matrices. This is because the process involves running the simulation and assignment stages of SATURN to determine the paths taken from each origin to destination, and this is obviously dependent on the <u>total</u> traffic using the network. Table 3 shows the results of the updating process in summary.

3.5 <u>Required form of data</u>

In this study we are testing the effect of rescheduling work times in the central area of Wakefield, and are looking only at the effect on the $1\frac{1}{2}$ hour morning peak period. Thus only the hatched areas of the home-based-work matrix on Fig. 12 (i.e. the journey <u>to</u> work in the central area) are directly affected by the test strategies. Trips in the other parts of the home-based-work matrix, and the other purpose matrices may be indirectly affected due to changes in network congestion - the model predicts changes in delays and routes for these trips, but not re-timing.

TABLE 3 SUMMARY OF UPDATE RUNS

	TURNS 1	TURNS 2	TURNS 3	TURNS 4	NEW TURN 4	SATOUT 4	FINAL SATOUT 4	SATOUT 5
Total trips assigned	14,578.44 (WAKOD8OF)	11,253.83 (WAKODUP1)	11,997.38 (WAKODUP2)	12,031.50 (WAKODUP3)	12,031.50 (WAKODUP3)	12,031.50 (WAKODUP3)	12,031.50 (WAKODUP3)	11,845.34 (WAKODUP4)
Average delay over network (secs)	12.57	4.20	5.03	5.12	5.34	4.70	4.79	4.48
Increasing at rate of (secs/cycle)	3.60	1.00	1.36	1.34	1.12	0.88	0.94	0.79
Total delayed time (veh hrs/hr)	908.0	272.2	333.1	346.4	343.5	368.0	364.7	258.4
Total free run time (veh hrs/hr	505.6	401.7	434.9	441.1	439.8	445.2	443.8	437.4
Total travel time (veh hrs/hr)	1,413.6	673.9	768.0	787.5	783.3	813.3	808.6	695.8
Overall ave speed (k.p.h.)	11.6	19.7	18.4	18.1	18.2	17.7	17.8	20.4
Total no. 1st stops/hr	-	14,591	14,152	15,354	15,169	15,029	14,893	14,476
Total no. stops/hr	32,662	27,920	27,972	29,124	29,062	31,847	31,440	21,997
Total fuel consumed (litres/hr)	3,578	1,732	1,867	1,930	1,918	1,959	1,948	1,777
% of chosen link volumes:								
within ± 5% of assigned	6.	55.03	58.38	57.05				59.06
within ± 10% of assigned	14.	60.39	62.40	63.76				63.08
within ± 25% of assigned	38.	72.46	73.80	72.47				76.49

		DESTINATION		
		Central	Intermediate	External
ORIGIN	C	C - C	C - I	C - E
	I	I - C	I - I	I - E
	E	E - C	E - I	E - E

Note: shaded cells are potentially affected by WJR

Fig. 12 Resultant parts of the O-D matrix for work trips

The trips made during the a.m. peak therefore fall into two groups

1. Those which can be directly altered by rescheduling strategies.
2. Those which are affected only indirectly.

When disaggregating the total origin-destination matrix (obtained as in Section 3.4) into discrete time slices, it is therefore, necessary to keep these two groups separated.

What we require then is (1) a set of O-D matrices for home-based-work trips to the central area, in discrete time slices covering the morning peak period; (these matrices will vary for different strategies although the total number of trips for each O-D pair across all time slices will remain constant) (2) a set of O-D matrices covering all other trips, for the same time slices (these matrices will remain fixed over all tests).

3.6 <u>Outline of disaggregation method</u>

There are two main stages in predicting the effect of the strategies being tested. These are firstly, the response to the strategy and secondly the effect of that response on traffic conditions.

In the method described here, the response to a strategy is not part of the model prediction procedure, but instead is part of the input to the model. In other words, the response for each workplace (in terms of the arrival profiles resulting from particular work schedules) is determined outside the model, based on surveys of the arrival profiles of similar firms on similar schedules. The production of these profiles was described in some detail in Chapter 2, but here we are discussing only the manner in which the profiles and other data were used to temporally disaggregate the total O-D matrix.

One or two caveats should be mentioned with regard to the method described. Firstly, SATURN does not process groups of vehicles over links in the network in the way that say CONTRAM would do. Rather, all trips in one O-D time slice are assumed to be loaded on to the network uniformly during that time slice. Moreover, the time slice in which any trip falls is assumed to depend on either the arrival time at the workplace (for work trips destined for the central and intermediate areas) or the cordon crossing time otherwise. Hence in this method the length of the time slices should not be less than the average journey time across the network.

Secondly, the method described for disaggregating the non-work O-D matrices depends on the inner cordon being located such that the majority of "through" trips pass around it rather than through it.

Section 3.4 described how the updated total O-D matrix ((9) of Fig. 10) was obtained. The rest of this section describes in outline the rest of the method from that stage. The following four sections will then describe each stage in more detail.

Referring again to Fig.10, the next stage is to disaggregate the total matrix (9) into three matrices by purpose. It is necessary to separate the HBW matrix because we wish to disaggregate it in different ways for different tests. It is not strictly necessary to separate the commercial vehicle matrix, but failure to do so is likely to lead to loss of accuracy, due to the different shape of the trip-time profile of CVs compared to other traffic.

Having obtained these O-D matrices for the peak period, the next stage is to disaggregate them into time slices of 15 minutes. Firstly, home based work trips with destinations in the central or intermediate areas are disaggregated by application of trip-time profiles obtained from firms' surveys, by destination zone. Secondly the commercial vehicle trip matrix is disaggregated by application to the matrix as a whole of trip-time profiles obtained from cordon counts of CVs. (Note that CVs are the only "purpose" group, capable of being separately identified from cordon counts.) Thirdly the remaining parts of the O-D matrix (i.e. HBW trips with external destinations, other home-based, non-home based and education trips), are treated as one, and disaggregated by means of a combination of cordon count profiles and firms' surveys.

3.7 Disaggregating the total O-D matrix by purpose

To carry out this process, it is assumed that the purpose split for each O-D pair is the same in 1980 as it was in 1975.

i.e. that $\dfrac{T_{ijp}^{80}}{T_{ij}^{80}} = \dfrac{T_{ijp}^{75}}{T_{ij}^{75}}$ where p denotes purpose.

Hence to obtain the 1980 matrix for purpose p we simply factor each element of the updated total O-D matrix by the relevant 1975 purpose split, i.e.

$$T_{ijp}^{80} = T_{ij}^{80} \times \frac{T_{ijp}^{75}}{T_{ij}^{75}}$$

This process maintains the same total number of trips in each O-D pair, hence the UPDATE previously carried out is not invalidated. It would not of course be able to deal properly with cases where major land use changes have altered the purpose split between zonal pairs. Table 4 shows the overall results of this process, with the 1975 purpose splits for comparison.

3.8 Temporally disaggregating the HBW private matrix

Fig. 13 shows in tabular form the 9 parts of the HBW private vehicle matrix and the nine parts of the "other" private vehicle matrix (CVs not included). This section describes the procedure used for disaggregating the first six parts of the HBW matrix, i.e. those with destination in the central or intermediate areas.

As already mentioned, the strategies to be tested applied only to firms in the central area, and therefore it was not necessary to have arrival profiles for individual firms in areas outside the centre. For HBW trips to intermediate area destinations therefore, one arrival profile was established for the whole area, this being the same as the aggregate profile for all central area firms.

Once profiles had been obtained or estimated as described in Chapter 2, they were added together on a zonal basis, weighted by the number of employees in each firm arriving by car. Then, by assuming that the profiles of firms employing less than 15 (which in 1976 accounted for 25% of total employees in the central area, 6% intermediate) are not substantially different from those employing more, these zonal arrival profiles were applied to those parts of the HBW matrix with destinations in the central and intermediate areas. The zonal arrival profiles were applied by destination zone, by applying a factor H_t to each element in the column where

$$H_t \doteq \frac{\int_{t+L}^{t+L+\Delta t} f(t)\,dt}{\int_{L}^{n\Delta t+L} f(t)\,dt}$$

Where H_t = factor for time slice beginning at time t, into which the trips are being apportioned.

TABLE 4

1975 and 1980 O-D Matrices (7.45-9.15 am) by Purpose

PURPOSE	1975	1980 UP DATE	
	%	%	TRIPS
CV	18	19	3151
HBW	53	51	8301
OTHER	29	30	4942
TOTAL	100	100	1,6394

Fig. 13 Relationship of cordon flows to parts of the matrix (Private veh. trips)

	1	2	3	4	5	6	7	8
Purpose	Part * of matrix	No. of trips	Covered by firms surveys	Remainder	Inner Cordon Inbound	Inner Cordon Outbound	Outer Cordon Inbound	Outer Cordon Outbound
Home based work	$C-C_w$	24	✓					
	$I-C_w$	57	✓		X			
	$E-C_w$	2855	✓		X		X	
	$C-I_w$	28	✓			X		
	$I-I_w$	38	✓		•	•		
	$E-I_w$	1383	✓		•	•	X	
	$C-E_w$	413		✓		X		X
	$I-E_w$	390		✓	•	•		X
	$E-E_w$	3113		✓	•	•	X	X
All other private veh. trips	$C-C_o$	121		✓				
	$I-C_o$	103		✓	X			
	$E-C_o$	1382		✓	X		X	
	$C-I_o$	87		✓		X		
	$I-I_o$	44		✓	•	•		
	$E-I_o$	560		✓	•	•	X	
	$C-E_o$	971		✓		X		X
	$I-E_o$	313		✓	•	•		X
	$E-E_o$	1360		✓	•	•	X	X

Key

X Trips intercepted in full by the given cordon.

• Only some trips intercepted - most pass around cordon.

* See Figure 12: w : work; o : other.

Δt = length of time slice

n = no of time slices over the period of the total O-D matrix

$f(t)$ = the arrival profile function

L = time lag

The time lag L is to account for the difference between the time at which vehicles traverse the cordon, and the (later) time at which the occupants of those vehicles arrive at work. It is an average figure, obtained from surveyed network times as 5 minutes.

3.9 Temporally disaggregating the "other" private vehicle matrix

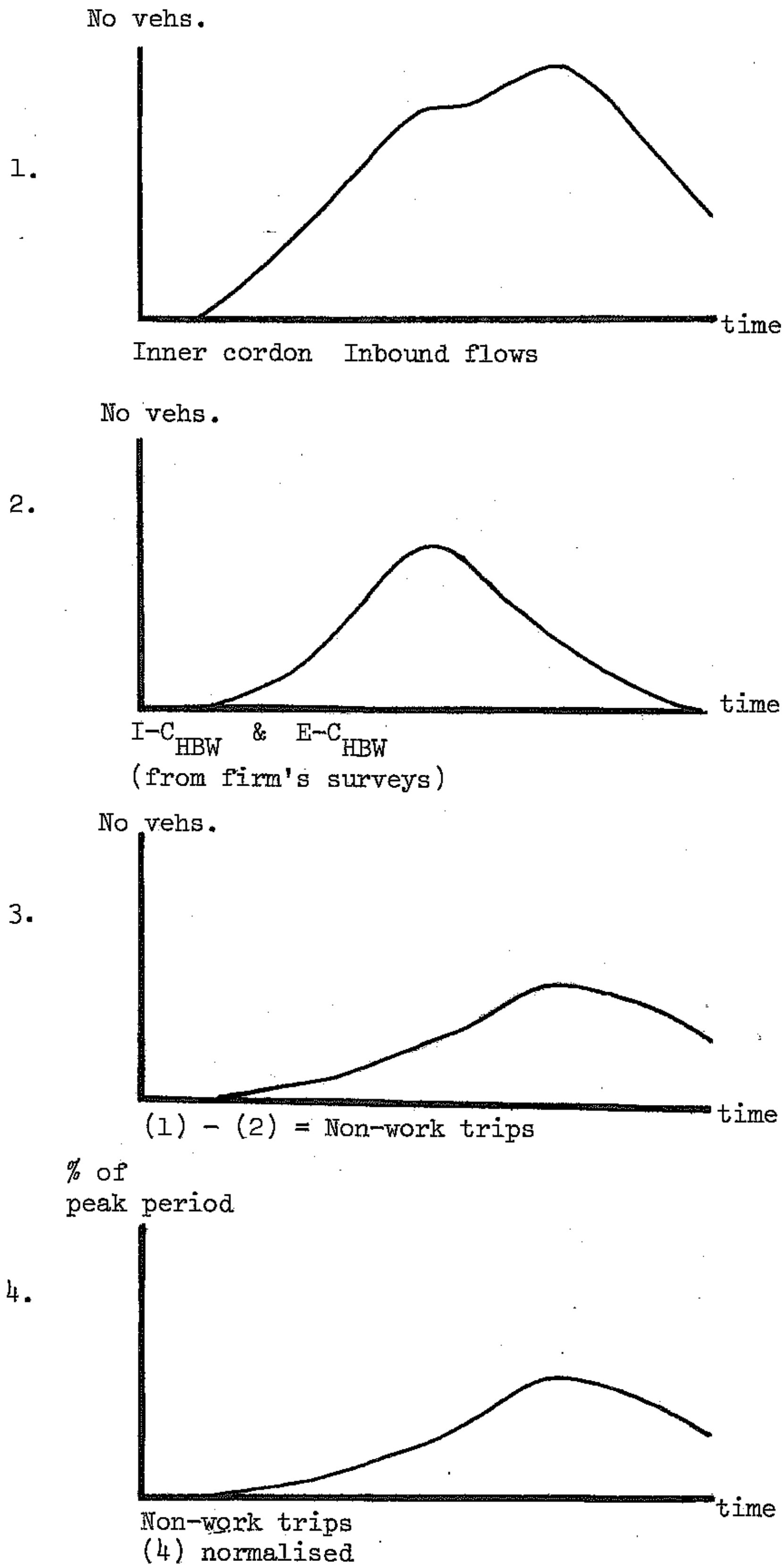
This section deals with the method for dealing with the remaining three parts of the HBW matrix (trips with external destinations) and all other private vehicle trips combined. Fig. 13, col. 4, shows the parts which have to be disaggregated and col. 2 shows the number of trips in each part (only those trips which traverse part of the SATURN network are included). Cols. 5 to 8 show the parts of the matrix which are intercepted by each of the two cordons, in each direction. It can be seen that the outer cordon outbound (col. 8) intercepts all the remaining portion of the HBW matrix, the equivalent parts of the "other" matrix, and nothing else. Hence profiles obtained from outbound flows at the outer cordon can be applied directly to the sum of these six parts (i.e. all trips with external destinations).

To avoid problems caused by route choice, the cordon flows were added to produce one profile, which was applied to the sum of the six parts uniformly (i.e. one factor per time slice).

Note that as we are not using the cordon flows in terms of absolute numbers, but rather are looking at the relative flows at different times in the peak period, it is not necessary to have a completely "car-tight" cordon, i.e. no harm will be caused by leakages through minor uncounted roads. (This is not so for the inner cordon as will be shown later.)

There therefore remain to be disaggregated, those parts of the "other" matrix with central and intermediate area destinations. As can be seen, no cordon matches these flows particularly well, (a perfect match being where the flows to be split are counted, and no other flows are counted.) However it is possible because of the location of the inner cordon (inside the inner relief roads) and the relative number of trips in each part of the matrix, to use the inner cordon inbound flows in conjunction with parts of the already disaggregated HBW matrix, as follows (see Fig. 14).

Fig. 14 Production of profile for application to "OTHER" private veh.matrix.



1. All private vehicle trips inbound at the inner cordon are summed and a flow profile produced as in Fig. 14(1). This profile shows numbers of vehicles by time period, rather than percentages.
2. The profile produced in (1) includes trips in six parts of the HBW matrix as indicated in Figs. 12 & 13. For four of these parts (intermediate to intermediate, intermediate to external, external to external, and external to intermediate) the number of trips intercepted by the cordon will be minimal, due to its location, and these parts can therefore be disregarded: However the intermediate to central area and external to central area HBW trips are fully intercepted by the cordon, and as these trips are likely to exhibit a markedly different profile from the non-HBW trips, their effect must be removed.
3. This can be done by obtaining the profile for these trips from the firm's surveys, and subtracting this from the cordon profile to produce a profile Fig. 14(3) composed mainly of parts 2 and 3 of the non-HBW matrix, i.e. intermediate to central and external to central area non-HBW trips.
4. There are still four parts of the non-HBW matrix either not covered or only partially covered by the profile obtained in (3). However the numbers of trips in all these parts bar one are relatively small and therefore their effect on the shape of the profile can be disregarded. The one exception is external to intermediate area trips. These form quite a substantial portion of the trips being temporally disaggregated, however there is no reason to think that their profile will be substantially different from the rest of the trips in the same purpose groups. Thus it is considered reasonable to apply the profile shape of Fig. 14(4) to all the remaining parts of the "other" matrix, i.e. those parts with central or intermediate area destinations.

3.10 Temporally disaggregating the CV matrix

Because it was possible to identify CV's during the cordon counts, it became possible to disaggregate the CV matrix using this cordon data.

As before, a profile was fitted to the cumulative cordon crossing count data in order to smooth out variations, but in this case a third-degree polynomial rather than a logit curve gave the best fit. For trips with central area destinations, the inner cordon inbound flows were used; for intermediate area destinations the outer cordon inbound flows were used, and for external destinations the outer cordon outbound flows were used.

4. SATURN MODIFICATIONS AND APPLICATION

4.1 Introduction

In order that we could model the effect of changes in the temporal distribution of trips throughout the peak period it was necessary that modifications be made to SATURN, which until that time was only capable of modelling a single (assumed uniform) time period. These modifications mainly concerned the passing over of queues found at the end of one time period to the subsequent period. Ideally the basic simulation and assignment algorithms in SATURN would have been exactly the same in the modified version as in the version used in the earlier UPDATE procedure. However, SATURN was in an active stage of development at the time, and in fact between our UPDATE stage and our strategy testing stage a fairly major improvement was made to the algorithm for simulating delays at roundabouts. This could not be ignored, as there were several roundabouts in the Wakefield network, and it was therefore necessary before testing any strategy, to recalibrate the network (particularly the parameters for roundabouts such as critical gap) against the total 1 hr O-D matrix. The results of this reclaibration are described in Chapter 5.

4.2 SATURNQ

Having recalibrated the network, we were then in a position to run SATURNQ (the version of SATURN which deals with linked time periods). The main problem in using SATURNQ (or any other model which treats flow as a continuous variable rather than discrete vehicles or 'packets' of vehicles) is that the model assumes that the O-D input represents average steady state conditions for the whole of the modelled period (1 hr; 15 minutes etc.). However O-D's and flows may actually be changing over the course of the modelled period, and hence some junctions, for example, may be undersaturated at the beginning of the period but oversaturated at the end. This leads to two problems:

(1) Does the assumption of 'average' flows lead to bias in the output results for delays, queues, etc.?
(2) How should the queues formed at the end of one period be passed on to the subsequent one?

For (1) we can be sure that, if the relationship of delays, queues etc. to flow is not linear then the 'average' delays etc. produced by assuming an average flow will be biased. In fact the relationship is not linear, but the bias so produced can be minimised by modelling sufficiently short time periods to minimise the non-linearity effect.

For (2) SATURNQ finds which queues have formed and not cleared at the end of the first period, and notes the paths which the vehicles in those queues were assigned to take. Before the second period O-D is assigned, the uncleared queues from period one are loaded on the network on their previously assigned paths, but all queues are set to zero.

Therefore the delays and queues reported for each time period are those which would be produced by the particular O-D in isolation, except in so far as the effective capacity of certain links in the network is reduced by the presence of flows from the preceding period. The SATURNQ documentation describes the procedure as follows:

"Since the simulation stage of SATURN is essentially static, the presence of queues cannot be modelled directly, and approximations are made when modelling queues passed between successive time periods.

It is assumed that queued traffic will clear during the following period and queues are loaded as fixed volumes on the routes determined in the first time period. One effect is that the overall statistics concerning delayed time may be inaccurate and should be taken as indications rather than absolute measures."

This is obviously not the perfect solution, and a better solution would be for example to pass on the queues as well as the flows. However this would have involved a considerable programming effort by the SATURN team, beyond the man-hours available at the time.

Nevertheless, it was felt that the simplified procedure adopted, while perhaps not being capable of reproducing the base conditions accurately, would still be capable, with the use of some manual adjustments, of reflecting the difference between the various test strategies.

The manual adjustments mentioned were required where it was desired to know the queue lengths and delays/vehicle at specific junctions. As already mentioned, the program set the queues to zero at the start of each period, so that if a queue on a link was uncleared at the end of period t, the delay to all vehicles on that link in period t + 1 would be under-reported by an amount approximately equal to the time it would take the previous queue to disperse.

These manual adjustments were carried out for all oversaturated links and are incorporated into the figures reported in this paper and in May and Montgomery (1983).

5. CALIBRATION, VALIDATION AND STRATEGY FORMULATION

5.1 Recapitulation

As described earlier in Chapter 3, the original O-D matrix was (1) updated to agree with measured 1980 hourly link flows, (2) growthed up from 1 hr to $1\frac{1}{2}$ hrs; (3) disaggregated by purpose and by time.

Before proceeding any further, it was thought prudent to check that the sum of the disaggregated matrices was still compatible with the results of the UPDATE runs, i.e. that no arithmetical mistakes had been made in any of the numerous manipulations described above. Table 5 shows the totals of the O-D matrices (all purposes) dissaggregated by time giving a total for the $1\frac{1}{2}$ hour period 7.45-9.15 of 16,378 trips. This compares with the total trips after updating (but before disaggregation) of 3151 (CV) + 8,301 (HBW) + 4,942 (OTHER) = 16,394 (TOTAL) i.e. 16 trips have been lost in the various manipulations of the disaggregation process (due to rounding errors) which is less than 0.1% of the total.

TABLE 5

O-D TRIP TOTALS FOR 1980 BASE STRATEGY BY TIME (ALL PURPOSES)

Time Period	Total Trips
7.45-8.00	2228.6
8.00-8.15	2733.5
8.15-8.30	3057.1
8.30-8.45	3032.5
8.45-9.00	2853.8
9.00-9.15	2472.5
TOTAL	16378.0

5.2 Calibration Runs

Having obtained a set of temporally disaggregated O-D matrices as already described, which because of the UPDATE process were known to be broadly in agreement with measured link flows (Table 3), it should then have been possible to proceed directly to the next stage of assigning the 15 minute O-D matrices to the network via SATURNQ. However as explained in Chapter 4, changes had been made to some SATURN algorithms in the interim, and it was therefore necessary to recalibrate the network in order that the total O-D matrix should still produce broadly the same flows, queues and delays as at the end of the UPDATE process.

The methods used for 'fine tuning' the network included: altering the minimum acceptable gaps at (1) priority junctions, (2) roundabouts in the simulation stage; adjusting the saturation flows at individual junction approaches; adjusting the assumed free-run time on individual links.

Furthermore, it should be noted that although the junction of Barnsley Road and Doncaster Road south of Chanty Bridge was geometrically a roundabout, it was always police controlled during the peak period and hence behaved operationally as a signal controlled junction. For this reason it was decided to model this junction as if it were signal controlled, with cycle time, green times and stagings obtained by observation. Minor changes to the green and cycle times at this junction therefore provided another source of fine tuning.

The criteria used to determine whether the network was being modelled correctly were: (1) hourly flows on the 11 links crossing the internal cordon inbound, separately and in total. (2) queue lengths at selected junction approaches.

Table 6 shows the progress of criterion (1) through the runs, where it can be seen that by the final run total cordon crossing inbound flows differed from the observed by less than 5%, with individual links differing by from 0 to ± 37%.

For criterion (2) there was no data on queue lengths available, so that this test consisted simply of ensuring that the modelled queue lengths were reasonably consistent with our local knowledge of the conditions at the given junctions.

TABLE 6

COMPARISON OF MODELLED VERSUS OBSERVED FLOWS FOR CALIBRATION RUNS

Station No.	1	2	3	4	5&6	7	8	9	10&11	TOTAL
Observed Flow	134	625	328	679	955	416	614	578	1218	5547
Modelled Flow										
CALIBRATION RUN NUMBER										
1										
2	518	562	160	494	980	353	685	668	953	5373
3	314	676	172	660	818	354	629	535	919	5077
4	580	662	163	615	887	353	692	593	1086	5631
5	615	647	174	582	914	354	682	630	1076	5674
6										
7	680	585	295	697	889	353	652	648	1022	5821
8	221	648	228	609	894	354	681	661	1064	5360
9	110	645	230	459	1043	353	693	737	1007	5277
10	109	673	201	504	1001	353	671	710	1089	5311
11										
12	145	689	209	547	960	354	643	710	1029	5286
13	165	691	206	539	955	354	638	713	1047	5308
% diff last run	+23	+11	-37	-21	0	-15	+4	+23	-14	-4.3

5.3 Validation

Having satisfied ourselves that the network and total O-D matrix were satisfactory, it was then possible to proceed with the next stage of assigning the temporally disaggregated O-D's using SATURNQ. Because the cordon crossing flows had been used in the disaggregation process, it was thought that it would not be very instructive to compare modelled and observed cordon flows. Rather, it had been decided at an early stage in the study that a useful measure of the accuracy of the whole modelling process would be the travel times on selected congested links through the peak. In order to measure these travel times, number plate matching surveys were carried out on three approach corridors, viz Barnsley Rd, Doncaster Rd and Westgate. One observer was stationed at each of several points on each route, and recorded the last four digits (3 numbers and year letter) of all buses and lorries and most cars. The registrations were recorded using portable tape recorders, and the time of day was also recorded at approximately 5 minute intervals so that when later transcribing the tapes a curve fitting routine could be used to relate clock time to the position on the tape for each registration (Montgomery, 1983).

After assigning a clock time to each registration number, a standard matching program was used to determine the mean travel time between survey points by 15 minute periods from 7.30 to 9.30 am.

Figures 15 and 16 show for Barnsley Rd and Doncaster Rd respectively, the measured mean travel times and those modelled by SATURNQ. It can be seen that for Barnsley Rd there is quite a large discrepancy for the first half of the modelled period reaching convergence in the second half. For Doncaster Rd however the discrepancies are remarkably small over the whole peak. (On Westgate both modelled and surveyed delays were very small.) It was considered that the results depicted in Figs. 15 and 16 were as good as could be expected, considering that:

(i) The number plate matching surveys were carried out on one day only at each site (18th and 19th November 1980) whereas the O-D matrices were based on 1975 data updated using link flows collected over several months in 1980.

(ii) The junction causing the delays on these two links was in fact a roundabout controlled by police, and was therefore modelled as if it were traffic signals.

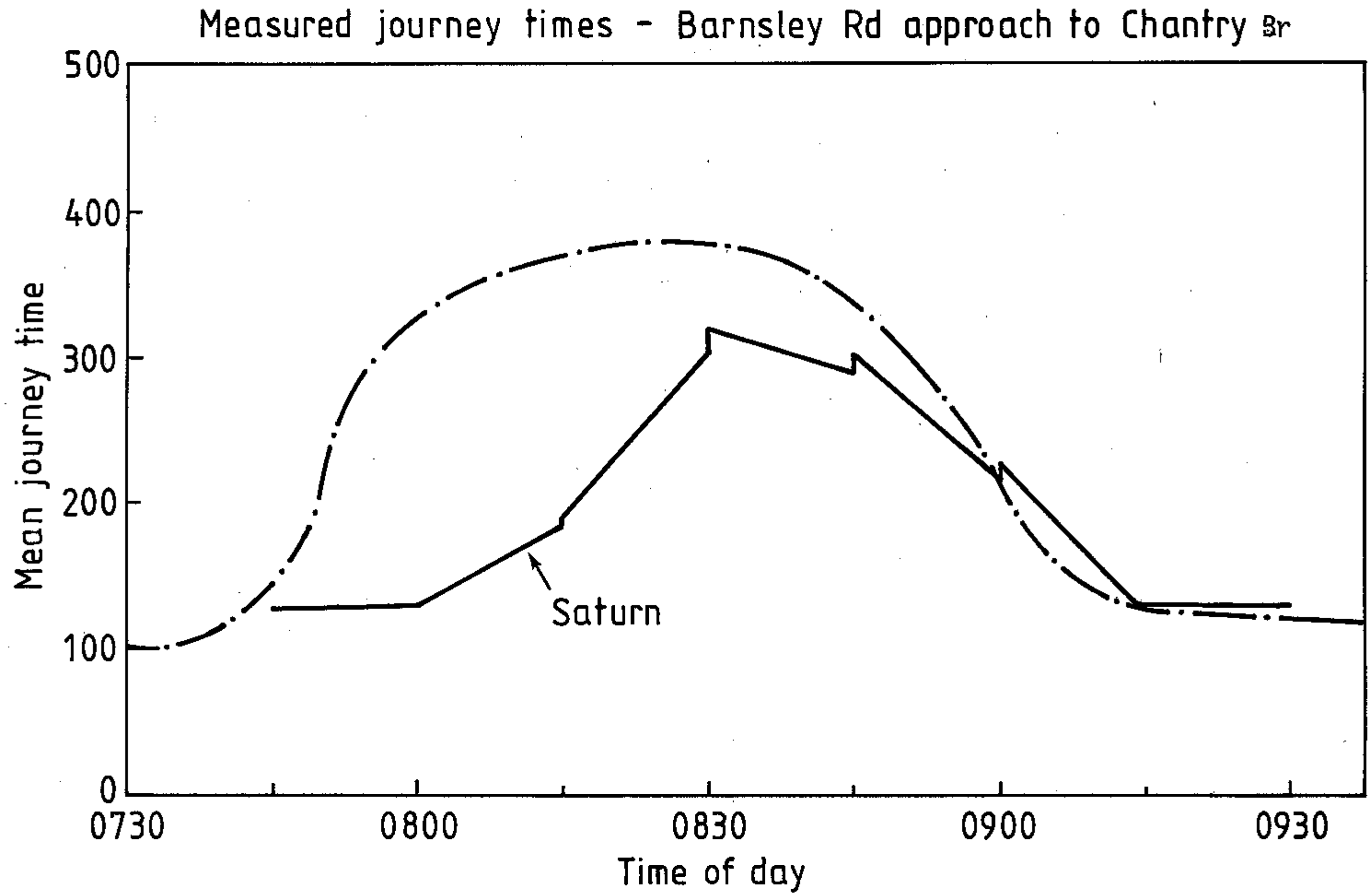


Fig. 15 d = 1.33 km, uncongested J.T. = 100 secs (at 30 mph)

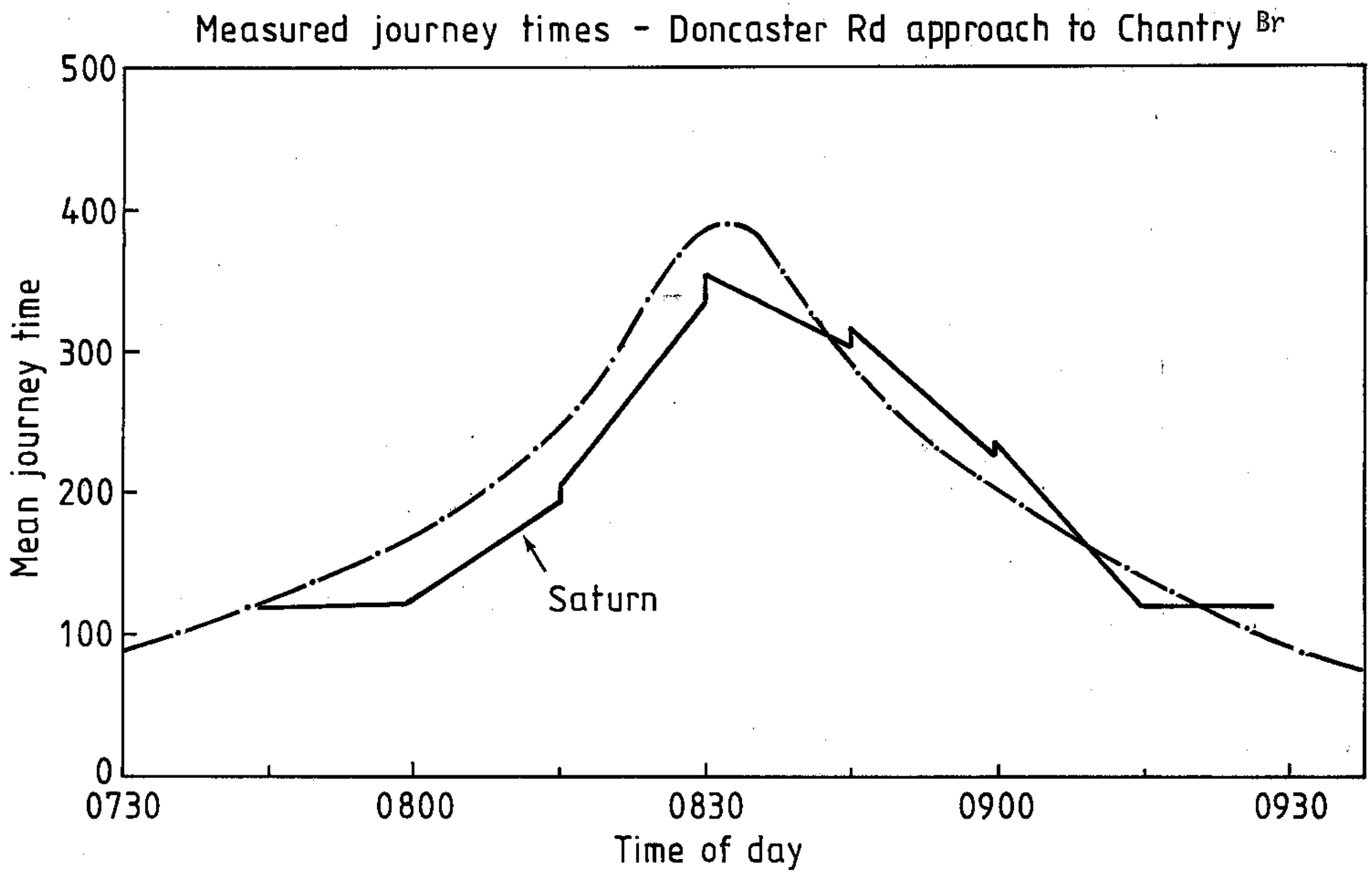


Fig. 16 d = 1.33 km, uncongested J.T. = 100 secs (at 30 mph)

(iii) The presence of 'outliers' in the travel times obtained by the matching process may have biased the mean travel time upwards. (The extent of this problem was not known at the time of the surveys, but has since been investigated at some length - see May, Montgomery and Fowkes, 1983).

5.4 Strategy Formulation

It had been decided at an early stage that, rather than attempt to predict the response and efects on traffic of one strategy for rescheduling, several strategies would be tested, thus providing an indication of the range of likely effects.

Strategy 1. Base Condition, the purpose of which was to validate the model as already described, and to act as the benchmark from which to compare the effects of other strategies.

Strategy 2. Previous Condition, the purpose of which was to estimate the benefits gained by those flexible and staggered hour arrangements which had already been adopted.

Strategy 3. Feasible FWH/Internal Staggering. This and the following two strategies were meant to reproduce the effects likely to be achieved if a local authority actively promoted work journey rescheduling in the central area. In this strategy only flexible hours and internal staggering (i.e. staggered work hours for employees within the same firm) are promoted, and it is assumed that half the firms concerned are unwilling to co-operate.

Strategy 4. External Staggering. As for 3, but where external staggering is promoted (i.e. start times of whole firms are staggered in relation to adjacent firms).

Strategy 5. Combination of Strategies 3 and 4.

Strategy 6. Maximum Effect. As for 5 except that the effect of 'lack of co-operation' was removed.

5.5 Details of Adjustments made to Model Strategies

Chapter 2 described how the arrival pattern of employees by car at each firm was modelled by a logit curve, with the parameters α and β, α representing the average arrival time and β the spread of times. This section describes for each strategy 1) How it was decided which firms would change their work hours; (2) How the size and type of change was decided upon. Table 7 summarises the numbers of firms and car drivers affected by each strategy.

Strategy 2 - Previous Condition

For this strategy a list was drawn up of all central area firms which were currently on flexible or staggered hours (46 out of a total of 97). In order to simulate conditions prior to the introduction of flexible hours in these firms, the β value for each firm was raised by 0.0455, this being the difference between the mean β for surveyed fixed hour firms (0.1154) and the mean β for other surveyed firms (0.0699). These means are the unweighted arithmetic means of the fixed hour firms, and flexible or staggered hour firms shown in Fig. 9.

Strategy 3 - Feasible FWH/Internal Staggering

For this strategy a list was drawn up of all central area firms which were currently on fixed hours (the converse of 2 above). Those firms for which flexible hours or internal staggering was considered feasible were then determined, on the basis of SIC and knowledge of individual firms. In general FWH/Internal Staggering was considered feasible in all except SIC No. 3 (Dairy company), 20 (Construction), 23 (Distributive Trades) and 26 (Miscellaneous), except that large stores (SIC 23) were considered feasible.

Having now obtained a list of all firms currently on fixed hours for which FWH/Internal Staggering was considered feasible, the effect of non-co-operation with a local authority promotional campaign was modelled by assuming that only 50% of these firms would in fact respond. The firms deemed to co-operate were chosen at random, and their change in work hours was modelled by lowering their β value by 0.0455, the same value used in the previous strategy.

TABLE 7

NUMBERS OF FIRMS (AND CAR DRIVER EMPLOYEES) AFFECTED BY EACH WJR STRATEGY

Strategy	1	2	3	4	5	6
No. of firms thought capable of co-operating (car drivers)	97 (2433)	-46 (-1365)	25 (640)	26 (428)	51 (1068)	51 (1068)
No. of firms 'asked' to co-operate (car drivers)	N/A	-46 (-1365)	25 (640)	22 (310)	47 (950)	47 (950)
No. of firms 'agreeing' to co-operate (car drivers)	N/A	-46 (-1365)	13 (375)	11 (179)	24 (554)	47 (950)

Strategy 4 - External Staggering

For this strategy again all firms currently on fixed hours were listed, but this time our interest was in those firms where FWH/Internal Staggering was considered infeasible (i.e. the converse of 3 above). A histogram was then drawn of the start time of these firms, from which it could be seen that the great preponderance (17 out of 26) started at 9 am. With the purpose of the exercise being to smooth the peak, it was considered that not all firms would be asked to change their hours, but only those whose employees were arriving at the peak time. The strategy decided upon attempted to achieve the maximum smoothing with the least amount of change to individual firms, and consisted of asking 2 firms starting at 8.45 to move to 8.55; 3 firms from 8.50 to 8.55; 5 firms from 9.00 to 9.05; 6 firms from 9.00 to 9.10; and 6 firms from 9.00 to 9.15. These firms' α values were changed accordingly.

Finally, once again the effect of non-co-operation was modelled by assuming that only 50% of those firms 'asked' would in fact change their hours, these firms being chosen at random. The change in start time was effected by increasing the α value by the appropriate amount.

Strategy 5 - Combination of 3 and 4

All firms deemed to co-operate in 3 plus all those deemed to co-operate in 4.

Strategy 6 - Maximum Effect

In this strategy the non-co-operation effect was removed, so that all firms where FWH/Internal Staggering was considered feasible in Strategy 3 were considered to co-operate, and all firms which were asked to change their hours in Strategy 4 (External Staggering) did so.

6. CONCLUSIONS ON OUTSTANDING MODELLING ISSUES

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 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.

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 fairly 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.

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.

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.

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.

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.

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TRAFFICQ	A comprehensive model for traffic management schemes. D.M.W. Logie, Traffic Engineering and Control, Nov. 1980.
TRANSIGN	'Control and Routeing in a road network' J.A. Charlesworth, Traffic Engineering and Control, Oct. 1979.

APPENDIX A

Summary of SIC Orders

1. Agriculture, Forestry, Fishing
2. Mining and Quarrying
3. Food, Drink and Tobacco
4. Coal and Petroleum products
5. Chemical and Allied Industries
6. Metal manufacture
7. Mechanical Engineering
8. Instrument Engineering
9. Electrical Engineering
10. Shipbuilding and Marine Engineering
11. Vehicles
12. Metal goods not elsewhere specified
13. Textiles
14. Leather, Leather goods and Fur
15. Clothing and Footwear
16. Bricks, Pottery, Glass, Cement etc.
17. Timber, Furniture etc.
18. Paper, Printing and Publishing
19. Other manufacturing industries
20. Construction
21. Gas, Electricity and Water
22. Transport and Communication
23. Distributive Trades
24. Insurance, Banking, Finance, and Business Services
25. Professional and Scientific Services
26. Miscellaneous Services
27. Public Administration and Defence

APPENDIX B

1. Requirements of a Model to Test the Response to Work Journey Rescheduling Policies

It is not intended at this stage that specific policies should be tested in Wakefield; rather the intention is to predict the effects of possible policies, and to understand the causal process by which such effects would occur. To do this it is necessary to construct a model which describes the process of choice of time of travel. Such a model could also help overcome the problems of isolation of effects of any one measure from seasonal and other changes, and enable the understanding gained from work in Wakefield to be transferred to and applied in other locations.

Such a model needs to be able to describe:

(i) the existing pattern of travel to work;
(ii) the constraints which limit choice of time of arrival;
(iii) the costs of using alternative modes at different times;
(iv) the choice process for selecting time of travel based on these constraints and costs;
(v) any changes in mode accompanying such changes in time of travel;
(vi) the response of the transport system to changes in the temporal and modal distribution of demand and hence changes in the costs in (iii) above;
(vii) the resulting costs and benefits accruing from transport system operation and use, including both the potential advantages and disadvantages described above.

2. Philosophy of this Approach

Certain a prior assumptions and assertions have been made regarding the decision process followed by an individual in deciding when to leave for work, and by which mode. These are:-

(1) The decision process is one of a limited choice within constraints.

(2) The constraints include those at the work end and at the home end of the trip. (But also see 7 below.)

(3) The workplace constraints are the earliest and latest official time for starting work. These two times will coincide when fixed hours apply.

(4) The household constraints include such things as: having to take children to school, giving/getting a lift from someone else, not being able to leave until all the children have been taken to school, etc.

(5) The household constraints come into play only when the workplace constraints leave room to manoeuvre and vary according to the 'life-cycle' of the worker (single person; married with no children; with pre-school children; with school children; with elderly relatives, etc.). For example a mother may take her children to school before going to work, and will thus be less able to vary her work times than a mother whose children have grown up.

(6) The avoidance of traffic congestion is not a constraint, but enters the decision process by contributing to the utilities of the available choice set.

(7) Within the personal constraints determined by the intersection of the workplace and household constraints, the choice of which time to leave for work, and by which mode, is based on utility maximisation, constrained by the availability of modes at certain times (including the effects of bus timetables, availability of lifts in cars).

3. Idealised Model Structure

Ideally the most suitable structure of model appears to be as shown in Figure 1. It is a two-tier model in which the first tier is a disaggregate model in which the decisions on time, and mode of travel of individuals in the light of constraints and costs are simulated. The output of this first tier would be a series of modal O-D matrices, one for each 'time-slice' of, say, 10 minutes. These would be input to the second tier of the model which would be one or more aggregate assignment models describing the effects on the private and public transport systems. Other inputs to this stage would be any changes in the costs of using the systems as a result for instance of restraint policies or fares changes. There would need to be feed-back from the second tier to the first to allow the revised congested link times calculated by the assignment model to be used as updated input to the first tier.

The most suitable form for the first tier of the model appears to be a microsimulation approach, and this is outlined in Section 4.

There are several candidates for the private transport element of the second tier of the model (SATURN, TRAFFICQ, CONTRAM, TRANSIGN) but all would require modifications in terms of programming language and ability to model short time-slices or to transfer queues from one time period to another and some are not capable of modelling large areas. It may well be that a modified version of SATURN is most appropriate since it is in-house and would require little modification.

There seem to be few options for the public transport element but one, TRANSEPT, may be appropriate.

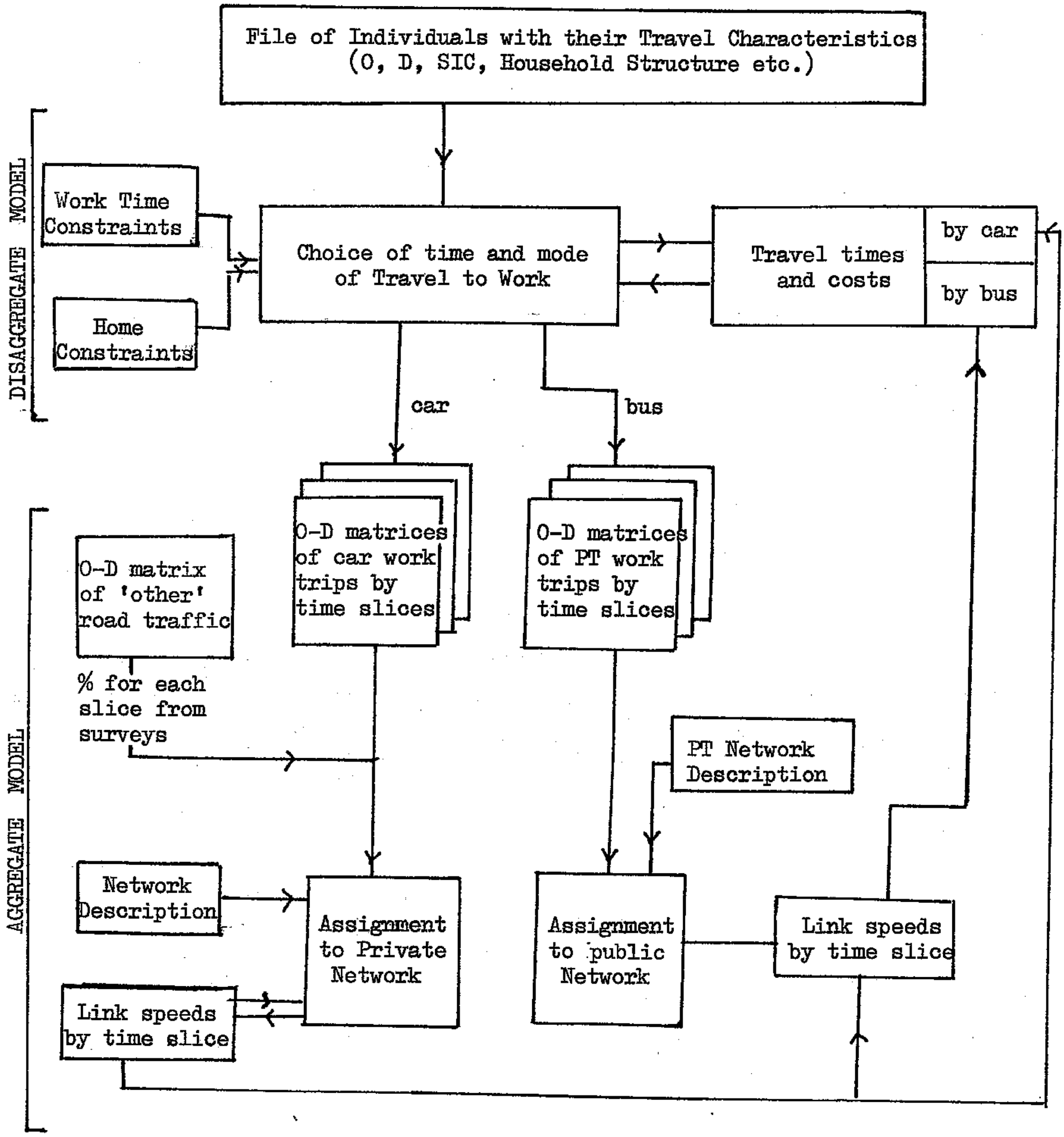


Figure 1. Idealised Structure for Work Journey Rescheduling Model.

4. Microsimulation Approach to Work Journey Rescheduling

In this approach we would:

Simulate the decisions of 'situation groups' (Kreibich 1978) (henceforth called 'decision groups').

Each 'decision group' defined by such parameters as life cycle group, sex, car availability, etc., and SIC of workplace.

The No. of Groups depends on distribution of the above parameters, i.e. life cycle groups, sex, car availability and on distribution of SIC.

For each group in turn, the microsimulation approach would simulate the decision made by the group as to what time to leave home for work, and by what mode. (The process really simulates the decision of one person, who is taken to have a representative probability of the whole group - i.e. we are assuming sets of people in each group, who have identical probabilities of making identical decisions, but this will not affect the outcome as long as person-to-person interactionsare not involved, as in car-sharing

It is assumed that the decision as to when to leave home for work depends on constraints at the workplace (earliest and latest allowable start times), constraints at the home end (earliest possible and latest possible time of leaving) and the time (traffic conditions, comfort, convenience) taken to travel from home to work. The remaining choice within the final constraints will be based on utility maximisation across available times and modes.

i.e.

CONSTRAINTS
HOME
PREFERENCES

$\xrightarrow[\text{congestion time}]{\text{free speed time}}$

CONSTRAINTS
WORK

Hence for each O-D pair/decision group combination, we firstly work out the choice set as follows:-

(Earliesttime of leaving home to satisfy work constraint) =	(earliest allowed time at work)(tw)	(+ lateness - early arrival)	- (journey time t_{ij} at time t_w by mode m)
	Sampled by MC* method from table of earliest allowed start times by SIC(from surveys)	Sampled by MC* from results of H-H interviews	from O-D table of congested journey times (one table for each time slice) iterative input

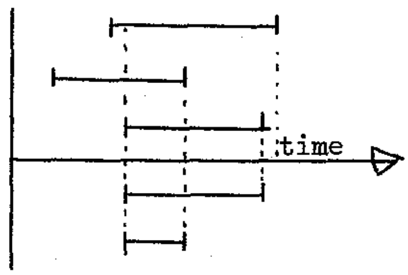
* MC = Monte Carlo

Similarly, the latest time of leaving home to satisfy work constraint, is found.

We now have earliest and latest times due to work and traffic, translated to the home end. (one set of earliest and latest times for each mode).

The second stage is to find the intersection of the above constraint ranges with the home constraints - the home constraints are found by MC* sampling from surveyed earliest and latest possible leaving times by life cycle group, sex, car availability and distribution of SIC.

e.g. Poss. times by car
Poss. times by bus
H.H constraints
Hence final choice set by car
final choice set by bus



The final decision within this choice set would be based on the utility of each mode at each time. The exact formulation of this choice model will require some considerable thought, but should ideally (essentially?) incorporate data on availability of each mode at each time (slice), to account for:- the discontinuous nature of bus/train services; the unavailability of cars for car sharing at certain times; unavailability of car parking space at work end after certain time.

When a time and mode has been chosen for each decision group within each O-D pair, the number of persons in the group is placed in the appropriate time slice of the O-D matrix. Once all decision groups have been simulated, the modal split could be calcualted and checked with existing data (for calibration) or for reasonableness otherwise. One would also have at this stage, the demand profile for each mode by zone of origin.

Notes: (a) As well as the HBW matrices from microsimulation, the 'OTHER' matrices (HBO, EDUC, NHB) would have to be assigned. Some heroic assumptions may have to be made regarding the time profiles of these matrices. However, errors in these assumptions (unless gross) should not affect the overall model too much because (1) the 'other' matrices are a minor element in the peak hour (but not so minor in the peak <u>period</u>).

---

* MC = Monte Carlo

(2) We are interested mainly in <u>Differences</u> in congestion etc., between policy options - a <u>constant error</u> will not affect these differences very much.

(b) There could be a danger of oscillation of trips <u>between time slices</u> in successive iterations, in much the same way as occurs <u>between routes</u> in A-O-N assignments.