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TRAVEL TIME MONITORING IN URBAN AREAS
SURVEY DESIGN

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Travel Time Monitoring in Urban Areas - Survey Design

CONTENTS

ABSTRACT

This paper describes the design of a survey to measure variations in travel time and their possible causes and to develop cost effective travel time survey instruments. After describing the background and objectives of the study it reviews in turn the uses to which travel time data can be put and the resulting survey requirements, the factors which might cause variations in travel time, and the available survey methods. The survey strategy outlined in the final section is based on these reviews. It concentrates on inbound peak period travel times over five radial routes in Leeds, and uses number plate matching to measure inter-vehicle variation, and moving vehicle observer methods to measure inter-period variation. Two other methods are also employed. The survey period is spread over 14 months to identify seasonal effects, but uses a Latin Square design to reduce the scale of the data collection task.

TRAVEL TIME MONITORING IN URBAN AREAS - SURVEY DESIGN

1. INTRODUCTION

The reduction of urban congestion and the associated delays and variability in vehicle travel time is one of the most important of transport policy objectives, and savings in travel time usually represent the major element in the quantified benefits of transport programmes. Evidence on trends in speeds and travel times must therefore be a vital element in the monitoring process which, as the DTp has emphasised (DoE 1975) is an essential input to the formulation of Transport Policies and Programmes. Despite this, few local authorities carry out regular surveys of travel times and most of those which are conducted involve small, infrequent samples which must be statistically suspect. Moreover, the DTp has recently abandoned its urban congestion study programme (Marlow and Evans, 1978) which, while also statistically suspect, at least represented an attempt to provide national trends.

Table 1 presents the results from this programme for central area speeds in five conurbations and eight towns, together with the GLC's data for central London (GLC, 1981). Outside London these suggest that peak period speeds have been rising despite growth in traffic flow; if these improvements are real they seem likely to be due partly to road improvement and partly to improved vehicle and driver performance, but largely to traffic and parking management. Comparison with off peak speeds has led central government (Department of the Environment, 1976) to suggest not only that conditions are improving but that there is little room for further improvement. In turn this led them to downplay the need for traffic restraint and other restrictive policies. The London results, however, tell a different story. They demonstrate that most of the gains in the early 1970's have been reversed since then, that there is a limit to the improvements that can be achieved through traffic management and that other factors (in this case, probably, reduced compliance with parking controls) can affect conditions adversely. The results of such monitoring exercises are clearly important for policy formulation at both national and local level; they need to be maintained, and the data collected in them needs to be sufficiently reliable for resulting policy decisions to be securely based.

Table 1 - CONGESTION LEVELS

SPEEDS (km/h) IN CENTRAL AREAS OF UK TOWNS AND CITIES

Year	Greater London		Provincial Conurbations		Provincial Towns	
	Peak	Off Peak	Peak	Off Peak	Peak	Off Peak
1967/8	20.3	19.7	14.9	17.6	18.2	19.7
1971	20.6	20.2	17.7	20.2	19.7	23.4
1974	22.7	20.6	n.a.	n.a.	n.a.	n.a.
1976/7	19.7	20.2	20.5	21.4	20.8	24.9
1980	19.4	18.6	n.a.	n.a.	n.a.	n.a.

SOURCE: Greater London, 1981
Other areas, DTp, 1978

While the DTp has abandoned its surveys, local government is actively trying to improve its procedures, through the work of an AMA study group (AMA, 1979). The problem which they face is to determine the cheapest way of obtaining trend data of a given level of statistical reliability. This in turn raises questions of the costs of alternative data collection methods, the reliability with which they can measure a given set of travel times or speeds, and the sampling procedure for selecting locations and times at which surveys should be conducted to represent conditions at other times or over a wider area. The problem is akin to one which the DTp's Traffic Appraisal Manual (DTp, 1981) has tackled in providing advice on traffic counting and on the reliability of flow estimates produced from such counts, but is one on which there has been little analysis or advice.

The Institute for Transport Studies at the University of Leeds has recently been awarded grants by the Science and Engineering Research Council and the Rees Jeffreys Road Fund to provide this advice. While this is the main objective of the study, an essential requirement for it is the development of a clearer understanding of the nature, and ideally the causes, of variations in travel time in urban road networks. This forms an important secondary objective of the study.

This paper describes and justifies the study design adopted. The design procedure involved separate reviews of:

- the possible uses to which travel time data can be put and the survey requirements to which these give rise (section 2)
- the factors which might give rise to variability in travel time and the ways in which these can be measured and their effects isolated (section 3)
- the range of data collection methods available and the sources of error, sampling issues, organisational problems and costs to which they give rise (section 4).

The survey strategy described in section 5 is based on these three reviews.

Subsequent Working Papers will describe the use of the two main survey methods, a comparison of their effectiveness and the study of possible causes of travel time variations.

2. USES OF TRAVEL TIME DATA

The introduction has concentrated on the measurement of in-vehicle time and, more specifically, on time spent on the particular sections of route which are covered by specific surveys. It is important to note that there are other elements of travel time which are of importance in policy assessment, for example time spent waiting for public transport, searching for parking spaces or allowing for unreliability or infrequent schedules, time spent in vehicles on sections of route not surveyed, and time spent in vehicles on alternative routes. Further, it is the total travel time for a journey (and for alternative routes, or destinations, or times of travel) which is often of importance in policy assessment, and one particular local authority has pressed upon us the importance of measuring total journey time. While we accept this argument, we consider that the problems of determining statistical reliability in measuring any element of travel time are considerable, and that the problems differ from one element to another. We have therefore made a conscious decision to limit our analysis to one of these elements, and to concentrate on one for which methodological advice is more urgently needed. We have elected to concentrate on in-vehicle time on specific sections of route, but would hope that the research can be extended in due course to other elements of travel time.

The prime objective of the study can therefore be restated as determining the cheapest way of obtaining in-vehicle travel times on specified routes to a given level of statistical reliability. This in turn raises questions of the types of route for which data is needed, the characteristics of the traffic conditions and movements to be studied, and the level of accuracy to which the data is needed. More specifically under each of these headings it is important to know

- for route type

    i) which urban areas are of interest

    ii) whether information is required both for major and minor roads

    iii) whether information is required for city centre networks, radial or orbital routes

- for traffic conditions

    i) which time periods are of interest

    ii) which times of the year are of interest

    iii) whether particular travel conditions (e.g. dry/wet; day/night are required)

    iv) whether all or specific movements are required

- for issues of statistical reliability

    i) whether measures of mean travel time or the dispersion of travel times are needed

    ii) over what time interval the mean or dispersion is to be measured

    iii) to what level of accuracy the information is required.

To provide guidance on these questions we sought information from DTp, TRRL, metropolitan counties and certain consultants on the uses to which they put travel time data, the form in which they collected the data for these purposes, the level of accuracy which they required and the data collection methods which they used. Answers on the first three of these are reviewed below and on the last in section 4. It is worth noting generally that few suggestions were offered on the level of accuracy required, and it seemed generally that local authorities had given little consideration to this issue.

The main uses to which travel time data can be put were identified as:

i) national performance trends
ii) local performance trends
iii) problem ranking
iv) scheme design
v) scheme selection
vi) highway scheme assessment
vii) traffic management scheme assessment
viii) model development
ix) behavioural studies.

Each of these is described below, and assessed against the questions raised earlier. It should be noted, however, that many of the recommendations given are based on our judgement in the absence of clear answers from our correspondents.

National performance monitoring was the main function of the urban congestion studies (Marlow and Evans, 1978), which were abandoned because they appeared to suggest that problems were diminishing and because, as a result, little use was being made of the data, which was expensive to collect and analyse. Were any reconstituted programme to follow the earlier format it would be sufficient to limit surveys to major roads in selected larger urban areas, to provide data separately at least for peak and off peak and for city centre, inner and outer city, to collect it for a representative and reasonably stable period of the year and not to concentrate on particular conditions or movement types. Simple averages for each time period and area seem sufficient, and, judging from past trends (Table 1) the ability to detect a 5% change with 95% confidence should be sufficient. Indeed, if the survey interval could be reduced from three years to one, detection of 10% changes might be acceptable.

Local performance monitoring is already conducted, for input to TPPs, by GLC, GMC and Tyne and Wear. Other metropolitan counties are interested in developing this facility. No clear specification for such surveys appears from replies received, but it seems reasonable to concentrate on main roads, and perhaps major rat runs, throughout the built up area, to limit coverage to peak and off peak, to provide some data for different times of the year and to ignore specific travel conditions and movement types. It may be necessary to provide averages for individual lengths of route (as GLC does) or simply as averages for areas and time periods; distributions of data are probably not required. No clear guidance is available on reliability requirements; that set out above for national needs may be appropriate.

Problem ranking as a precursor to scheme design has been introduced by West Midlands and the GLC and is being developed by West Yorkshire. Travel times and flows are clearly an important input to the identification of congestion as a problem. For these purposes it seems reasonable to concentrate on main roads throughout the built up area, both peak and off peak; there is probably little need to measure speeds at different times of year (provided that consistent or comparable times of year are always used) or for different travel conditions, but several movement types, and particularly side road delays, may need to be measured. Ranking is probably based on mean travel times per unit distance (or aggregate delays) for individual sections of route and junctions; there may be some merit however in looking at variability in travel time as an additional problem indicator. Differences in such values between locations of less than 10% are probably unimportant.

Scheme design requirements are largely limited to those of traffic management schemes and particularly linked traffic signal systems, where offsets can be designed and redesigned in the light of travel time changes. These are probably of most importance on road networks in and adjacent to the city centre; all roads involved will need to be surveyed, possibly at different times of the year and certainly for several different times of day; individual movements and routes will need to be separately studied but not, probably, differing travel conditions. Both the mean and, for platoon dispersion data, the distribution of travel times will be needed for individual movements over periods probably as short as 15 to 30 minutes. Accuracy requirements appear not to have been studied but must clearly be measured in terms of fractions of a signal cycle, perhaps with errors as low as ± 10 sec.

Scheme selection methods have been developed by several counties particularly for the ranking of highway schemes (Scotland, 1980). They use measures of travel time and congestion in much the same way as problem ranking techniques, the one distinction being their use of predicted values after scheme implementation as well as actual values. Their requirements for pre-scheme measurement are identical to those of problem ranking.

Highway scheme assessment through before and after studies is rarely conducted in practice. Where it is, locations are clearly determined by the schemes themselves, and data can probably be limited to the major roads and any affected rat runs and side road delays, to peak and off peak periods and to one time of the year (provided that the same or comparable times of year are selected before and after). Different travel conditions and movement types probably do not need to be measured. Most comparisons are likely to be based on mean travel times, although a reduction in the dispersion of travel times may indicate additional benefits. These are probably only needed for individual links, and for whole peak or off peak periods. While even quite small changes can be important for economic assessment, changes of less than 10% for high cost schemes are unlikely to be important.

Traffic management scheme assessment through before and after studies is more common, and in particular is frequently conducted for urban traffic control schemes (Holroyd and Owens, 1971, Waller, 1981). Again the nature of the scheme will determine the location for study, but much more detailed information will be required on all roads and movements in the affected network. Otherwise requirements are probably similar to those for highway scheme assessment, with the important exception that greater accuracy is required. As an example, urban traffic control schemes are often reported to achieve average savings of between 5% and 15% (Holroyd and Robertson, 1973; Hunt et al, 1982); this suggests the need to obtain an accuracy of at least ± 5%.

Model development requirements range widely from those of relatively coarse assignment models to detailed signal optimisation and simulation techniques, and from the speed flow relationships required for scheme design to those required for cost-benefit analysis Several respondents have expressed the hope that the data which we collect may be of value in helping to test the performance of existing speed-flow models and in developing new ones, but little guidance is yet available on the level of detail or accuracy required. It seems sensible to start with the coarser specifications, which would limit data requirements to main roads peak and off peak without specification of time of year, movement type or traffic conditions. Mean travel times and dispersions would however be needed for individual links and for periods short enough to experience stable flow levels, which probably limits them to 15 minute periods. Accuracy levels will depend on model use and cannot be specified.

Behavioural studies again can range widely in their requirements and few respondents have been specific as to their needs. Applications suggested ranged from an understanding of route choice and mode choice to the identification of accident causation. Clearly the more detailed of such studies could make very considerable demands on information for different roads and movement types, times of day and travel conditions, and require both means and distributions of times for very specific periods and groups of traveller. Again, accuracy levels required cannot be specified.

Table 2 attempts to summarise these requirements.

It is clear that applications (iv) (vii) and probably (ix) make much more complex demands, and this has led us to concentrate initially on the needs of applications (i) - (iii), (v) (vi) and (viii). This leads to the following requirements:

a) data collected and methods tested should ideally be appropriate to, and representative of any urban area

b) the emphasis should be on major roads and possibly rat runs

c) all areas within urban areas need to be covered

d) peak and off peak conditions need to be studied

e) any time of year can be used, but the ability to compare different times of year and to identify seasonal fluctuations is important.

Coverage \ Applications	(i) National Performance Monitoring	(ii) Local Performance Monitoring	(iii) Problem Ranking	(iv) Scheme Design	(v) Scheme Selection	(vi) Highway Scheme Assessment	(vii) Traffic Management Scheme Assessment	(viii) Model Development	(ix) Behavioural Studies
Urban Areas	Sample	All	All	Selected	All	Selected	Selected	Sample	Sample
Major/minor roads	Major	Major + rat runs	Major	All	Major	Major + rat runs side rds	All	Major	All
Centre/inner/outer	All	All	All	Centre	All	Selected	Selected	All	All
Time periods	Peak/ Off peak	Peak/ Off peak	Peak/ Off peak	Several	Peak/ Off peak	Peak/ Off peak	Peak/ Off peak	Peak/ Off peak	Several
Time of year	Any	Several	Any	Several	Any	Any	Any	Any	Any
Travel conditions	-	-	-	-	-	-	-	-	Several
Movement types	-	-	Main/ Side Rd	Several	Main/ Side Rd	Main/ Side Rd	Several	-	Several
Mean or dispersion	Mean	Mean	Mean and possibly dis- persion	Mean dis- persion	Mean and possibly dis- persion	Mean and dis- persion	Mean and dis- persion	Mean and dis- persion	Mean and dis- persion
Measurement interval	Peak/ Off peak	Peak/ Off peak	Peak/ Off peak	15 to 30 mins	Peak/ Off peak	Peak/ Off peak	Peak/ Off peak	15 mins	?
Measurement location	All roads by area	Indi- vidual links	Indi- vidual links	Indi- vidual move- ments	Indi- vidual links	Indi- vidual links	Indi- vidual links	Indi- vidual links	?
Accuracy	± 5%	± 5%	± 10%	± 10 sec	± 10%	± 10%	± 5%	?	?

- : Not required
? : Not known

Table 2

Travel Time Data Requirements

f) different travel conditions and movement types are unimportant, with the exception that side road delays should ideally be identified

g) both means and distributions are required for periods as short as 15 minutes and for individual links

h) an accuracy of ± 5% at a 95% confidence level appears to be required.

Resource limitations have in fact forced us to restrict the number of these requirements which we can meet. In particular, we have only been able to study one urban area, one type of major road movement (peak inbound on radials) and one time period (see section 5). Requirements (a) (b) and (d) will therefore necessitate further study if they are to be satisfied.

3. FACTORS INFLUENCING VARIABILITY IN TRAVEL TIME

Every commuter knows that the travel time from point A to point B is not a fixed quantity, but varies from day to day about some average value. Most commuters are also aware that journey times tend to be higher at certain times of the year (e.g. winter), certain days of the week, and under certain weather conditions (e.g. heavy rain). These effects will be noticed by those commuters who regularly set off for work at exactly the same time each day: in addition, those who vary their start times will realise that journey times tend to vary throughout the day. On top of all this we know that two drivers setting off from point A at precisely the same time on the same day, and heading by the same route for point B, will not arrive exactly together.

One of the main purposes of this study is to examine the above (and other) variations in travel time, attempt to separate them and then to explain them. We will now look at each of the types of variation in a little more detail.

Unexplained Random Variation. The two cars mentioned in the previous section would not have exactly the same travel times because of

1) differences in acceleration/braking characteristics of the cars
2) differences in driving styles
3) differences in traffic lanes chosen
4) differences in the traffic conditions met once the cars have become separated

These differences are best described as random variation. Thus for each short (say 15 minute) period, car travel times will have a distribution about the mean value. Buses and lorries will have similar but different distributions. We are now interested in the variation in the mean travel times between such periods.

Hopefully most of this variation will be explained by the factors outlined in the following paragraphs, but some will remain unexplained, as residual errors.

The effect of traffic volume. One would expect that, other things being equal, travel times would increase with increasing flow. Numerous past studies have shown however that the relationship is quite complex even for single links. The relationship along a route consisting of several links may be simpler (because high journey times on one link may be compensated for by shorter times on the next) or more complicated because the effect of flow in preceding time periods cannot be ignored.

The effect of traffic composition. The proportion of buses and lorries in the traffic stream will affect car travel times because these vehicles tend to be slower moving, have less acceleration and are more difficult to overtake.

We have excluded motorcycles and pedal cycles from consideration because, from observation, they do not appear to interfere with the flow of other traffic. This may not hold true in areas with very high cycle use.

Effect of time of day. Over and above the forementioned two effects, there are several reasons why travel times will depend on the time of day. These include:

i) Altered network characteristics due to bus lanes, parking/loading restrictions and roadworks which may apply for only part of the day.

ii) Changes in signal linking plans through the day.

iii) Changes in the proportion of regular commuters who know the route well and are generally "in a hurry", compared with other purposes such as shopping.

iv) Altered visibility and road surface conditions.

v) Changes in the proportion of turning movements at junctions.

vi) Changes in pedestrian activity (affecting the probability of being stopped at pelicans, zebras, school crossing patrols, etc.).

Effect of day of week. As we are only considering week days, this effect may be quite small, with most of the day to day variation being explainable in terms of the previous three factors.

Effect of specific incidents. Incidents such as road accidents, bus strikes, burst water mains, sudden cloud bursts, blizzards, etc. obviously affect travel times and must be recorded if they occur. However the data collected under these conditions may be so atypical that it cannot be said to form part of the overall distribution of journey times, and would therefore have to be analysed separately.

Effect of weather. Aside from the extremes as mentioned above, there is evidence to suggest that travel times increase during adverse weather conditions such as rain.

Effect of time of year. This seasonal effect may be completely explainable in terms of flows, weather etc. as above.

Effect of secular trends. There are many reasons why travel times may be getting steadily longer or shorter, such as improvements in vehicle performance, gradual changes in the age distribution of drivers, gradual deterioration in the road surface, marginal improvements to signal linking schemes, or gradual deterioration as base data for signal settings becomes more outdated.

To the extent that all these potential influences are considered important, the survey design must allow each of them to vary, and the analysis procedure must enable the separate effects to be identified.

Separating the Effects

Fig. 1a. shows a putative scattergram of travel time by time of day for one particular morning peak, where we can see both the random variation in any given time period, and the trend in average journey time over the peak. Fig. 1b. shows the same scattergram for several days, where we can see that there is a further dimension of variation. Fig. 1c. shows a vertical slice through Fig. 1b. and therefore shows the scattergram of travel time by date for a specific time of day.

These three types of variation (within time periods, within dates and between dates) have different distributions and require different analysis procedures as follows.

Within Time Periods. Some data collection methods (such as Moving Vehicle Observer) deliberately attempt to remove this source of variation - by instructing the driver to 'keep with the traffic stream' and/or by correcting the journey times obtained according to the number of vehicles passing or passed by the observer car. With methods which measure travel times directly such as number plate matching however, this variation is fully present in the data.

Within Dates. The variation in average journey time within dates could conceivably be considered at the same time as the variation between dates. However the problem about 'within dates' variation is that of collinearity i.e. the travel time in period t is strongly influenced by the travel time in period t-1. For this reason it is considered better to examine within dates variation separately from between dates. The precise form of model has not yet been decided upon, but would probably incorporate some device for modelling effects which decay with time as in Koyck (1954).

Between Dates. In this analysis we are looking at the variation in journey times corrected for flow effect, at a specific time of day, between days of the week, weeks of the year, and also between different routes. In order to enable this analysis to be carried out with the most efficient use of data, a Latin Square design was used for the main survey programme such that, over a 5 week period each of 5 routes was surveyed once on each day of the week, and once on each week of the period.

Fig. 1a. - Travel Time Variations for a Specific Day

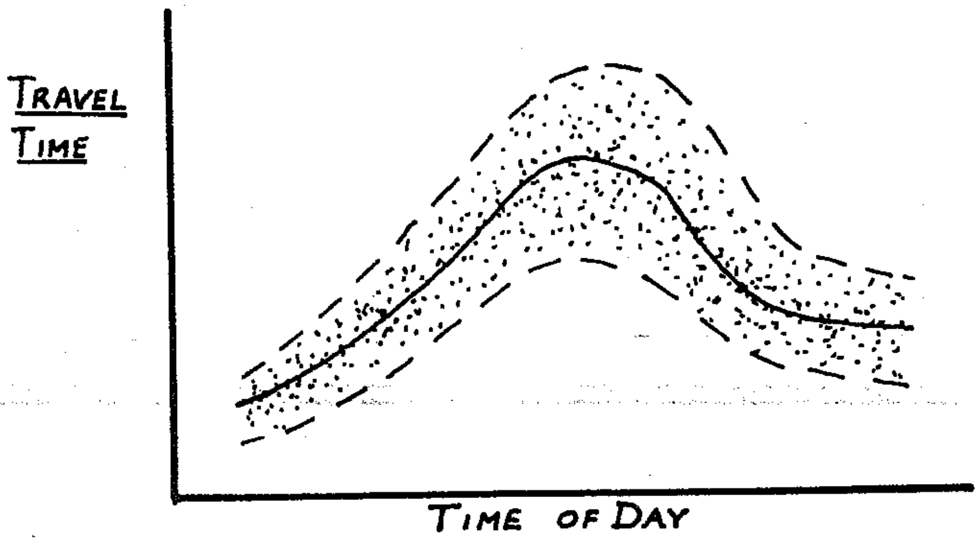


Fig. 1b. - Travel Time Variations over Several Days

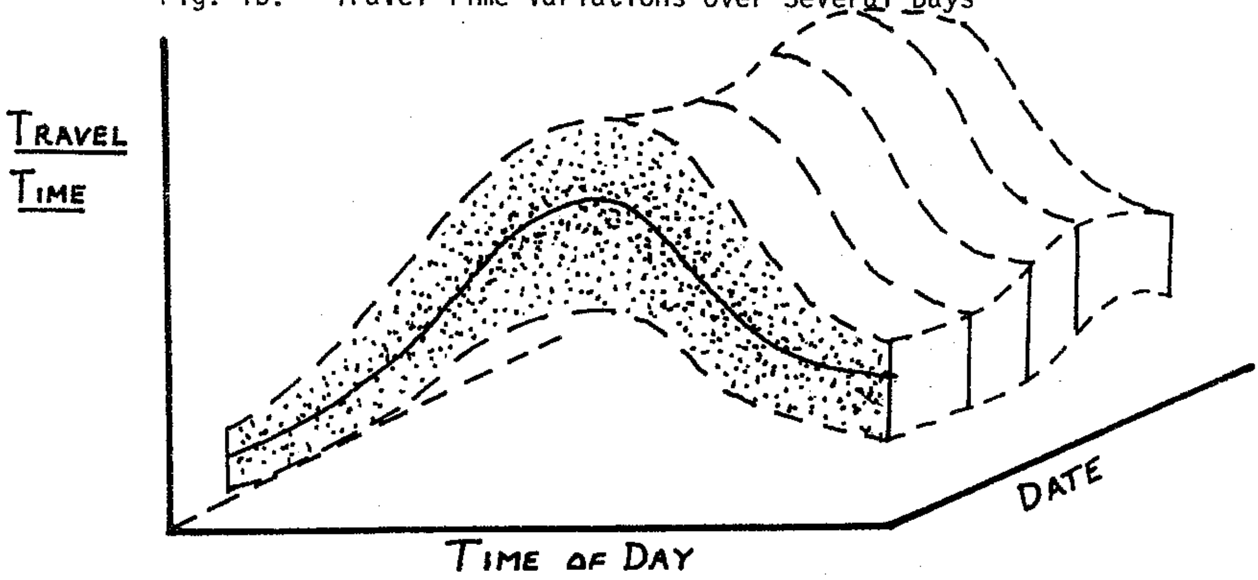
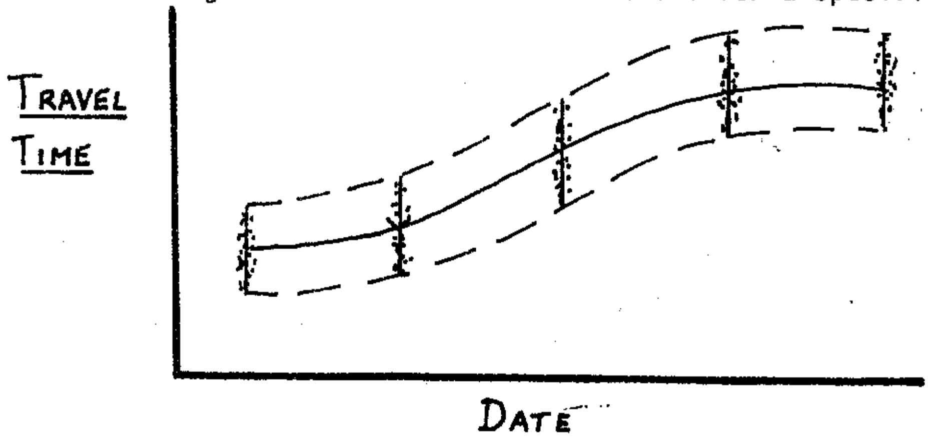


Fig. 1c. - Travel Time Variations for a Specific Time of Day



The model employed is $\theta_{ijk} = \theta + \theta_i + \theta_j + \theta_k + \varepsilon_{ijk}$ (1)

where θ = mean journey time (corrected for flow) at the given time period over all routes etc.

θ_i = day of week effect

θ_j = week effect (trend, seasonal, weather, etc.)

θ_k = route effect

ε_{ijk} = residual error

θ_{ijk} = mean journey time (corrected for flow) at the given time period on day i, week j, route k.

Assuming we have observations X_{ijk} from samples size n_{ijk}. (Our X_{ijk} are the travel times adjusted for flow and incidents.)

$$\text{then } \hat{\theta} = \frac{\sum_i \sum_j \sum_k X_{ijk}}{\sum_i \sum_j \sum_k n_{ijk}} \quad (2)$$

$$\hat{\theta}_k = \frac{\sum_i \sum_j X_{ijk}}{\sum_i \sum_j n_{ijk}} - \hat{\theta} \quad (3)$$

$$\hat{\theta}_j = \frac{\sum_i \sum_k X_{ijk}}{\sum_i \sum_k n_{ijk}} - \hat{\theta} \quad (4)$$

$$\hat{\theta}_i = \frac{\sum_j \sum_k X_{ijk}}{\sum_j \sum_k n_{ijk}} - \hat{\theta} \quad (5)$$

The usual significance tests can be performed to determine if any of the effects are 'real'.

4. DESCRIPTION OF DATA COLLECTION METHODS

There are five main groups of method, each with several variants in sampling method and data collection and transcription. These are now described in turn.

NUMBER PLATE MATCHING (NPM)

These methods involve stationing an observer at points along the route of interest. The observers record all or part of the Registration Plate of vehicles, together with their times of passing. The registration numbers thus collected are then matched by a computer program which outputs the matches plus journey time statistics.

Variants

- recording all or selected/classified vehicles
- recording full or part number plate
- using recording sheets; tape recorders; voice recognition; video recording
- recording individual times or incorporating a time base.

Application

Used for measuring travel times and also for estimating origin-destination patterns. In the former use, the method allows a large sample of travel times to be obtained over a short period (providing most of the flow on the route being studied is "through" at least two survey points). This enables the variation in journey times within short periods to be studied. It is possible to measure total flow at the survey points, but not at any intermediate points. Similarly the method provides no record of incidents, pedestrian activity etc. en route.

Organisational Problems

Choice of observation site is important, as the traffic should not be travelling at more than about 40 mph, and observers must have a clear view yet not be too conspicuous lest they influence driver behaviour. Provision must be made for working under inclement weather conditions - heavy rain can dissolve paper forms and short-circuit tape recorders as well as soaking the observers.

The method requires a fair degree of effort in setting up and supervision. The main problems are the maintenance of synchronisation between observers' watches (although the advent of digital watches has made this much easier), and ensuring that all sites are covered at all times. With the latter the problem is that a late observer results not only in missing data at his station but also useless data at other stations.

MOVING VEHICLE OBSERVER

These methods all involve the use of a survey car which is driven in the stream of traffic under study. An observer in the car records the time of passing selected points on the route. Depending on the precise survey method used, these journey times may be used directly as an estimate of the mean journey time of all cars over a short period centred on the survey car's start time, or else tally counts of overtaking and overtaken vehicles can be used in conjunction with an estimate of the vehicle flow to adjust the measured journey time.

Variants

- operating at different headways (sample rates)
- following an individual car; driving 'normally'; overtaking as many as overtake; or recording net overtakers and flow, travel time in the opposite direction
- using manual records; instrumented vehicles; or video recording
- recording individual time or incorporating a time base.

Application

Used for measuring journey times and (optionally) flows. The method allows a larger, more complex network to be covered more easily than with number plate matching. Because the method attempts to obtain the 'average' journey time of the stream of vehicles, it is inappropriate for looking at the variation of times within short periods. By the same token however it may be more appropriate than other methods for examining within days and between days variation. It is possible to record ancillary information such as incidents en route, pedestrian activity etc.

Organisational Problems

The survey drivers and observers must be fully conversant with the routes, and the observers must be trained in the survey method (to a larger extent than with Number Plate matching). However once the training has been done the method is comparatively easy to organise. Watches do not require to be synchronised as each car is more or less self contained. When using more than one car per route it is undesirable for the cars to close up on each other. Avoiding this can be surprisingly difficult on some routes.

EMPLOYEE LOGS

In this method a volunteer panel of commuters in one or more firms are given simple travel diaries, in which they are asked to keep as accurate a record as possible of their time of leaving home, arriving at work and (optionally) intermediate points.

Variants

- using different numbers of employees travelling at different times during the peak
- recording manually or using time-based recording equipment.

Application

The method provides data on journeys spread over a wide range of origins and modes. It is thus not very well suited to studies of a particular route or corridor, but may be very useful as a low cost means of monitoring the effects of area wide measures such as UTC, parking charge increases, etc.

Organisational Problems

The panel is obtained by circulating a short questionnaire to all employees of the chosen firms. Interested employees reply giving their name, address and normal mode of travel, from which information the panel can be selected. During the survey period some of the panel may fall ill, go on holiday or change jobs.

FLOW AND OCCUPANCY DETECTOR

Past studies have indicated that there is a relationship between the occupancy of a presence detector and the travel time on the link. (By occupancy is meant the proportion of time that a vehicle is present over the detector.)

Variants

- detecting at one or more points on the link
- interrogating the detector at differing rates.

Application

Detectors are expensive and immobile, and require a good deal of effort in "setting up" and calibration. However, once in place the method could provide continuous data on flows and journey times at a very low cost. The method is still at the developmental stage, but would seem to have its best application in UTC areas, where the necessary back up hardware and expertise already exists.

Organisational Problems

Once installed and calibrated, "organisation" consists of remembering to record the data. Loops are liable to be broken by statutory undertakers during a survey programme, and once broken usually take some time to repair.

AERIAL PHOTOGRAPHY

A camera (cine or video) is fixed to a high point (high building, lamp post, etc.) or flown from a helicopter or airship. The whole area under study is photographed simultaneously. In later analysis one can either obtain the time-mean speed of vehicles by link (by measuring the distances moved in successive frames) or one can follow specific vehicles through the network to obtain representative journey times.

Variants

- transcribing data for all or selected vehicles
- transcribing manually or semi-automatically.

Application

There is always a trade off between field of view and resolution, and this means that the method is unsuitable for studying long routes (say over 2 km). It is ideally suited to the intense study of a small area (say a complicated junction) where one may be interested in several interdependent variables such as flows, turning movements, O-D patterns, signal timings, pedestrian flows, parked vehicles etc. However, the survey only really starts in the office and data transcription often proves to be a much longer and more arduous task than anticipated.

Organisational Problems

It is not often that a ready made site for a high level camera presents itself. The alternative of using a helicopter or airship is more costly, and is only suitable for short survey periods. In some areas (e.g. Central

London) low level aircraft are not allowed. With any high level camera there is always the possibility that cloud or fog will obscure vision on the survey day.

All of the above five methods are feasible as ways of meeting all the data requirements in section 2, although many of the more automated processes require further development and testing. However, some raise more severe practical problems than others, some are more suited to link that route data, or vice-versa, and some are better able than others to provide travel time and supplementary data in the degree of detail indicated in section 3. Table 3 summarises these issues.

5. SURVEY STRATEGY

In previous sections we have listed the requirements for data collection, the factors which might influence travel times, and the data collection methods available. In this section we describe how the survey was designed so as to measure travel times over as wide a range of conditions as possible within the available budget, and with as wide a range of collection methods as possible.

Selection of Study Area

1) Choice of city. While we note above that the data collected and methods tested should ideally be appropriate to, and representative of any urban area, it has not been possible in practice to collect data for more than one urban area. This is likely to have greater implications for our conclusions on variability in travel time data than for those on survey methods. Travel times in similar conditions may well vary between cities because of the characteristics of the drivers, the road network or traffic management measures. However, the appropriateness of a particular measurement method is much more likely to be influenced by the particular road and routeing pattern than by the slowness of traffic. We have naturally selected Leeds, which also provides the opportunity for comparison with past urban congestion study data.

2) Choice of route. As noted above we would wish to study major roads, and possibly rat runs, throughout the urban area. Again we have had to be selective, and have chosen to study radial routes because

Table 3 Suitability of Alternative data collection methods

METHOD	NPM	MVO	ELG	APH	FOD
REQUIREMENT					
Data for individual routes	*	*	*	****	***
several individual links	***	*	**	**	*
complex networks	*****	**	*****	**	***
Dispersion of travel times					
within small time periods	*	*****	*****	*	**
within dates	*	**	***	**	*
between dates	**	*	*	****	*
Supplementary data					
flows	**	**	****	*	*
composition	**	***	****	*	****
incidents/pedestrians/ parking	****	**	***	*	****
Organisational effort					
setting up	*	**	**	****	*****
operation	***	**	*	**	*
transcription/coding	****	**	*	*****	**

* Very easy

***** Very difficult

i) they are a major source of congestion

ii) they present a much more manageable problem than city centre networks

iii) they provide a range of different conditions.

It seemed sensible to concentrate on those periods - the peaks - when travel times varied significantly, and we have chosen the morning peak 07.15 - 09.45 because daylight is more generally available. We accept that our conclusions will not be transferable to city centre networks, and that NPM methods will be impracticable in hours of darkness.

3) <u>Choice of radials.</u> As shown in figure 2, there are 16 main radials approaching Leeds city centre. For reasons explained below, five were selected to represent as wide a variety of conditions as possible. In particular it was thought necessary to select roads with different road widths, incidence of major junctions and turning movements, variations in flow, land use and parking and pedestrian activity. The five routes selected, and their start and finish points are indicated in figure 2. Table 4 provides further details.

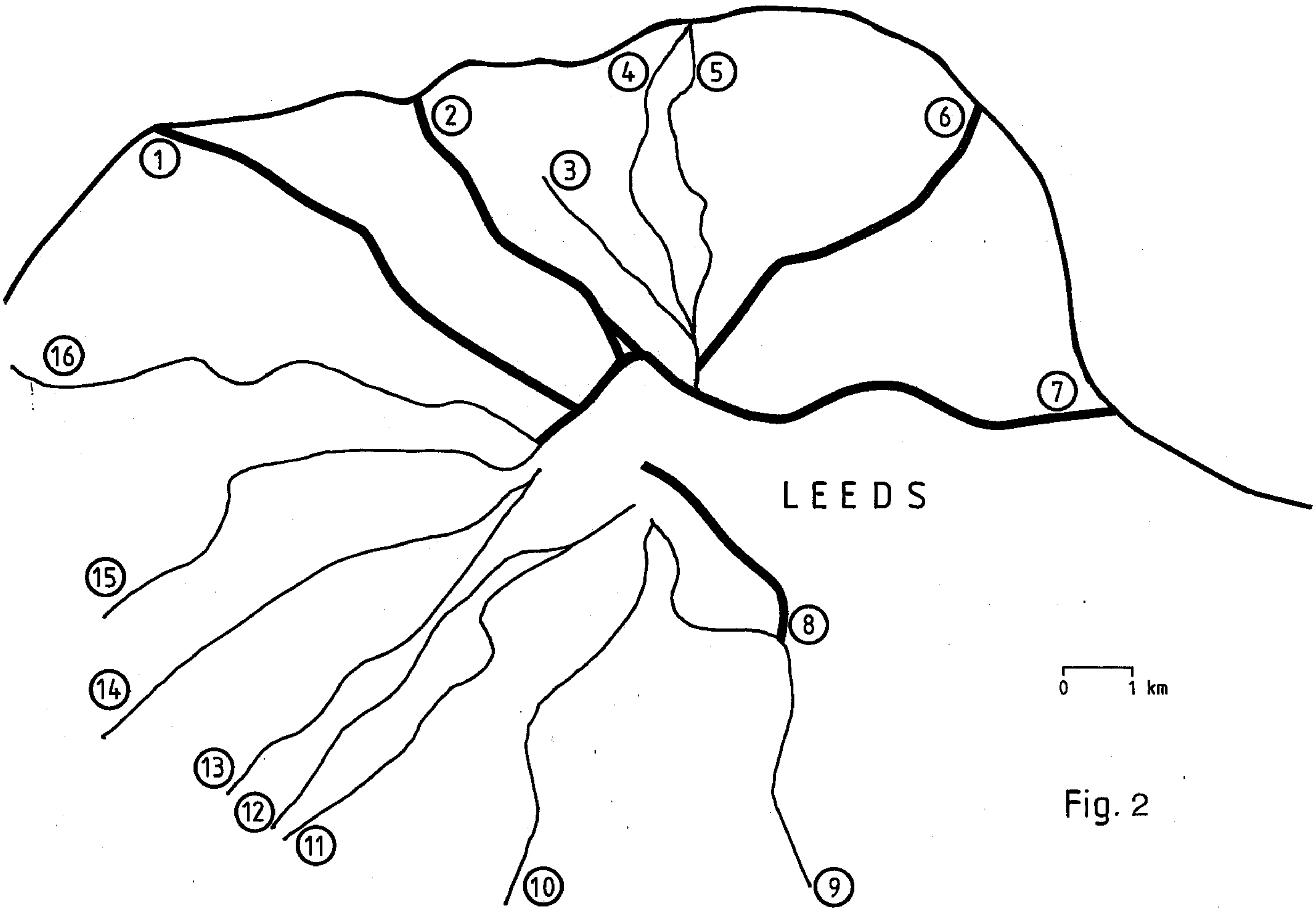


Fig. 2

Table 4 Routes selected

Route	Description
OTLEY ROAD A660 (2 on fig. 2) 4.58 km (1)	Mainly 30 mph 2 lane inbound single c/w. Road width very restricted over long sections. Bus lane from outer ring road to suburban shopping centre where heavy turning movements occur. Flows very peaked and variable from day to day due to effect of education trips (forms main route to University and Poly from Student Residences, and also to Grammar Schools from high income areas).
ROUNDHAY ROAD A58 (6 on fig. 2) 5.65 km (2)	First half mainly 40 mph 2 x 2 lane dual c/w to complex signalled junction from where mainly 30 mph 2 lane inbound single c/w. Most of delay occurs at complex junction. Flows peaked but less variable than route 1.
YORK/SELBY ROAD A64/A63 (7 on fig. 2) (3)	Short 40/30 mph 2 lane inbound single c/w stretch through suburban area then 40 mph dual c/w to end. Dual C/w is mixture of 2 x 2 lane and 2 x 3 lane, some high standard with grade separation, but with 3 delay sources (1 roundabout and 2 signalled inter-sections). Flows very high and peaky but less variable than 1.
HUNSLET ROAD A639 (8 on fig. 2) 3.11 km (4)	Mainly 30 mph 2 lane inbound single c/w with short stretches of 30 mph 2 x 2-3 lane dual c/w. Route passes through somewhat depressed semi-industrial area, and parallels M1. Lightest flows of 5 routes.
KIRKSTALL ROAD A65 (1 on fig. 2) 7.55 km (5)	Short 30 mph 2 lane inbound single c/w stretch through surburban area then 40 mph 2 lane inbound single c/w with dual sections. Finally 30 mph 2 lane single/dual c/w. Flows high and peaky but less variable than 1.

Major radials not included were as follows (as numbered on fig. 1).

3. Meanwood Road 4. Scott Hall Road (A61) 5. Chapeltown Road/Harrogate Road	excluded because they all lead into the Sheepscar interchange which was the subject of a major traffic management/roadworks scheme over the survey period. It would therefore have been very difficult if not impossible to distinguish the effects we were interested in from those due to changes in capacity.
9, 12 Motorways M1 and M621	outside terms of reference of study.

10. Dewsbury Road (A653) 11. Elland Road (A643) 13. Gelderd Road (A62) 14. Whitehall Road (A58)	)))))	similar condition to Hunslet Road, in that they are paralleled by motorways, pass through semi-industrial areas and have much the same flow patterns.
15. Tong Road (B6154) 16. Stanningley Road (A647)	))	Similar condition to Kirkstall Road/ York Road but the interweaving pattern of these and other routes in this area makes the use of the NPM method rather difficult.

4) Comparison with other locations. Time and resources permitting, we may examine a well known rat-run which parallels route 1. We may also study variations in delay to side road traffic on this route compared with delays to straight-through traffic at the same time of day.

Selection of study dates

1) The Latin Square design. Given the need to survey among routes and days of the week we have adopted a Latin Square design, as below.

Routes	WEEK NO. 1	2	3	4	5
Kirkstall Rd	Mon	Tue	Wed	Thu	Fri
Otley Rd	Tue	Wed	Thu	Fri	Mon
Roundhay Rd	Wed	Thu	Fri	Mon	Tue
York/Selby Rd	Thu	Fri	Mon	Tue	Wed
Hunslet Rd	Fri	Mon	Tue	Wed	Thu

Such an arrangement suggested partitioning the study into 5-week blocks. The advantage of this design is that the between route variation can be separated out from the week to week variation (if any) and the day of week variation.

2) Seasonal effects and secular trends. Rather than collect data by day of week throughout the year, we have concentrated our five day per week data collection into two 5-week blocks which we expect to be as different as possible in terms of traffic and driving conditions and survey requirements. For the remainder of the year, one day of the week, Thursday, was selected to measure seasonal effects and secular trends. The Latin Square approach was used to select the route to be surveyed on each Thursday. Fig. 3 shows the weeks during which each

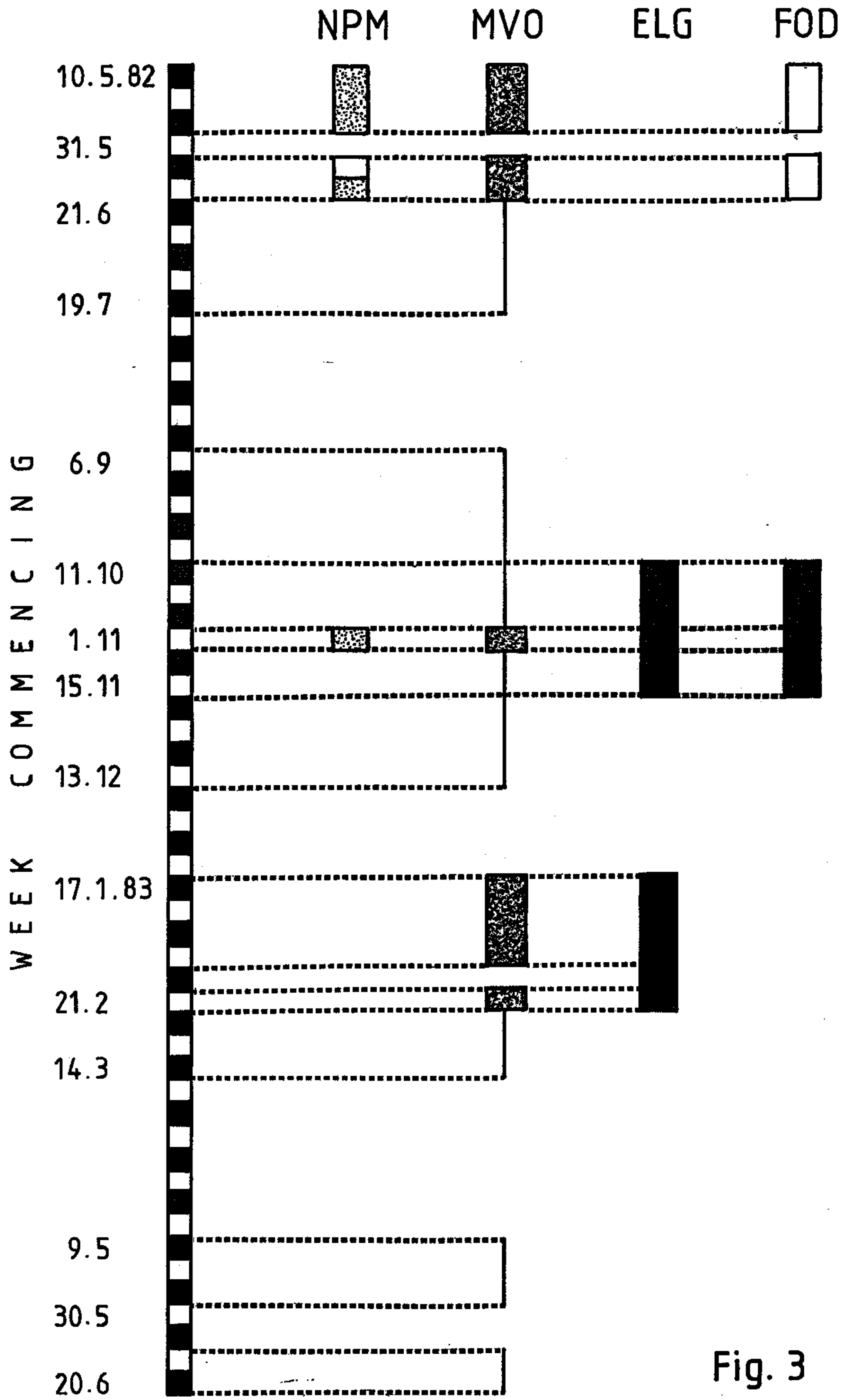

NPM
MVO
ELG
FOD
10.5.82
31.5
21.6
19.7
6.9
11.10
1.11
15.11
13.12
17.1.83
21.2
14.3
9.5
30.5
20.6
WEEK COMMENCING

Fig. 3

survey method was used. Thick lines denote surveys 5 days per week, thin lines Thursdays only. Empty boxes denote that although surveys were carried out, no results were obtained due to equipment malfunctions etc. As can be seen, the first 5-week block was from 10th May to 18th June 1982 (avoiding the Bank Holiday week w/b 31st May). These dates were chosen because

1) May and June are fairly 'neutral' times of the year, when schools are in session, the University and Polytechnic have examinations, and most workers are not on holiday.
2) Daylight and weather conditions are suitable for NPM surveys.
3) It was desirable to collect the bulk of the data at an early stage in the programme, so that transcription and analysis could get underway.

The second 5-week block was from 17th January to 25th February 1983. This enables the effects of different weather and visibility conditions to be analysed. In addition surveys were carried out every Thursday throughout the periods 21st June - 23rd July 1982; 6th September - 17th December 1982; 28th February - 18th March 1983; 9 th May - 27th May 1983; 13th June - 24th June 1983, thus providing an overlap period one year after the initial surveys.

Survey methods

Travel time measurement. Based on Table 3 it was decided not to pursue aerial photographic methods, but to attempt all the others in combinations which made use of their particular strengths. Thus NPM methods were used in the first 5 week block to obtain the dispersion of travel times within short periods, while lower cost MVO methods were used to obtain the variations between periods, dates and routes. ELG and FOD methods were tested for five week periods alongside these methods, for comparison purposes. Within individual methods a number of sub-methods were tested.

1) NPM methods. These are labour intensive, but provide detailed information on variations within short time periods, and therefore enable the representativeness of MVO and ELG methods to be tested. They were applied throughout the first five week period, recording all vehicles, classified into cars, commercial vehicles and buses at both ends of

the route. The last 4 characters were recorded and observers were instructed, when flows were too great, to record at least all light coloured cars. It will be possible to simulate the effect of recording solely selected final digits. Data were recorded on tape-recorders on which times were also recorded at approximately five minute intervals; correct times were then assigned to individual vehicles by a curve-fitting routine as described in an Institute Technical Note (Montgomery, 1983). Pilot tests were also made of tape recording of 4 and 7 characters and manual recording of white cars only. During week beginning 7th June 1982 remote microphones were tried out instead of the built-in condenser microphones. Unfortunately a loose connection on one of these microphones led to intermittent loss of data from that station, and the NPM surveys for that week had to be repeated in week beginning 1st November 1982.

2) MVO methods. These have been the main method used throughout the surveys. Two vehicles per route, providing approximately ten runs per peak period, have been used. Numbers overtaking and overtaken have been recorded together with classified vehicles met and travel times against the flow (the standard Moving Vehicle Observer method). Other simpler 'floating' methods can be simulated from this data, as can the use of only one vehicle. Data were recorded manually, but on two weeks TRRL made available their instrumented cars, and Golden River's data logger was tested for a one month period.

3) ELG method. From 11th October - 19th November 1982, a small pool of eight city centre employees using the five routes recorded the times at which they left home, passed the start and finish points of their route, and arrived at work. Some with passengers used digital watches and manual recording sheets, others driving solo used memory stopwatches. From 17th January - 25th February 1983, the same procedure was adopted with a larger pool of city centre employees. In this second survey some of the volunteers used a Casio CP10 printing clock/calculator to record their times.

4) FOD method. As part of the Leeds UTC system a total of 4 inbound detectors have been installed on the five routes. A record of occupancy

and flow data has been stored in the UTC centre over the same six week period as the ELG survey.

Supplementary data

Flow data is obtained from the NPM and MVO surveys, WYMCC's automatic traffic counters and the UTC system's detectors. In addition the two former sources record composition.

The MVO and ELG surveys provide information on incidents observed, and the MVO record extends to information on weather, road surface conditions and visibility, illegal parking and school crossing patrols. In addition the UTC centre's incident log provides details of reported accidents, breakdowns, roadworks and detector and signal malfunctions.

REFERENCES

DEPARTMENT OF THE ENVIRONMENT. Transport Policy - A Consultation Document, Vol. 2, Paper 3. 1976.

DEPARTMENT OF THE ENVIRONMENT. Transport Supplementary Grant Submissions for 1977/78. Circular 125/75.

DEPARTMENT OF TRANSPORT. Traffic Appraisal Manual, APM Division, 1981.

G.L.C. Traffic Monitoring Review, 1981. Statistical Series No. 4, 1981.

METROPOLITAN COUNTIES TRANSPORTATION DATA GROUP. Traffic Monitoring in Metropolitan Counties. A report prepared on behalf of the Metropolitan Counties Transportation Data Group, May 1979.

MARLOW, M. & EVANS, R. (1978). "Urban congestion survey 1976: traffic flows and speeds in eight towns and five conurbations". TRRL, SR 438.

SCOTLAND, W.F. (1980). A Comparative Study of Transport Investment Appraisal Systems. MSc Thesis, University of Leeds, 1981.

HOLROYD, J. and OWENS, D. Measuring the effectiveness of area traffic control systems. LR 420. TRRL, Crowthorne 1971.

WALLER, M.H. (1981). UTC. The West Yorkshire experience. TEC, July 1981.

HOLROYD, J. and ROBERTSON, D.I. (1973). Strategies for area traffic control systems, present and future. LR 569, TRRL, 1973.

HUNT P.B. et al (1982). The SCOOT on-line traffic signal optimisation technique. TEC, April 1982.

KOYCK, L.M. (1954). Distributed Lags and Investment Analysis. North-Holland Publishing Co. Amsterdam, 1954.

MONTGOMERY, F.O. (1983). Accurate Journey Times using portable tape recorders. ITS Technical Note. ITS, University of Leeds, 1983.