VALIDATING AND ESTIMATING THE BENEFITS OF INTRODUCING URBAN TRAFFIC CONTROL SYSTEMS

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ABSTRACT

This paper examines the traffic signal control systems in the road network in South Dublin County Council (SDCC), Ireland. A study was conducted to ascertain the functionality of the traffic network within the county. Where areas demonstrated that traffic congestion existed in the network, methods to alleviate it were explored. At present the traffic signals under the control of SDCC operate under two forms of traffic control known as Vehicle Actuated (VA) and Micro-processor Optimized Vehicle Actuated (MOVA). Neither of these systems have the ability to communicate with the adjacent upstream and downstream traffic junctions. This has the affect of individual junctions operating autonomously with no awareness of the conditions of the surrounding junctions, within the network. This problem is magnified when junctions are in close proximity to each other, and vehicular progression between adjacent junctions is inhibited. Traffic systems that reduce this from occurring are called Adaptive Traffic Control Systems. For this reason, research was carried out to explore the different methods of controlling traffic signals under Adaptive Traffic Control in South Dublin.

An adaptive traffic control system was chosen, and installed in a test area within South Dublin. The test area incorporates three traffic junctions and one pedestrian junction. This location was chosen because several junctions are situated in close proximity to each other, and the lack of co-ordination between the traffic signals has been generating excessive traffic queuing in the region. A number of adaptive traffic control systems were examined, and it was decided to install a SCOOT system (Split Cycle Offset Optimisation Technique). Once the adaptive traffic control system was operating fully, several testing procedures were conducted to gauge the performance of the system. These tests included an Automatic Number Plate Recognition journey time survey. The results of the testing conducted suggest that the implementation of the adaptive traffic control system was successful in achieving traffic progression, and reducing the journey times of vehicle within the test region.

Keywords: ITS, Traffic analysis

INTRODUCTION AND BACKGROUND

This paper evaluates current traffic congestion problems in an area in Tallaght, South Dublin and evaluates the introduction of an Urban Traffic Control (UTC) system to alleviate this congestion. South Dublin is one of the four administrative regions that make up county Dublin. In 2006, South Dublin had a population of just under 250,000 (CSO, 2006). The region like many other urban areas has several traffic problems, which are concentrated around the central administrative and retail area of the region. The traffic control systems in this region prior to the adaptive system being installed operated under two forms of traffic control known as Vehicle Actuated (VA) and Micro-processor Optimized Vehicle Actuated (MOVA). The main drawback of these systems was that neither of these systems have the ability to communicate with the adjacent upstream and downstream traffic junctions. The purpose of the research conducted for this paper was to ascertain the benefits that could accrue from introducing a number of Split Cycle Offset Optimisation Technique (SCOOT) junctions in the region.

To measure the benefits of introducing a system of SCOOT junctions in the region four junctions were converted to SCOOT for a trial to determine the travel time-savings that were possible using the system. This paper reports the results of the trial period and details the benefits of using an adaptive traffic control system such as SCOOT. This paper contains five sections; the second section contains a literature review of adaptive traffic systems and the benefits. The third section of the paper describes the methods used to analyse the SCOOT system and to measure the travel time-savings. The fourth and fifth sections contain the results from the travel time analysis. The paper concludes with a discussion and conclusions section.

LITERATURE REVIEW

Urban Traffic Control (UTC) describes when signalised traffic junctions, in close proximity to each other, are connected together to enable them to communicate with each other. As technology developed, this concept was expanded to allow the traffic junctions not only communicate to each other, but to also communicate with a common in station mainframe that can communicate to all traffic junctions within the network. Co-ordinated signal control systems use predefined signal plans that reflect the volumes of vehicular traffic being experienced by an intersection. Signal timings of major movements are linked to allow progression through several junctions, increasing the rate of throughput within a network.

Signalised traffic junctions can be classified into three broad groups. The first two, fixed time and co-ordinated traffic signals, have been outlined above. These systems operate using fixed time plans and although co-ordinated traffic signals can adapt to changes in traffic volumes; cycle times, splits and offsets are not adjusted to promote progression between adjacent junctions. The final type of traffic control is called ‘Adaptive Traffic Control Systems’ (ATCS) (or UTC) and this system is similar to co-ordinated traffic control except timings, including cycle time, are allowed to change every 3-5 minutes. ATCS signal systems make constant changes to signal timings based on measured flows, reacting to these flow variations results in reduced delay, shorter queues and decreased travel times (Feng et.al, 2003).

By making gradual small changes to the timings of the traffic signals, SCOOT tries to minimise its Performance Index (PI). This PI is made up of the measured delay, queue length, and stops in the network. SCOOT generates Cyclic Flow Profiles (CFP) based on actual street demands, and uses the generated CFP to inform the downstream intersection of platoon movement coming in its direction. Data received from the detection system measures the flow and occupancy of vehicular activity, which creates a Link Profile Unit (LPU). SCOOT consists of out-station units, which are the individual traffic controllers, and an in-station unit. The in-station unit needs to be powerful enough to process the data being received from the out-station units, and must have the capabilities to return decision commands in real time. Another feature of SCOOT is its three optimisers. The first optimiser is the cycle time optimiser; this calculates the optimum cycle length for the critical intersection within the network and runs typically every 5 minutes. The second optimiser is the split optimiser, which assigns green splits based on cycle length and offsets, which runs 5 seconds before each stage change. The final optimiser is the offset optimiser, which computes offsets between junctions to promote progress between junctions, and it runs once per cycle.

SCOOT has been installed in over 200 cities and towns around the world, and since it was conceived in the early 1980's it has been continuously developed to meet the requirements of the traffic manager (Bolger et.al, 2007). SCOOT is an online traffic system, which monitors traffic flows continuously from on-street detectors by using a traffic model of the network to predict the delays and stops caused by a particular set of traffic signals. SCOOT uses detector information to recalculate the traffic models every second, and makes alterations to the timings as deemed necessary (IHT, 1997).

Traffic infrastructure systems with real-time adaptive signal control strategies in place perform better than those systems without this facility (Kosmatopoulos et.al, 2006). When adaptive control traffic systems are put into operation, average journey times decrease and cruise speed increase, making a more efficient road network. By reducing stopping and starting, cars emit less fumes and pollutants, hence, better for the environment. Several studies have been carried out to demonstrate the effectiveness of SCOOT. The results show that SCOOT improves both network and corridor performance by reducing delay, queue length and travel time. It has also been commented that SCOOT is effective up until the point in which saturation is reached, typically 90%, after this point SCOOT can be classed as a sophisticated fixed time plan implementer. This supports the theory that SCOOT can delay the onset of congestion and reduce recovery time, but once saturation is reached, congestion is inevitable (Feng, 2003). Different studies have varying opinions on the effectiveness of SCOOT, but most agree that on average SCOOT can yield between 12-20% savings in delay compared to optimised fixed time plan systems (*4*). One such study found that, 'SCOOT reduced network delay, travel time, intersection delay, and queue length by 28.3%, 22.8%, 30.7%, and 24.2%, respectively, relative to the optimized plan-based control' (Chilukuri, 2004).

METHODOLOGY

SCOOT System installed

This project required a substantial amount of construction works to facilitate the installation of the UTC system. This work involved the installation of communication and traffic ducting. Figure 1 below illustrates the test area in which the ducting was installed. The red line indicates the chosen route. This stretches from the pedestrian crossing at location one on the Greenhills road, travelling south down Greenhills road past test junction locations 2, 3 and 4, until it reaches the N81 Tallaght Bypass. The ducting network measures approx. 5 km and connects the traffic controllers, known as out-stations, along that route to the main in-station in the Traffic Management Centre (TMC) located in SDCC. At traffic junctions, existing ducting was already in place. This usually stretched to 40m, but only on approaching arms of the junction.

Figure 1 Junctions on the SCOOT system

Measuring the performance of the SCOOT System

In order to validate the travel time reductions a travel time reduction survey was conducted using automatic number plate recognition (ANPR). Eight cameras were required to satisfy the OD matrix over four nodes. The purpose of the ANPR journey time survey was to carry out an independent journey time survey separate to the

UTC system. As such, the operation of the ANPR journey time survey produced journey time information that reflects the operation of the UTC system. There is no connection between the UTC system and the ANPR system, so any journey time results obtained are completely independent. The locations of each of the ANPR cameras used in the study can be found in Figure 2.

The ANPR journey time survey was carried out in two parts. In part one the journey times were recorded for one week when the UTC was in normal operational mode. Part two repeated the same journey time survey but with the UTC system turned off and all junctions in the test region operating in VA mode. For both scenarios it is important that consideration is given to checking that traffic volumes are similar for all test period under review. Dissimilar traffic volumes can yield incomparable journey time results.

Figure 2 illustrates an aerial view of the ANPR survey test site. The location of the ANPR cameras will determine whether they capture the front or backs of the vehicle registration plate. The ANPR cameras were located in five locations L1 to L5, as shown in Figure 2. The main corridor in the test region runs along the Greenhills Rd. The 'In To Town' (ITT) flow travels in a north-east direction, while the Out Of Town (OOT) flow travels in a south-west direction. The second test conducted on the system, involved using the UTC ASTRID facility to interrogate the UTC system for the said test period. An investigation took place into the potential effects the status of the UTC system had on output parameters such a delay and stops.

Figure 2 Locations of ANPR cameras

ANPR SURVEY RESULTS

The ANPR journey time survey was carried out over a two-week test period. The UTC system was turned 'Off' for one week starting on Monday the 21st of June 2010 and finishing on Sunday the 27th of June 2010. For the second week the UTC system was turned 'On' from Monday 28th of June 2010 until Sunday the 4th of July. As the idea of the UTC system is to promote progression between upstream and downstream traffic junctions, it would be expected that the ANPR journey time results would be lower for the time period that the UTC system was switched on. The journey time output of the ANPR cameras is given in seconds, so the time quoted is a representation of the time it takes a vehicle to travel between two ANPR locations.

The journey time analysis was carried out by analysing the two main peaks within one day, i.e. AM peak and PM peak. A comparison was carried out between a day when the UTC system was off, and the same day when the UTC system was on. The journey time between two points for when the UTC system was on was taken away from the journey time for when the system was off, and the resulting time represents the time saving. This was done on a like day to like day comparison for the weekdays of Monday to Friday. When a journey time result was returned by the database for a chosen route it was important not to judge the time saving on this alone, several other key factors, including traffic volumes, could have influenced the variation in journey time. A reduction in journey time may be simply owing to the fact that there is a reduction in traffic volumes within the network. Another factor that must be taken into account is the existing weather conditions, as severe weather conditions are known to alter journey times. Weather conditions were observed, and weather analysis data obtained from a nearby National Road Authority (NRA) weather station confirmed that there was no significant weather fluctuation during the test period. This allowed weather condition to be eliminated as a contributing factor toward journey time variance.

Four routes were chosen to carry out journey time analysis. These routes carry the majority of the traffic in both the AM and PM traffic peaks. Furthermore, local knowledge of the area has shown that this to be the case, as these four routes serve the main trip attractors within the test region. The locations in the 'Location O-D' column relate to the locations highlighted in Figure 2.

Table 1 Route description for the ANPR survey

Route	UTC Nodes	Location O-D
R1	Node 4 to Node 3	L1 to L3
R2	Node 1 to Node 4	L5 to L1
R3	Node 4 to Node 1	L1 to L4
R4	Node 3 to Node 4	L3 to L1

Journey time analysis was carried out on all four routes. Initially it was envisaged to carry out analysis from Monday to Sunday, but after a full week's analysis was done for route 1, it became clear that this would not serve any great purpose. Weekend patterns were so varied that it was difficult to establish a pattern of traffic flow in any given direction, relative to a specific time of the day. Furthermore, traffic volumes were significantly lower on the weekend with no definitive vehicular pattern or platoon movements, making it difficult to achieve any reasonable co-ordination between signals. Under circumstances like this the mode of traffic control should revert back to Vehicle Actuated (VA). This would also be the case for late at night, and this is why the UTC system is only on from 07:30 to 20:00 hrs. For these reasons journey time analysis for routes 2, 3 and 4 was confined to Monday to Friday. A Microsoft Access database was built to generate journey times from the data captured from the ANPR cameras. This database had to be tailored to suit this specific application, so a maximum journey time had to be chosen to eliminate undesired anomalies within the journey time database.

These anomalies could arise from a number of sources, such as a vehicle entering the test region, but stopping within it for a given time, only to carry on their journey at a later time. Within the test region there are several trip attractors, such as Kilnamanagh Shopping Centre and the Broomhill industrial estate. Premises like these can account for several large journey time results, where people stop at these places for a given length of time, and then continue their journey. Some of the minor roads within the test region are housing estates that would also incur broken journeys, revealing an inaccurate journey time. For reasons such as these, the journey times within each route were timed and reasonable timings were found. A figure of 360 seconds was decided on as a suitable time to act as an upper limit cut off parameter. A time of this order will remove any illegitimate journey times from the database, while ensuring that genuinely congested journey times are not unduly shortened.

Analysis conducted

There are many possibly routes within the test region as outlined above. Similar to most traffic network strategies, the key objective is to keep the traffic with the heaviest flows moving, this usually translates into the In to Town traffic movements in the AM peak, and the Out of Town traffic movements in the PM peak. This is also the case with this test region, so the main traffic movements flow between UTC node 1 to UTC node 4 in the AM peak, and the opposite from node 4 to node 1 in the PM peak. The lunch time peaks have been noted to experience heavy traffic volumes, but form no particular pattern, so the UTC system allocates the timing setting as best it can to reflect traffic flows at that time. Prior to the installation of the UTC system, the main point of congestion for the whole day was being observed in the PM peak between node 4 and node 2.

Tables 2 – 5 detail the selected results from the ANPR survey. The results examined were recorded on the 22nd and 29th of June 2010. During the study two weeks of data were collected one week with the UTC system operating and the other week with the system not operating. A comparison between the results for each of the days collected was consistent and for the purposes of demonstrating the impact of the UTC, a comparison between the results recorded on the two Tuesdays is presented in this paper. Eight different steps were taken in the measurement of the data collected.

Step 1: Measures the average travel time in seconds for each of the routes examined.
Step 2: Measures the percentage difference between the average travel times calculated in step 1, when the UTC system was turned off and for when the UTC

system was turned on.
Step 3: Measures the actual time saving between the two UTC system statuses (as calculated in step 1). A positive result indicates that when the UTC system is operational that the results indicate a travel time saving, and vice a versa.
Step 4: Measures for correlation between the two data sets examined in this study. A standard 'T-test' was conducted to ascertain if the two datasets were correlated. Values less than 0.05 demonstrate that there is no correlation between the datasets.
Step 5: Total daily traffic volumes
Step 6: Reports the averaged traffic volumes in numbers of vehicles per-hour.
Step 7: Measures the percentage difference in traffic volume between when the UTC system was off and when it was on.
Step 8: In this step the time saved in the network was estimated. The time saved as calculated using equation one. This approach relies on the fact that improving one link within a region will improve the journey times of not only that link, but it also has the knock on effect of improving all the links within that portion of the test region. This works on the principle that the vehicles taking less time to travel the improved link, will also improve the journey times of vehicles travelling in the opposing links.

Equation 1

$$\text{Time saving in the network} = \frac{\text{Actual time saved} * \text{Average volume}}{360} * \text{Saturation level}$$

Step 9: estimates the value of travel time saved using the value of time. A value of €8.10 for commuting times was placed on the AM and PM time-savings (*8*). A vehicle occupancy rate 1.4 is assumed in this estimation. Equation 2 used to estimate this value of travel time saving.

Equation 2

$$\text{Cost savings per hour} = \text{Time saving in the network} * \text{value of time} * \text{average occupancy}$$

Tables 2-5 detail the results from each of the four routes examined using the eight analysis steps outlined. The results for the first route show an average journey time saving of 9.85% in the AM peak and 2.75% in the PM peak. It should be noted that when comparing the journey time saving results that the total volumes per hour were marginally lower during periods when the UTC was on. The results for route 2 in Table 3 show a more modest decrease in journey time of 9.73% in the AM peak and 0.97% decrease in the PM peak. The results for route 3 show an increase in the journey time saved in the AM peak of 10.96% and a 3.84% saving in the PM peak. The results for the differences between the traffic volumes when the system is on and off are very similar to those found for route 2 in Table 3. The findings presented for route 4 in Table 5 show similar journey time-savings and traffic volumes to those found for route 3 (see Table 4). The results for the value of travel time-savings found for each of the routes demonstrated a sizable hourly monetary saving for each of the routes with the exception of route 2 in the PM peak.

Table 2 ANPR Survey results – route 1

Step		System off 24/06/2010 – AM Peak	System on 01/07/2010 – AM Peak	System off 24/06/2010 – PM Peak	System on 01/07/2010 – PM Peak
1	Average journey time (seconds)	121.11	110.25	166.74	162.28
2	% difference		-9.85%		-2.75%
3	Actual time saved (seconds)		10.86		4.46
4	Statistical significance at a 95% confidence level		.028		.000
5	Total volumes (Veh/Hr)	25,622	21,578	26,022	26,930
6	Averaged volumes	6,406	5,395	6,506	
7	% difference		- 18.74%		-3.37%
8	Time saving in the network (seconds * Veh/Hr)		122.05		66.74
9	Cost saving per hour (€)		€1,384		€756

Table 3 ANPR Survey results – route 2

Step		System off 24/06/2010 – AM Peak	System on 01/07/2010 – AM Peak	System off 24/06/2010 – PM Peak	System on 01/07/2010 – PM Peak
1	Average journey time (seconds)	118.31	107.82	130.00	131.28
2	% difference		-9.73%		-0.97%
3	Actual time saved (seconds)		10.49		-1.28
4	Statistical significance at a 95% confidence level		.221		.775
5	Total volumes (Veh/Hr)	32,801	28,151	32,811	34,422
6	Averaged volumes	8,200	7,038	8,203	8,606
7	% difference		-0.17		30.05
8	Time saving in the network (seconds * Veh/Hr)		174.28		-27.47
9	Cost saving per hour (€)		€1,976		-€311.49

Table 4 ANPR Survey results – route 3

Step		System off 24/06/2010 – AM Peak	System on 01/07/2010 – AM Peak	System off 24/06/2010 – PM Peak	System on 01/07/2010 – PM Peak
1	Average journey time (seconds)	122.75	110.63	147.05	141.61
2	% difference		-10.96%		-3.84%
3	Actual time saved (seconds)		12.12		5.44
4	Statistical significance at a 95% confidence level		.109		.613
5	Total volumes (Veh/Hr)	32,801	28,151	32,811	34,422
6	Averaged volumes	8,200	7,038	8,203	8,606
7	% difference		-0.17%		0.05%
8	Time saving in the network (seconds * Veh/Hr)		201.40		117.06
9	Cost saving per hour (€)		€2,283		€1,327

Table 5 ANPR Survey results – route 4

Step		System off 24/06/2010 – AM Peak	System on 01/07/2010 – AM Peak	System off 24/07/2010 – PM Peak	System on 01/07/2010 – PM Peak
1	Average journey time (seconds)	94.47	93.07	99.79	94.72
2	% difference		-1.50%		-5.35%
3	Actual time saved (seconds)		1,39		5.07
4	Statistical significance at a 95% confidence level		.096		.097
5	Total volumes (Veh/Hr)	25,622	21,578	26,022	26,930
6	Averaged volumes	6,406	5,395	6,506	6,733
7	% difference		-18.74		3.37
8	Time saving in the network (seconds * Veh/Hr)		15.66		66.37
9	Cost saving per hour (€)		€177.55		€752

Table 5 outlines the Total Cost Savings and the Average Journey Time Saving for the results for the two weeks of analysis conducted. These figures are the averaged totals of the ANPR journey time survey that corresponding to the AM and PM peaks only. Note the while the cost savings on route 2 are negative; a journey time saving is still achieved of 4.07 second on that route. The total average journey time savings are shown as 9.05 seconds, this is approximately the time saving one you expect from installing an additional traffic lane, but at a greatly reduced cost. The total cost saving is shown as €76,297. This reflects one week, and is only represent the AM and PM peaks. More savings could be found outside these times. The approximate cost of installing this UTC system was €150,000, so it is clear to see that the payback period would not take long. The fibre optic communications and UTC in-station costs of the UTC system are once-off costs, so any further expansion of the UTC system would be considerable lower. The financial savings that are achieved go to society as a whole. The investor of the UTC system does not receive the financial benefits of the system directly. This can be one of the major drawbacks when sourcing funding for such projects.

Table 5 Summary of all cost and time savings

Route	Total Cost Savings (€)	Average JT Saving (Sec)
R1	28477.14	10.10
R2	-9113.16	4.07
R3	32335.31	8.90
R4	24597.75	13.14
Total	76297.05	9.05

ASTRID ANALYSIS OF UTC PERFORMANCE

The ANPR journey time survey results provide an unbiased reflection of the performance of the UTC system under different modes of operation. This information has proved to be helpful in accessing the capabilities of the UTC system. ASTRID is a function that the UTC uses to analyse the performance of SCOOT. So far in the analysis process the ASTRID facility has only been used to establish traffic volume flows and link saturation levels. The UTC system retrieves traffic information relating to the behaviour of traffic on the street via the vehicle detection system installed in the network. The UTC system uses this information to supply the three UTC optimisers with the relevant data. The ASTRID facility uses this data as a reporting function. The ASTRID facility can interrogate the UTC system, retrospectively, to assess historical traffic trends. These trends include flow, stop, delay, congestion, saturation, delay per vehicle, and cycle time. All of these facilities can be utilised to assess the UTC system when the system is ON.

Unfortunately, some of the ASTRID facilities functionality becomes limited for the purposes of this project. This is because in this project a comparison is carried out between the performance of the test traffic region when UTC is on and when UTC is off. When UTC is off, the ASTRID facility still runs in the background, but the UTC system is trying to optimise the information received from the street instead of just analysing it. For instance, congestion is calculated as the proportions of time vehicles are stationary over an induction loop, relative to the over all cycle time. When UTC is on, the cycle time is varied according to traffic volumes, but when UTC is off and in VA mode, the cycle time is fixed, hence an ASTRID congestion comparison is not representative of the true conditions on the street. Similarly, saturation is a proportion of green time used when traffic is discharging relative to the available road space. Since the green splits are varied in UTC mode this comparison in ASTRID would reveal skewed results. Not all of the ASTRID functionality is affected. So far it has been shown that the ASTRID output flow gives a good comparison between the UTC system when on and the UTC system when off. Other analysis parameters that can be assessed are stops and delays.

Table 6 outlines the resulting data for the ASTRID Delay per Vehicle output. An improvement of 4.61 % is achieved with the UTC system turned on compared to when it was turned off. Table 6 also outlines the resulting data for the ASTRID stops output. An improvement of 2.61 % is achieved with the UTC system turned on compared to when it was turned off.

Table 6 ASTRID Results

Delay with UTC off	8.13 seconds
Delay with UTC on	7.77 seconds
% Change	4.61%
Total stops with UTC off	2988.23
Total stops with UTC on	2912.11
% Difference	2.61%

CONCLUSIONS

Each of the methods used to evaluate the performance of the UTC system found an improvement in the traffic network within the test region, when compared to the previous traffic control mode. The ANPR journey time testing provided the most rigorous investigation of the scheme, and as such formed a major part of the analysis of the UTC system. Four journey time routes were established within the test region. Of the four journey time routes, the route 1 was identified as the key intersection causing excessive congestion; therefore, it was this route that was classified as the critical node within the test region. 1.4 million registration plate captures was achieved via the ANPR test system, making the samples obtained satisfactorily large enough for a true representative of the journey times taking place on the street.

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