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CAR TRAVEL TIME VARIABILITY ON LINKS OF A RADIAL ROUTE IN LONDON: RESULTS

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ABSTRACT

This working paper describes the results of a study of the variability of travel times and its causes on links of a section of the A41 radial route in north London in the spring and summer of 1987. The objectives were to estimate the extent of variability of travel times of private car users and to explain the observed variability by means of models incorporating a range of traffic factors, including traffic flow, and incorporating seasonal differences. In general the spring was slower and showed more travel time variation between time periods than the summer. Slower and more variable links in the spring tended to behave similarly in the summer. The models produced explained around two thirds of the travel time variation between periods, but the explanatory power and explanatory variables differed between links. Blocking of the downstream exit from links was the single variable which was significant in affecting traffic times on most links.

1. Introduction

1.1 General

This Working Paper is one of three describing a study of travel time variability experienced by car drivers on the A41 radial route in North London, carried out in the spring and summer of 1987.

The objectives of the complete study were:

(i) to produce an estimate of the amount of variability of travel time for car travellers, both within short time periods and between time periods, including different days;

(ii) to estimate the importance of the observed variability to the car users;

(iii) to attempt to explain the observed variability;

(iv) if the variability could be satisfactorily explained in a general model, to use and/or adapt an existing traffic network model to simulate travel time variability and thus investigate the potential effects on it of traffic engineering and transport planning measures;

(v) if variability was found to be of major importance to develop proposals for the research necessary to investigate user perception of and response to variability more fully.

To achieve these objectives the study was designed to have two distinct and self-contained parts. One part (the "engineering study") was concerned with measuring variability on links of the A41 and explaining it in terms of the traffic characteristics of the links. The other part (the "panel study") was concerned with recording the day to day travel time variability experienced by a selected group ("panel") of regular car commuters, both for their entire door-to-door journey and for sections within it. The methodology and results of the panel study are contained in ITS Working Paper 277.

This Working Paper is one of two describing the engineering study. The first of these (Working Paper 278) describes the engineering study methodology, survey programme and data processing procedures. This Working Paper concentrates on the results and their analysis.

1.2 Summary of Scope, Methodology and Limitations

Consideration of route selection, methodology and variable selection and measurement are described in Working Paper 278, but are summarised here. The specific objectives of the engineering study were:

(i) to determine the amount of travel time variability on links of cars in the traffic stream

  (a) within short time periods (inter-vehicle variation), and

  (b) between time periods (inter-period variation);

(ii) to explain the observed variability through the development of existing statistical models;

(iii) if the variability could be explained in a general model, to use and/or adapt an existing traffic network model to simulate travel time variations.

It was considered best to carry out the study on a London radial route. Consideration was originally given to including both London and Leeds, but resources did not permit this, and Leeds radials had been examined in an earlier study (May and Montgomery 1984).

In order to measure the amount of travel time variability of cars, a section of major radial route was sought which had the following characteristics:

(i) junction control by traffic signals

(ii) mixed frontage

(iii) uniform geometry within links.

Based on these criteria, a section of the A41 was identified which was 5.0km in length, from the junction with Fortune Green Road in the north to the junction with Baker Street in the south. It includes thirteen signalised junctions, giving twelve road links between them. The route is shown in Figure 1, and in its north London context in Figure 2. The characteristics of the links are contained in Table 1.

The surveys were carried out on weekdays over three weeks in both spring (March/April) and summer (August) of 1987, in order to incorporate seasonal differences. Survey resources were organised such that four contiguous links were surveyed simultaneously on five consecutive weekdays in the first week, four other contiguous links in the second week and the remaining four in the third week, in each season. Surveys were restricted to the morning from 0730 until 1030, for traffic inbound to central London. The morning period was preferred to the evening because it is the time when punctuality of arrival was expected to be of more importance. The three hour period was chosen to cover the build up to the peak period, the commuter peak itself and the period following it, in each of which sub-periods traffic volume, traffic composition and driver behaviour could be expected to change, giving a wider range of both inter-vehicle and inter-period variation.

Table 1: Link Characteristics

Link No	Length (Km)	From (upstream)	To (downstream)	No of Lanes	Permitted Movement	Other Features
1	0.47	Fortune Green Road	Heath Drive	3	** all	Bus lane to 10.00 am, with setback. Mainly residential frontage. Dual carriageway.
2	0.23	Heath Drive	Frognal Lane	3	straight, left	Bus lane to 10.00 am, with setback. Mainly residential frontage. Dual carriageway.
3	0.43	Frognal Lane	Arkwright Road	3	straight, left	Bus lane to 10.00 am, with setback. Mainly residential frontage. Dual carriageway.
4	0.53	Arkwright Road	Finchley Road Tube (Canfield Gardens)	3	straight only	Bus lane to 10.00 am, without setback. Residential with shops in south part. Dual carriageway.
5	0.52	Finchley Road Tube (Canfield Gardens)	Swiss Cottage North (Fitzjohns Avenue)	3	straight only	Bus lane to 10.00 am, with setback. Bus lane goes left into Fitzjohns Avenue. Shopping frontage. Dual carriageway.
6	0.31	Swiss Cottage North (Fitjohns Avenue)	Swiss Cottage South (Hilgrove Road)	3 6	all (left is	Link is part of gyratory system, with signalised junction on it. Office, residential and shopping frontage.
7	0.88	Swiss Cottage South (Hilgrove Road)	Grove End Road	2	all	Mainly residential frontage. Dual carriageway in north only, with rest 2-way.
8	0.16	Grove End Road	Circus Road	2	all	Residential and shopping frontage. 2-way road.
9	0.44	Circus Road	St John's Wood Road	2	straight only	Residential and institutional frontage. 2-way road. Lords Cricket Ground at southern end.
10	0.37	St John's Wood Road	Hanover Gate	2	straight, left	Roundabout (to Regents Park) on link. Residential frontage. Regents Park Mosque near Hanover Gate. 2-way Road.
11	0.42	Hanover Gate	Rossmore Road	2	straight	Residential and institutional frontage. 2-way road.
12	0.25	Rossmore Road	Baker Street	4 5	straight right	Residential and institutional frontage. One-way. Bus lane in south through downstream junction.

* In survey direction only
** at downstream end

The earlier work, carried out on radial routes in Leeds in 1983 (May and Montgomery 1984), had suggested several factors which might be expected to affect car travel times and their variability. These were used as a basis for the explanatory data collected in this project, which were:

(i) traffic flows and turning movements in an inbound direction at the downstream end of each link and the upstream end of the first link;

(ii) traffic composition;

(iii) parking at various distances upstream and downstream from junctions;

(iv) whether or not any exit from a junction was obstructed;

(v) whether a queue remained at a junction stop line at the end of the green phase;

(vi) any incidents which might affect travel times, and their location and duration.

Manual data collection techniques were used for the collection of these data. For data items (i) to (iv) above, the information was collected by individual signal cycle, which ranged from 60 to 90 seconds, depending on location and time of day, and recorded on a specially designed form.

Based on pilot surveys in Leeds and London, and on the findings of an earlier study of data-capture devices (Bonsall et al 1988) it was decided to record link travel times using hand-held electronic data loggers to collect partial registration numbers for a colour-based sample of cars. In some cases, where flows were high or a large sample was needed, tape recorders were used.

Data transcription and processing had several stages, described fully in Working Paper 278 and summarised as follows:

(i) downloading daily registration plate data from the data loggers to a microcomputer in London;

(ii) downloading the registration plate data from microcomputer to mainframe in Leeds;

(iii) transcribing tape-recorded registration plate data and manually-collected flow and other traffic data into mainframe computer files;

(iv) matching the registration plates over each link on each day in both seasons to obtain car journey time distributions within each of these analysis periods;

(v) treatment of spurious matches in the travel time data due to chance matching as a result of recording only partial registration numbers;

(vi) treatment of outliers, which are travel-time observations from cars which stopped, or deviated from the main route, between timing points. Being mostly in the right-hand tails of the distributions, their inclusion in the analysis can bias the travel-time statistics.

The processed travel time data and traffic data were combined into single data files, by link and day, for further analysis. Slowness (secs/km) was used in the analyses, rather than travel time, to account for differences in link lengths.

Problems (described in Working Paper 278) were experienced in the spring surveys, particularly due to the use of tape recorded registration numbers and to availability of personnel, which described together resulted in the loss of a significant amount of spring data.

2. Variability and Analysis Period

2.1 Variability

May and Montgomery (1984) suggested that the variation in travel times can be thought of as having three components:

(i) variation within small time periods

(ii) variation between periods (within days)

(iii) variation between days

The first of these was termed 'inter-vehicle variation' and provided the time-period is small enough for general traffic demand not to change greatly (say around 15 minutes or less) this variation is likely to be caused by differences in car characteristics, driving styles, choice of traffic lane, time of arrival at traffic signals and (in less congested conditions) opportunity to select a speed. This inter-vehicle variation is best measured with regard to the dispersion of the distribution of travel times within each short time-period, particularly the standard deviation of link travel times or link slownesses.

The second and third of the components of variation were termed 'inter-period variation', and could be described by comparing the mean travel times (or some other measure of central tendency) of different periods.

2.2 Definition of the Analysis Period

The data on travel times, collected by registration-plate matching, was continuous, while data on traffic flows and other causal factors was collected by individual signal cycles. It was necessary to define the time-period to be used as a single observation, for subsequent correlation and regression analysis. May and Montgomery (1984) chose a 15 minute period as the basis of analysis, as this was the sub-division of data most often used in routine traffic studies and because it was considered a short enough period to be mostly free of variations in time-related causal factors. Travel time variations within 15 minute periods were therefore considered to be inter-vehicle variations, and to have a largely different explanation from variations between 15 minute periods (inter-period variation).

In the case of the present study, it was not possible to use 15 minute periods, because cycle times (the basis for the 'causal' data) on the route under study were, at different locations and times of day, 60, 70, 80 and 90 seconds in duration. Ideally, a lowest and common multiple of these values should be used, but in this case that would result in an observation period which was far too long. Consequently it was decided to combine the data into observations each of which was a specified number of cycles. By inspection of the data, the results of using various analysis periods were assessed, ranging from about 5 minutes to 15 minutes. The assessment was made by balancing the opposing effects of smaller sample sizes within shorter time periods against the 'smoothing' effects on mean travel times by using longer time periods. The decision was assisted by carrying out regression analyses, using a subset of the data, and using in turn 5, 7 and 10 cycle analysis periods. The results from these regressions indicated that generally 5 cycles was rather too short a period. The number of travel time observations in a 5-cycle period was sometimes rather low and the values of the coefficient of determination from the regressions was less than for the 7 and 10 cycle cases. Consideration of the results using 7 and 10 cycle observation periods suggested that 7 cycles was to be preferred, as this gave a sufficient number of travel time observations, and the time period (in the range 7 minutes to 10.5 minutes, depending on location and time of day) was sufficiently short to be internally reasonably free from time-related effects.

The effects of combining observations into 5-minute and 15-minute observation periods are shown in Figure 3, as are the individual travel times, for an example link. The smoothing effect of using the 15-minute mean in comparison to the 5-minute mean is quite clear, particularly for the period around 0830.

For each analysis period, for each day, link and season, summary travel-time statistics were calculated relating to the central tendency and dispersion of the data. The travel-times used were those produced after applying the weighting procedure (described in Working Paper 278) to correct for the possibility of spurious matches.

3. Travel Time Distributions

A selection of distributions of link travel times for individual vehicles, each for one link on one day, are shown in Figure 4. The cut-off point indicated is the time beyond which observations were discarded, in accordance with the treatment of outliers described in Working Paper 278. The discarded travel times beyond the cut-off point are not shown.

Figure 4(a) shows a link with a positively-skewed distribution. Most distributions were found to be somewhat positively skewed. However, some showed almost now skewness, as in the example in Figure 4(b), and some exhibited negative skewness, as in Figure

4(c). Figure 4(b) and 4(c) also show a bi-modal pattern. This was quite commonly encountered and is probably attributable to the effects of traffic-signal linking and the comparatively free-flowing traffic conditions which existed only for the first 15-20 minutes of each survey day. Each link tended to exhibit a travel time distribution of similar shape over all days of survey, unless disturbed by an unusual traffic event. The effects of such an event are shown in Figure 4(d). On August 4th there was a major Muslim festival at Regents Park Mosque, which attracted a very large attendance. As part of the management of traffic on that day, one left-turn off the A41 by the Mosque (Hanover Gate), normally heavily used, was closed. Traffic congestion was particularly severe, giving rise to the travel time distribution shown.

4. Comparisons Between Seasons, Links and Days

In order to make comparisons of travel times between links of unequal length, all travel times were converted to slowness (secs/km). For each 7-cycle observation period the mean and standard deviation of slowness were calculated, the latter being a measure of inter-vehicle variation. Table 2 shows, for the mean and standard deviation of slowness, the mean, minimum and maximum values separately by link: Table 2(a) for the spring and Table 2(b) for the summer. The problems associated with the use of tape recorders at Fortune Green Road and Baker Street meant that data for links 1 and 12 were not available for the spring, so were excluded from seasonal comparison. The low and varied sample sizes in the spring reflect the loss of data resulting from equipment and personnel failure which are described more fully in Working Paper 278. It is important to note that the majority of the missing data consisted of complete missing days rather than, for example, periods consistently missing at the start or end of each day's survey. Consequently, the loss of data will have caused little systematic bias. In the summer, the only major loss was of one complete day on link 10.

Overall, travel times were greater in the spring with a mean slowness (weighted by sample size) of 192 secs/km (18.8 km/hr), compared to 171 secs/km (21.1 km/hr) in the summer. This is as might have been expected, with schools and some commuters on holiday in the summer period.

The summer travel times were greatly increased by the unusually congested conditions in the southern part of the study section on August 4th when the Muslim festival took place. The effects of this on journey times have already been illustrated in Figure 4(d). If the data for August 4th are discarded, the mean slowness in the summer is reduced from 171 secs/km to 156 secs/km (23.1 km/hr).

Inter-period variation was compared between spring and summer by calculating, over all links, the value of the standard deviation of the mean slowness for each season. In spring the value was 96 secs/km and in summer 87 secs/km, reducing to 82 secs/km if August 4th is excluded. This indicates considerably less inter-period variation in the summer.

Table 2(a) Mean and Standard Deviation of Slowness, by Link (Spring)

SLOWNESS STATISTIC	VALUE (SECS/KM)			N
	MEAN	MINIMUM	MAXIMUM	
		LINK 2		
MEAN	219.8	83.3	557.0	23
STDEV	81.9	40.9	168.7	23
		LINK 3		
MEAN	344.6	96.6	753.1	23
STDEV	67.0	29.3	159.1	23
		LINK 4		
MEAN	174.1	88.7	348.7	72
STDEV	34.7	14.8	68.5	72
		LINK 5		
MEAN	156.4	83.9	257.7	66
STDEV	34.4	13.2	63.2	66
		LINK 6		
MEAN	249.6	131.7	465.1	56
STDEV	66.1	19.2	188.9	56
		LINK 7		
MEAN	164.8	83.5	310.6	37
STDEV	28.0	8.6	92.6	37
		LINK 8		
MEAN	243.1	97.7	469.1	71
STDEV	91.5	8.1	204.9	71
		LINK 9		
MEAN	149.1	113.7	211.8	40
STDEV	35.1	11.6	81.4	40
		LINK 10		
MEAN	183.9	95.1	371.4	20
STDEV	44.2	15.3	90.7	20
		LINK 11		
MEAN	97.9	73.5	122.7	50
STDEV	32.3	14.0	76.8	-

Table 2(b) Mean and Standard Deviation of Slowness, by Line (Summer)

SLOWNESS STATISTIC	VALUE (SECS/KM)			N
	MEAN	MINIMUM	MAXIMUM	
	LINK 1			
MEAN	129.6	76.5	497.0	98
STDEV	26.3	6.3	99.9	98
	LINK 2			
MEAN	171.2	85.6	408.9	105
STDEV	63.0	21.9	123.8	105
	LINK 3			
MEAN	207.2	89.0	436.0	105
STDEV	47.6	28.6	89.2	105
	LINK 4			
MEAN	162.2	98.2	356.3	84
STDEV	35.8	20.7	74.2	84
	LINK 5			
MEAN	149.9	102.1	349.9	80
STDEV	32.5	14.8	96.7	80
	LINK 6			
MEAN	188.2	97.3	298.5	69
STDEV	55.4	14.5	126.2	69
	LINK 7			
MEAN	105.7	70.2	376.3	112
STDEV	22.7	7.9	146.1	112
	LINK 8			
MEAN	177.2	28.9	954.1	105
STDEV	80.1	20.0	256.1	105
	LINK 9			
MEAN	246.1	91.2	1137.1	98
STDEV	51.8	17.9	213.6	98
	LINK 10			
MEAN	138.0	93.4	542.5	54
STDEV	31.3	5.1	90.3	54
	LINK 11			
MEAN	143.0	60.2	540.9	69
STDEV	44.6	13.4	153.4	69
	LINK 12			
MEAN	320.2	87.7	1014.0	76
STDEV	137.5	9.2	425.6	76

Although spring was slower than summer, the mean values of standard deviation of slowness (inter-vehicle variation) were about equal in both seasons at between 51 and 52 secs/km.

There was a prior expectation that slower links in the spring would also be slower in the summer. This was tested by means of rank correlation, the links being ranked by their mean slowness in both spring and summer. The results, shown in Table 3, indicated no significant relationship, suggesting that the expectation was false. However, the effect of August 4th is striking: when data for this day were excluded, the relationship became strong, positive and significant. This showed that, but for the unusual conditions on that one day, slower links in spring tended to be slower in summer. Inspection of the link-by-link mean values of mean slowness in spring and summer suggest that in both seasons certain links may be critical and may possibly control the performance of the links upstream and downstream: links 3 and 6 in particular may be acting as a choke on traffic movement within their local link groups.

A similar rank correlation of links was carried out for inter-vehicle variation measured, for each link, by the mean value of the standard deviation of slowness. Significant positive correlation was again found, but the exclusion of August 4th in this case made little difference to the strength of the relationship (Table 3).

Table 3

Spearman rank correlation coefficients comparing link performance between spring and summer

Slowness Statistic	All Days	Excluding 4th August
Mean	ns	0.92
Mean st dev	0.78	0.79

ns = coefficient not significantly different from zero at the 5% level

The comparisons also revealed that the slowest links in both spring and summer tended to be those with the greatest inter-vehicle variation: rank correlatious between mean slowness and the mean standard deviation of slowness gave correlations of 0.80 for both seasons (summer excluding 4th August).

Table 2 shows the considerable differences in mean slowness between the links. In the spring the range was from 98 secs/km (37 km/hr) on link 11 to 250 secs/km (14 km/hr) on link 6. In the summer the range was from 96 secs/km (37 km/hr) on link 11 to 207 secs/km (17 km/hr) on link 3, if August 4th is excluded. If August 4th is included, link 9 becomes slowest with 246 secs/km (15 km/hr). In spring and summer, and if August 4th is excluded, links in the southern half of the route, from the exit of Swiss Cottage gyratory (point 7 on Figure 1) to Baker Street, tended to be both faster and less variable in terms of inter-period variation (measured by the range of mean slowness). Only the most southerly group of links were surveyed on August 4th so it is reasonable to exclude the data for that day in this generalisation.

Of the southern links, link 8 (Grove End Road to Circus Road) was significantly slower and showed more inter-period variation than the others. Its inter-vehicle variation was also close to the largest of all study links in both seasons. This link is by far the shortest of the study, with a length of 160 metres. The shortness of the link accounts for the high inter-vehicle variation, as arrival at a green or red aspect of the Circus Road traffic signals would be critical to the travel time on the link. This could also account for the slowness and inter-period variation experienced. With the exception of link 8, the links south of Swiss Cottage generally showed less inter-vehicle variation than those in the north.

The graphs in Figure 5a-c show, using the same vertical scale, the change in mean slowness through the survey period separately for five consecutive weekdays on three example links. Figure 5a shows a link with a typical amount of day to day variation. Figures 5b and 5c show more extreme cases. In Figure 5b (Baker Street) the day-to-day variation is very large indeed; the Tuesday was atypical because it was the day of the Muslim festival (August 4th), but there is no similar explanation for the erratic fluctuation of the mean on the Wednesday. In the period after about 0915, however, Monday, Thursday and Friday show a very similar pattern.

Figure 5c shows a link which was normally very stable from day-to-day and from hour-to-hour except in exceptional circumstances. Again, the Tuesday was August 4th, indicating very dramatically the effect of such a festival on travel times. On the Wednesday, at 0759, a Volkswagen Golf ran into a Jaguar just downstream of the exit to this link, blocking one of the two London-bound lanes. The vehicles were not moved until 0820 and, as can be seen clearly from Figure 5c, the effect on travel time took a further 20 minutes to disperse completely.

5. <u>The Relationship Between Mean and Standard Deviation of Slowness for Individual Time Periods</u>

Spearman rank correlation coefficients were calculated, for each link and season, to determine the strength of relationship between the mean and the standard deviation of slowness. These are shown in Table 4. With only one exception (link 6 in the spring) the relationship was significant and positive in both seasons, indicating greater inter-vehicle variation when traffic is generally slow moving. Figure 6 shows the data set which gave the highest rank correlation.

Figure 6, and also the plots for some other links, suggested visually the possibility that standard deviation for individual time periods might be related to the logarithm of mean slowness. To investigate this, Pearson correlations were performed on all the data, for linear relationships with and without log transformation. The log transformation did not improve the correlation in comparison to the linear form, so there was no evidence to suggest that, overall, the relationship was logarithmic.

Table 4

Correlations Between the Mean and Standard Deviation of Slowness (Spearman)

LINK	SPRING		SUMMER	
	SAMPLE SIZE	CORRELATION COEFFICIENT	SAMPLE SIZE	CORRELATION COEFFICIENT
1	0	-	98	0.76
2	23	0.72	105	0.59
3	23	0.61	105	0.40
4	72	0.53	84	0.55
5	66	0.65	80	0.40
6	56	n.s.	69	0.19
7	37	0.54	112	0.48
8	71	0.44	105	0.86
9	40	0.42	98	0.67
10	20	0.78	54	0.71
11	50	0.45	69	0.67
12	0	-	76	0.92
ALL	458	0.64	1055	0.69

note: n.s. = coefficient not significantly different from zero at 5% level

6. Analysis of the Causes of Variability

6.1 General

Inter-vehicle and inter-period variation may be expected to be related to different factors, the former being likely to need more of a 'micro' approach to analysis (May and Montgomery 1984). Most of the analysis which follows in this section is concerned with explaining inter-period variation. However, since some of the variables likely to affect inter-period variation might also affect inter-vehicle variation to some extent, this aspect also receives some attention in the following analyses. It was hoped that this analysis would reveal certain variables which were common in explaining both inter-period and inter-vehicle variation on different links.

The variables suggested by May and Montgomery (1984) for the analysis of inter-period variation were as follows: traffic volume (though they note that the relationship may be complex for single links, exemplifying the work of Branston in 1976); traffic composition; specific incidents (accidents, road works, etc.); weather; time of day (other than time-of-day effects on variables already linked); day of week; time of year and the effect of secular trends. In the present study, most of these variables, other than those related to secular trends, were incorporated into the analysis.

One of the chief findings of May and Montgomery (1984) was that travel times in a particular time period may be more strongly affected by the traffic flow in the previous (15 minute) time period(s), rather than simultaneous traffic flow. For this reason, most of the variables in the present analysis, including flow, were examined in their lagged, as well as un-lagged form.

6.2 Explaining Inter-Period Variation

Analysis was performed, using the procedures in the mainframe program SAS, to examine the relationship between individual variables and mean slowness. This was carried out by link, combining all five days' observations on each link separately for each of the two seasons. In order to account for any systematic day-to-day variations in behaviour on the link, dummy variables were introduced to represent different days. This was considered necessary as indications were (see Section 4 above) that the values and patterns of slowness on a given link were often different between different days.

Earlier work (May and Montgomery 1984) had indicated in Leeds that inter-period variation in slowness was not strongly related to traffic flow in the same short time period: rather, it was most strongly related to flow in the preceding time period and also, increasingly less strongly, to flows in time periods before that. For this reason, flow values for preceding time periods (lagged flows) were also introduced as variables in the current analysis. If lagged flows were found to be a general explanatory variable, a more complex lag structure could later be explored, to increase the explanatory power of the relationship between slowness and flow.

The initial exploration of the effects of lagged flow on slowness included the use of up to 24 lags: this meant that any possibility of flow at the start of the survey period affecting slowness at the end, was accounted for. In fact, it was found that lagged flow values beyond the first lag had no effect on slowness, and that the no-lag and first lag values were roughly equally important in explaining slowness, taking all links and both seasons into account. For this reason, subsequent analysis of the effects of flow used only the unlagged and first lag values.

The conclusion from this preliminary investigation of lagged flow contrast with the results of the work in Leeds (May and Montgomery 1984), which found for all five routes studied, that the first, second and third lag of flow had a significant effect on slowness. The difference may be explained by noting that the Leeds work was based on route travel times (the routes ranging from 3 to 7 kilometres in length) rather than links (which ranged from 160-900 metres) as in the present study. Lagged flow is intuitively likely to be a more important explanatory variable for routes than for links, particularly where, as in Leeds, the flow was recorded at the upstream end of the route. In this study it was recorded at the downstream end of each link.

The other principal explanatory variables (parking, queueing and blocking) were also entered into the analysis in lagged (first lag only) and unlagged forms.

Preliminary investigation of explanatory variables of importance was carried out using simple correlations between mean slowness and each variable.

Rank correlation was used (Spearman's method) in the analysis rather than parametric linear correlation (Pearson's method) as the shapes of any relationships were not known in advance and many relationships, for example between slowness and traffic flow, could be expected to be non-linear. Spearman's correlation, unlike Pearson's, is valid in non-linear situations (provided they are monotonic) and is typically only about five percent less powerful, even in a situation where the relationship is linear, in identifying significant relationships.

In non-linear conditions, the difference in power between the two techniques decreases and continues to do so with increasing non-linearity. In addition to the correlations, the key variables were plotted against slowness, in order to be able to detect the shape of the relationship, where one existed. The plots were important because the data were concerned mainly with the peak period, during which traffic theory suggests that the relationship between slowness and traffic flow may be parabolic as a result of congested (forced flow) conditions. This would not be apparent from the correlations, which in such cases could produce poor coefficients for what in reality may be a strong relationship.

The results of the correlations with mean slowness were as follows (significance, when referred to, is at the five percent level).

(1) On only three links in summer, and three (different) links in spring were individual correlations greater than 0.6 found. On two links in spring, no significant explanatory variable was found.

(2) In both seasons, the variables with significant correlations were generally different between different links. In addition, where a particular variable was significant on more than one link, its sign was frequently different. This was particularly true of flow and lagged flow.

(3) Where flow was significant, sometimes it was lagged flow alone, sometimes flow (unlagged) along, and sometimes both. When both were significant, neither flow nor lagged flow showed a consistently higher correlation than the other.

(4) Dummy variables for day of the week were frequently significant, suggesting that the explanatory variables considered were not sufficient in themselves to explain inter-period variation.

(5) Blocking of the downstream straight ahead (main route) exit from the link was, on most links, correlated with slowness, often strongly, and the correlation was always positive, with blocking being associated with slower traffic movement. In almost all cases where blocking straight was a significant variable, a queue remaining at the stop line was also significant and also always positive.

The correlation results, particularly those summarised in 2-4 above, suggested that the search for common explanatory variables was likely to be unsuccessful, the exception to this being the widespread effects in slowness of blocking of the straight ahead link exit.

It was realised that some relationships might not be monotonic, and that if this were so, the use of the correlation coefficient alone would obscure them. To allow for this, each explanatory variable was individually plotted against slowness. This procedure generally did not uncover further strong relationships, however.

Given the importance of blocking as an explanatory variable, it was considered that blocking might be obscuring the effects of traffic flow on slowness. The correlations were therefore repeated, excluding all observations in which blocking straight occurred. This procedure did not have the expected effect: on only one link (link 3 in the spring) did it cause flow to become significant where it had not been so before, and on only one link (link 9 in the summer) did it cause a previously negative relationship with flow to become positive. Also, surprisingly, it caused flow to cease to be significant on several links where it had been significant before. There was also no indication that the removal of blocking caused other explanatory variables to become generally important.

The relationship between slowness and traffic flow was, as has been shown, generally not great and could either be positive or negative when it was significant. An examination of the plots of traffic flow against slowness showed that the range of flow values was in many cases not great, suggesting (borne out by observation) that links were operating near capacity for much of the survey period of 0730-1030. If so, conditions would correspond to the area of the turning point of the speed-flow curve, which is the most difficult to model. In addition to this congestion effect, the relationship between flow and slowness is more complex for single links than for routes. May and Montgomery (1984), showed that, although lagged flow was significant in explaining slowness on all their 5 routes, on some routes unlagged flow was significant and sometimes not. On one route where unlagged flow was significant, its relationship was negative. Thus there are some similarities between the results from Leeds and those from the present study.

In order to extend the analysis into modelling, to take account of the combined effects of variables and to determine what proportion of the variation in slowness they could account for, multiple regression analysis was carried out with mean slowness as the dependent variable and with up to 5 independent variables. A regression procedure was used which selected independent variables such that a maximum coefficient of determination (R^2) was ensured, for a given number of independent variables. Equations with more than 5 independent variables were considered unwieldy and of increasingly less value as a potential predictive model. In any case, it was shown that in no case did the addition of further variables add significantly to the explanatory power of the equation. Table 5 shows the highest coefficients of determination achieved with one and five independent variables, by link, for spring and summer. All regressions were carried out also on the data subset from which observations with blocking had been removed: Table 5 includes these.

Table 5

Coefficients of Determination for Link Regression Models Explaining Inter-Period Variation

LINK NO	SPRING				SUMMER			
	ALL DATA		WITHOUT BLOCKING		ALL DATA		WITHOUT BLOCKING	
	1var	5vars	1var	5vars	1var	5vars	1var	5var
1					0.56	0.77	0.22	0.50
2	0.37	0.85	0.37	0.85	0.41	0.56	0.19	0.21
3	0.80	0.94	0.99	0.99	0.11	0.36	0.12	0.37
4	0.33	0.58	0.49	0.90	0.32	0.57	0.32	0.62
5	0.21	0.57	0.37	0.74	0.43	0.57	0.11	0.41
6	0.22	0.34	0.22	0.34	0.32	0.52	0.38	0.53
7	0.12	0.45	0.47	0.94	0.73	0.80	0.08	0.28
8	0.26	0.52	0.24	0.51	0.75	0.82	0.16	0.37
9	0.32	0.65	0.28	0.55	0.93	0.97	0.22	0.48
10	0.27	0.48	0.27	0.48	0.58	0.68	0.58	0.69
11	0.29	0.57	0.36	0.58	0.65	0.85	0.85	0.93
12					0.56	0.78	0.68	0.97

In Table 5, the variables are not shown as they differ widely between links. Several points emerge from Table 5, as follows:

(1) Links on which slowness is well explained in the spring are not necessarily those on which it is well explained in the summer. However, inspection of the full results indicated that there was some tendency, for each link, for the significant variables in the spring to be significant in the summer. There was also a tendency for their signs to be the same; if flow had a negative relationship in spring it generally was also negative in summer. The main general exception to this similarity of variables between seasons was the dummy variables for day of the week, which, when significant, differed between seasons.

(2) For the full data set, the proportion of variation explained varied greatly by link, ranging from 11 percent to 93 percent with one variable, and from 35 percent to 97 percent with five variables, over both seasons. The mean R^2 for one variable was 0.32 in the spring and 0.53 in the summer. For five variables the mean was 0.60 for the spring and 0.69 in the summer: the summer inter-period variation was thus easier to explain using these variables.

(3) For the partial data set (blocking included), the sample sizes varied according to the amount of blocking experienced. When there was little blocking, R^2 values were similar to those for the full data set. At the other extreme where there was a great deal of blocking, R^2 values are generally quite different. It may also be noted, though it is difficult to explain, that in the spring, removal of observations with blocking increased R^2 on most links; in summer the opposite effect can be seen.

6.3 Explaining Inter-Vehicle Variation

The same routine was followed for inter-vehicle variation, measured by the standard deviation of slowness within each 7-cycle observation period, as for inter-period variation. The same explantory variables were also used, including their first lag value. The preliminary correlation analysis, as for the inter-period analysis, showed that the variables of significance varied from link to link. Individual correlations were much lower than for the inter-period analysis: on only two links in the summer and one (different) link in the spring were individual correlations greater than 0.6 found. In the few cases where flow was significant, its sign was generally negative, indicating that on those links lower flows gave greater inter-vehicle variation, perhaps by allowing drivers a greater choice of lane and speed.

The ability of multiple regression equations to explain the standard deviation of slowness is shown in Table 6. Several points may be made:

(1) Links in which inter-vehicle variation is most fully explained in spring are not necessarily those most fully explained in summer. Inspection of the results showed that there was also no tendency for the significant variables on each link to be similar in spring and summer.

(2) For the full data set, the proportion of inter-vehicle variation explained varied by link, varying from 5 percent to 62 percent with one variable, and from 17 percent to 85 percent with five variables. The mean R^2 for one variable was 0.18 in the spring and 0.29 in the summer. For five variables the mean was 0.47 in the spring and 0.43 in the summer.

That rather less than half of the inter-vehicle variation was explained is not unexpected, given that the variables chosen were mainly for the purpose of analysing inter-period variation and also because of the known difficulty of explaining inter-vehicle variation due to the many micro-level factors involved.

Table 6

Coefficients of Determination for Link Regression Models Explaining Inter-Vehicle Variation

LINK NO	SPRING				SUMMER			
	ALL DATA		WITHOUT BLOCKING		ALL DATA		WITHOUT BLOCKING	
	1var	5vars	1var	5vars	1var	5vars	1var	5vars
1					0.52	0.69	0.17	0.30
2	0.35	0.69	0.35	0.69	0.27	0.37	0.06	0.20
3	0.43	0.85	0.98	0.99	0.06	0.21	0.06	0.21
4	0.18	0.38	0.21	0.66	0.12	0.30	0.15	0.32
5	0.11	0.48	0.53	0.86	0.15	0.26	0.06	0.19
6	0.09	0.38	0.09	0.38	0.06	0.20	0.06	0.21
7	0.20	0.57	0.59	0.95	0.24	0.30	0.14	0.17
8	0.06	0.17	0.05	0.16	0.28	0.44	0.06	0.20
9	0.05	0.32	0.04	0.30	0.62	0.72	0.08	0.23
10	0.27	0.61	0.22	0.60	0.12	0.28	0.13	0.42
11	0.06	0.24	0.10	0.25	0.51	0.69	0.34	0.57
12					0.54	0.75	0.31	0.89

7. Summary, Conclusions and Recommendations

(1) Car speeds in spring (18.8 km/hr) were significantly lower than in summer (21.1 km/hr) and inter-period variation greater, but the amount of inter-vehicle variation was similar in both seasons.

(2) Slower links in spring tended strongly to be slower in summer and links with the greatest inter-vehicle variation in spring tended to be those with greatest inter-vehicle variation in summer.

(3) Slower links showed more inter-vehicle variation, in both spring and summer.

(4) Average car speeds varied from link to link. The range of link average speeds in spring was 14-37 km/hr and in summer 15-37 km/hr. The faster and less variable links were in the southern half of the study route.

(5) Unusual events had major effects on travel times. On the day of a Muslim festival, journey times on nearby links were up to 10 times the usual values; a fairly minor traffic accident near a junction caused journey times to increase on the upstream link to four times usual.

(6) Travel time standard deviation (inter-vehicle variation) was related to mean travel time.

(7) This relationship was described equally well by a linear or logarithmic relationship. Investigation of the effect of lagged traffic flow on link travel times indicated that either simultaneous flow (unlagged) or the flow in the immediately preceding time period (first lag) could be important. It was found that lags beyond the first had negligible effect.

(8) Inter-period variation was often well explained by regression analysis in terms of the traffic and other independent variables employed: the average and maximum R^2 values achieved for the spring data being 0.60 and 0.94 respectively; with corresponding R^2 values of 0.69 and 0.97 in the summer.

(9) The ability to explain inter-vehicle variation in terms of the same variables was less than for inter-period variation. However, the choice of variables and techniques was made in order to explain inter-period rather than inter-vehicle variation.

(10) Despite achieving a high or satisfactory degree of explanation on many links, the variables of significance in the models varied from link to link and where the variables themselves were in common, their coefficients often had different signs. This lack of generally important variables may be related to the congested conditions prevailing in much of the network through much of the survey period.

(11) Blocking of the downstream exits of links was the only variable which was significant on most links in explaining inter-period variation. However, by removing observations where blocking occrured from the analysis, the explanatory power of the other variables, including traffic flow, was not enhanced, nor did other variables of common importance emerge.

The conclusions of the study suggest some recommendations for further work, as follows:

(1) The difficulty of achieving a consistently high explanation of inter-vehicle variation and the lack of common variables other than blocking leads to the following suggestions:

(a) Extension of the work to other congested London corridors would indicate whether the lack of general variables is unique to the A41. At the same time information could be collected on additional variables, such as activities along the links (rather than only near junctions).

(b) Extension of the work to include a wider range of traffic flow regimes, to determine whether the general lack of importance of flow as an explanatory variable in this study is chiefly because a wider range of flow conditions were not included.

(2) It would be of value further to investigate the idea that a particular few links are critical to the performance of much of the corridor, because of their possible controlling effect.

(3) The importance of blocking as an explanatory variable suggests the value of continued development of traffic signal control strategies which discourage the backing-up of queues to junctions upstream.

References

Bonsall P W, F Ghahri-Saremi, M R Tight and N W Marler (1988). The performance of handheld data-capture devices in traffic and transport surveys. Traffic Engineering and Control, January 1988, pp10-19.

May A D, P W Bonsall and N W Marler (1989a). Car travel time variability on links of a radial route in London: Surveys, analysis and data processing. ITS Working Paper 278.

May A D, P W Bonsall and N W Marler (1989a). Travel time variability of a group of car commuters in north London. ITS Working Paper 277.

May A D and F O Montgomery (1984). Factors affecting travel times on urgan radial routes. ITS Working Paper 177.