The influence of flow variability on the evaluation of responsive traffic systems by micro-simulation

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Introduction

If the same journeys were made every day at the same time under the same conditions, traffic could be effectively controlled using a fixed signal plan which minimised costs. Traffic flows however, vary and therefore responsive urban traffic control (UTC) systems have been developed which measure the flows and respond by adapting signal plans to attempt to maintain minimised costs. Responsive UTC systems have been used in the UK since the early 1980s and are now commonly used in both the UK and many other countries throughout the world. On-street trials of the SCOOT UTC system have demonstrated travel-time savings of up to 12% and fuel consumption savings of up to 6% over fixed time operation. On-street trials, however, are fraught with difficulties when trying to measure small changes such as these. Lots of data needs to be collected to ensure that any measured changes are due to the introduction of the new system and not just due to inherent variability. Data collection can be expensive, so it is often the case that insufficient data is collected to arrive at statistically sound conclusions. It is also impossible to ensure that the before and after conditions are precisely the same. There is no way of forcing travellers to make the same trips at the same times and making the same decisions on different days or of ensuring the same network conditions, such as the weather, accidents, roadworks etc. are the same. The before condition may also use an old fixed time signal plan which is no longer optimal for current conditions. Such problems can easily raise doubts about the declared benefits of using responsive systems.

To address these problems it is becoming increasingly common to assess the likely benefits of responsive control systems by using computer micro-simulation tools. These tools model the movements of individual vehicles travelling round a road network. Their motion is governed by car following and lane changing rules, and the vehicles obey priority rules and traffic signals at junctions. Such tools are especially suitable for assessing responsive control systems as they can model the interactions with the control systems in a realistic fashion. Real UTC systems can be connected to the tools. The simulation tools can provide the responsive UTC system with vehicle detection data from simulated vehicles moving around the network and passing over simulated detectors. The UTC system can then calculate signal plans which minimise costs and these are passed back to the simulator where they are implemented. The traffic conditions in the simulation runs are under the complete control of the modeller. Identical sets of trips can be specified for each before and after run. Data collection is easy and many runs can be quickly carried out to determine the sensitivity and statistical significance of the results.

If traffic flows followed an average daily flow profile precisely, a responsive system would tend to duplicate the performance of a series of fixed time plans. Responsive systems achieve their benefits by adapting to variation in the flows away from the expected daily flow profile. The amount of flow variability used in simulation is therefore critical to any evaluation of a responsive system. If there is too little, the performance of the responsive system would be underestimated. If there is too much the performance of the fixed plan used for comparison would be poor and the performance of the responsive system would be over estimated. Therefore to assess a responsive system using micro-simulation, runs should be carried out that include realistic variations in the traffic flows. This project therefore aimed to:

- acquire, interpret, quantify and categorize data on traffic flow variability;
- incorporate the variability into a set of micro-simulation runs linked to a responsive UTC system;
- analyse the simulation outputs to assess how benefits vary with the level of variability;
- produce a report giving recommendations for including variability in assessments of responsive systems using micro-simulation.

Collection of flow data

Sources of traffic flow data for analysis were sought. Although it is quite common to collect flow data for input into traffic models and during field trials, much of this data is usually only collected for a short time period. Data for this analysis was sought which had been collected continuously over time periods in excess of a year so that long term as well as short term variability could be analysed. Counting may be done manually by an individual standing by the roadside with pen and paper or a mechanical or electronic recording device. Manual counts can be limiting in both the time span of the survey and the volume which an individual is able to accurately record. No sources of manually collected data were found which covered a sufficiently long time period. Therefore automatically collected data was

used. Local authorities often collect traffic flow data and Leeds City Council were able to provide automatic traffic count data for study during this project.

Detectors are not only used in a monitoring capacity but may also be used in a more active mode where information from the detectors is passed to a computer, which is attempting to optimise the signal settings in a region. Count information may be collected from these systems but the counting task is only a subsidiary one. Unfortunately the data collected by this method is sometimes not precisely flow data but a hybrid measure based on flow and occupancy. Further work was carried out during this project (Boddy, 1998) in order to ensure that accurate flow data could be extracted from this hybrid measure. The Instrumented City in Leicester (Bell et.al., 1996) has been collecting such data from the SCOOT UTC system since November 1990, along with ancillary data which is very useful in determining the causes of variation. This includes information on accidents, road works and the weather. The SCOOT UTC system has also been providing flow data for ASTRID databases in both London and Southampton. The Instrumented City data is available in five minute intervals and the ASTRID data in fifteen minute intervals. Torino City Council have also been collecting traffic counts from their UTOPIA UTC system as part of the 5T project. They have made this data available for the project.

City / Town	Links	Source	Data interval (mins)	Data period	Dates	Peak flow (v/h)
Leeds (UK)	A61 A62 A660 B A660 W	ATC	15	00:00-24:00	03/96-06/97	1800 700 950 1400
Hinckley (UK)	N5321a N5321b	SCOOT	5	07:30-19:30	11/94-12/95	600 650
Melton Mowbray (UK)	N2622c N2626c N2626d	SCOOT	5	07:30-19:30	2/94-12/95	450 600 600
Leicester (UK)	N0338c N1222l	SCOOT	5	07:30-19:30	2/94-12/95	1400 1100
London (UK)	N20/076m N23/047a N23/070k N30/018f N30/025g	SCOOT	15	00:00-24:00	11/95-07/97	1600 1700 1700 700 800
Torino (Italy)	23-38-23-39 19-89-19-90	UTOPIA	5	00:00-24:00	1/97-11/97	700 800

Table 1: The flow data collected and analysed

Obviously, the characteristics of traffic flows within a signalised area will depend on the signal settings, therefore most effort has been directed at links on the edges of the networks, before they come under the influence of the signals. Data on a total of eighteen links, shown in Table 1, was collected and analysed.

Analysis of flow data

The variation in traffic flows was investigated. As traffic flows vary according to the time of day, the day of the week and the season, for each link investigated the flows were therefore grouped according to these variables. Mean daily flow profiles for each group were determined and standard statistical techniques used to examine these profiles. This work is reported in more detail in Fox and Clark (1998).

The first step in the analysis was the removal of flow data on Public Holidays. As can be seen in the example from London given in Figure 1 the flows on these days are either much lower than usual or are very similar to flows on Sundays.

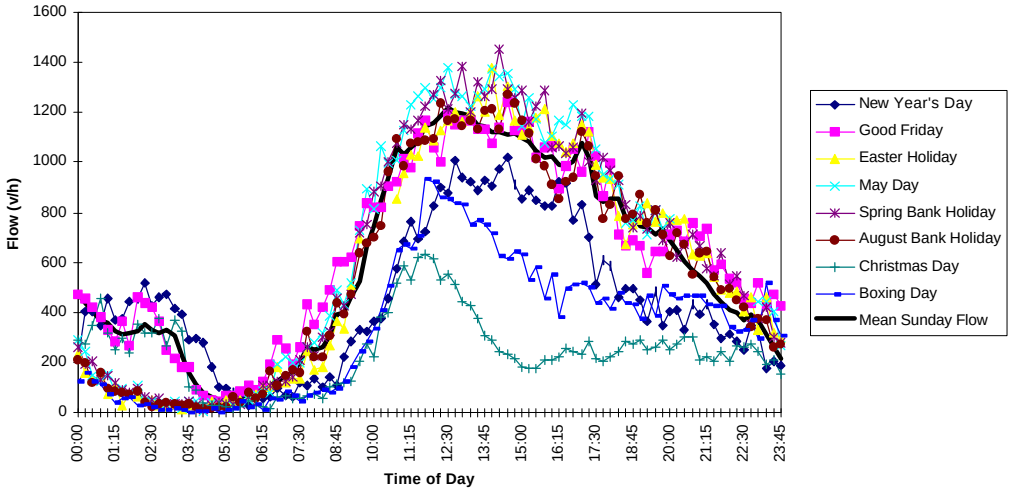

Figure 1: Flows on Public Holidays - Kingston Bridge, London

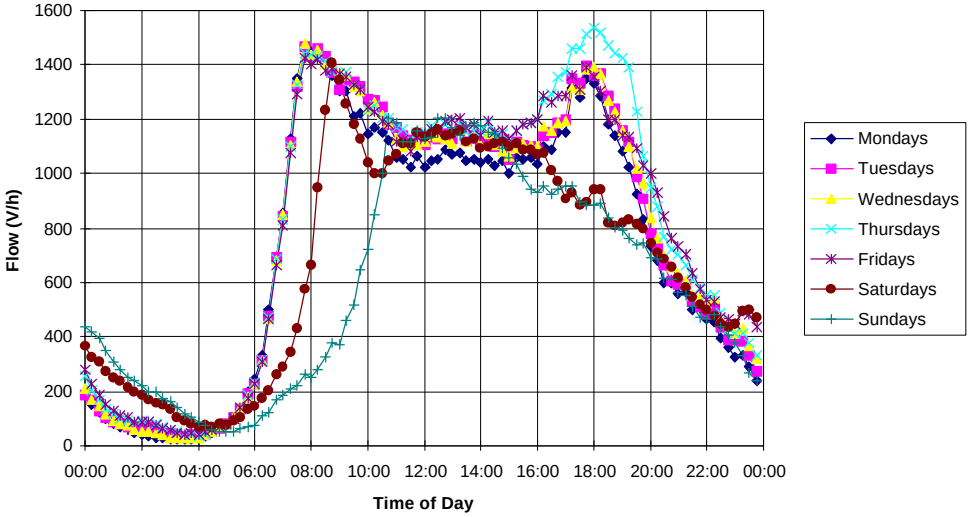

Figure 2: Mean flows by day of the week - Kingston Bridge, London

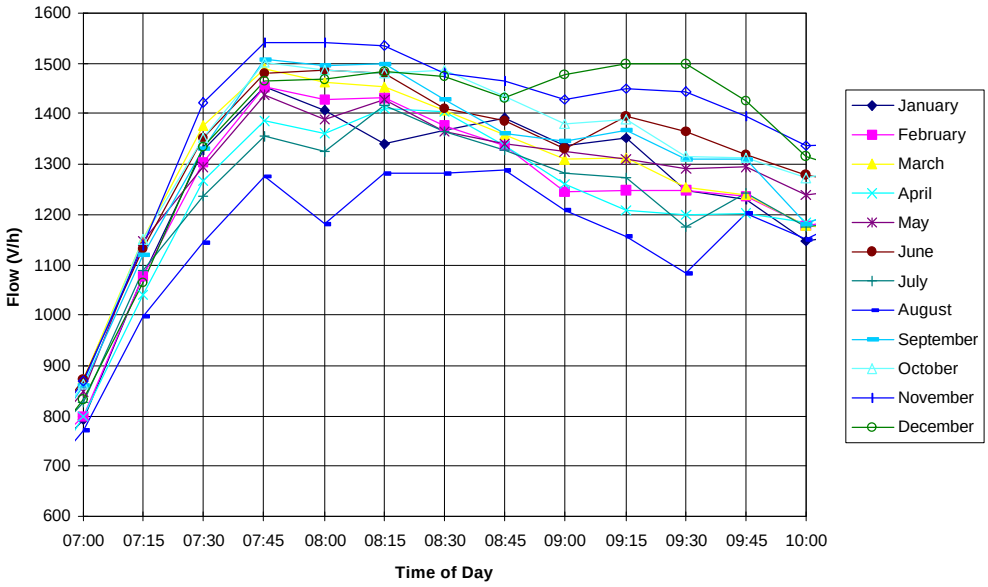

Figure 3: Mean Flows by Month (AM Peak), Kingston Bridge, London

The next stage in the analysis was to look at flows by the day of the week. As many Public Holidays occur on Mondays it is very important to remove the Public Holiday flows to avoid bias being introduced when analysing flows by the day of the week. A typical weekday plot is shown in Figure 2. It is clear that mean flows on Saturdays and Sundays are both distinct from one another and are lower than during the rest of the week. For the other days of the week the flows are very similar to each other. It is however very common for the flows on one or two other weekdays to be slightly different from the rest due to a market day or late-night shopping. This is evident in Figure 2, where the flows on Thursdays, and to a lesser extent Fridays, are higher than the other weekdays during the PM peak.

Plotting the mean weekday flows by the month of the year can reveal seasonal dependencies. Figure 3 shows the mean flows by month during the AM Peak period on Kingston Bridge in London. The data only covers weekdays and all the data from Public Holidays has also been removed. It is clear that the weekday flows in August, when many people take their summer holidays, are lower than the other months of the year.

The properties of the distributions of the data were now investigated. The data was examined to see if the distributions at each fifteen minute data point were approximately normal. There are a number of simple tests which can be carried out to test for normality. A perfectly normal distribution will have both a skewness and a corrected kurtosis of zero and the Inter-Quartile Range (IQR) divided by the standard deviation will be approximately 1.3. All these tests showed that there is a degree of skewness early in the day but for most of the day the data points are close to having a normal distribution.

Now that it has been determined that for much of the day the data is approximately normal, a useful statistic to calculate is the coefficient of variation. This is defined as:

$$Coefficient\ of\ Variation = \frac{s*100}{Mean}$$, where s is the sample standard deviation.

Since 95% of all values sampled from a normal distribution are within ±1.96σ of the mean value, then approximately twice the coefficient of variation gives the percentage difference from the mean value for 95% of the values in the distribution. The coefficients of variation were now calculated for the datasets, after removing all the known sources of variation, i.e. Public Holidays, August data, unusual weekdays with late-night shopping and market days.

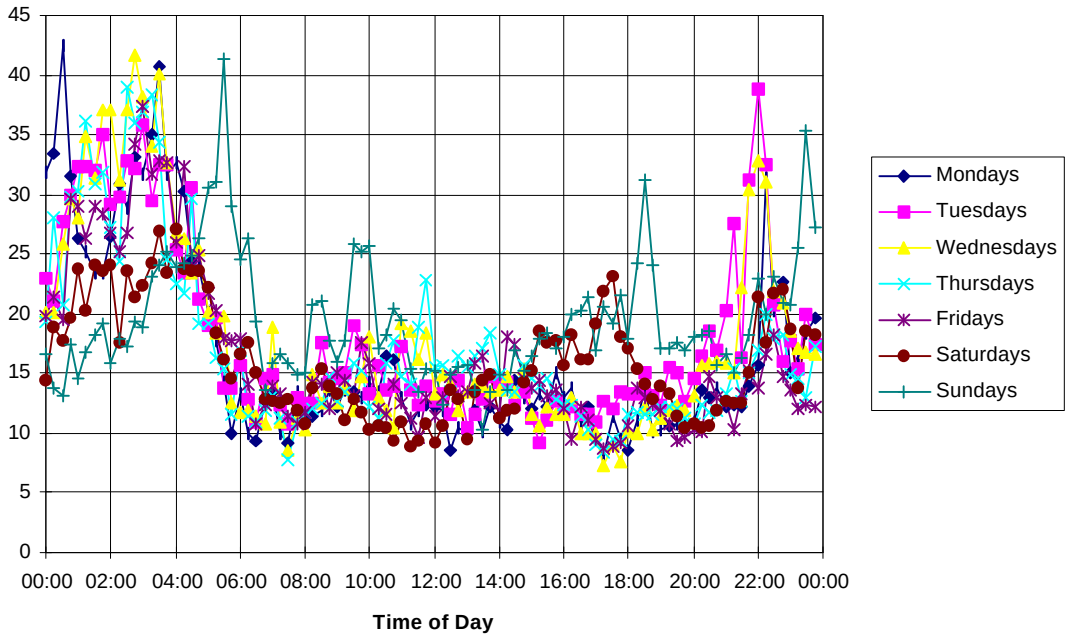

Figure 4: Coefficient of variation, Link N20/076m, Croydon

The example shown in Figure 4 is fairly typical. The variation is usually much higher early in the morning, but after about 06:00 it remains approximately constant for the rest of the day. The amount of variability on Saturdays and Sundays is also usually slightly different from the rest of the week. An important point to note is that the amount of variability is different from location to location. This is illustrated in Figure 5, which shows the coefficient of

variation profile for two links, N1222L in Leicester and N2626D in Melton Mowbray. In both cases the lines presented have only included data from weekdays, with market days, August data and public holidays removed.

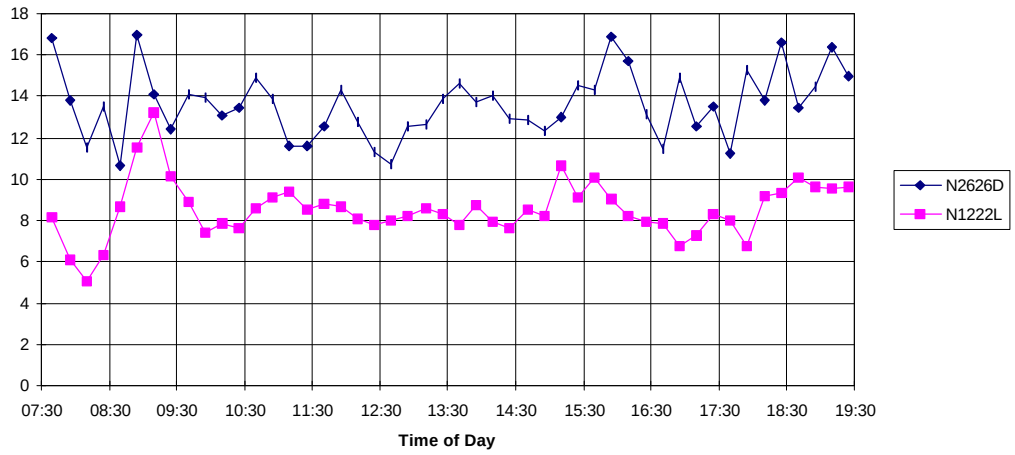

Figure 5: Coefficient of Variation for weekday flows on two different roads

An attempt was now made to glean more details about the nature of the variability. One obvious question to ask is if the flows on a given day are lower/higher than the mean value at one time, are they likely to be lower/higher at a later time (termed auto-correlation). Another question that needs answering is if the flows are lower/higher than the mean at some time on one link in a network are they likely to be lower/higher at the same time on a different link in the same network (termed cross-correlation). If there is any such correlation then this could indicate that there is something that is affecting the whole network, such as very bad weather or a major incident. This analysis revealed periods when systematic anomalies occurred. By using other sources of information, such as the broadcast radio road traffic incident reports which are stored in the Instrumented City database it was usually possible to reveal the cause of these anomalies.

Application to the assessment of a responsive UTC system

Simulation runs were carried out with different levels of variability in the input flows in order to see how the benefits of using a responsive UTC system depend upon the variability. The AIMSUN2 micro-simulation package (Ferrer and Barceló, 1992) was used, linked up to a SCOOT UTC system (Bretherton, 1989). AIMSUN2 provided SCOOT with vehicle detection data from simulated vehicles moving around the network and passing over simulated detectors. SCOOT then calculated signal plans which minimised stops and delay and these were passed back to AIMSUN2 where they were implemented. The network used for the simulations was Kingston-upon-Thames in London, as this had already been used in a previous study. This work is reported in more detail in Fox et. al. (1998a) and Fox et. al. (1998b).

Mean values of flows on links in the network were used to calculate a set of fixed time signal plans using the TRANSYT program (Vincent et.al., 1980). A set of runs were then carried out under both fixed time and responsive system operation. Sets of flow profiles were generated by adding random variability sampled from a normal distribution to the mean flow profile. Two different levels of variability were used, the first corresponding to a coefficient of variation of 8.0%, the second to a coefficient of variation of 16.0%. An AM peak period from 06:30 through to 10:30 was simulated for each run. The mean number of seconds for a vehicle to travel one kilometre was used as the measure of comparison between the runs (calculated by dividing the total vehicle travel time by the total distance travelled by all vehicles in the network during the simulation period).

The results are shown in Table 2. A set of one tailed t-tests can be used to determine the confidence levels that the observed changes are real. These reveal a 97% confidence level that SCOOT reduces travel times for a variation level of 8%, and a 99.9% confidence level for the 16% variation level. Most importantly, there is a 96.2% confidence in the benefit of SCOOT with the 16% variation level being greater than the benefit with the 8% variation level.

	Variation = 8%			Variation = 16%		
Run No.	TRANSYT	SCOOT	Benefit	TRANSYT	SCOOT	Benefit
1	154	156	-2	157	148	9
2	153	152	1	165	154	11
3	155	150	5	149	138	11
4	172	153	19	165	147	18
5	159	154	5	166	157	9
6	154	157	-3	167	164	3
7	166	161	5	170	155	15
8	168	165	3	170	164	6
9	155	150	5	156	145	11
10	161	152	9	153	146	7
11	177	158	19	174	153	21
12	161	152	9	167	154	13
13	152	144	8	155	148	7
14	154	145	9	160	148	12
15	176	170	6	172	161	11
Mean	161.1	154.6	6.533	163.1	152.1	10.921
s.d.	8.634	6.947	6.255	7.573	7.418	4.645

Table 2: Benefits in the mean seconds per km (s/km) for different levels of variability

Conclusions

The variability in flows in urban road networks has been analysed. Some causes of variability have been identified and quantified. It has been discovered that the amount of variability, as indicated by the coefficient of variation, is usually approximately constant for much of the day. The value of this statistic does however vary from location to location. This analysis has been used to determine how the level of variability can affect the benefits that can be gained by using a responsive urban traffic control system. This analysis is based on micro-simulation model runs of the Kingston-upon-Thames network under SCOOT control. It concludes that the benefits achieved by using a responsive UTC system depend critically upon the level of variability in the traffic flows in the network. It is recommended that all future assessments of responsive UTC systems should take this into account.

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