UNIVERSITY OF LEEDS

Monograph:
Shepherd, S.P. (1993) Metering Strategies Applied to Signalized Arterial Networks. Discussion Paper. Institute of Transport Studies, University of Leeds , Leeds, UK.

Working Paper 404

Institute of Transport Studies
University of Leeds

Published paper

Shepherd, S.P. (1993) *Metering Strategies Applied to Signalized Arterial Networks.* Institute of Transport Studies, University of Leeds. Working Paper 404

UNIVERSITY OF LEEDS
Institute for Transport Studies

ITS Working Paper 404 *ISSN 0142-8942*

August 1993

METERING STRATEGIES APPLIED TO SIGNALIZED ARTERIAL NETWORKS

SP Shepherd

This work was undertaken on a project sponsored by the Science and Engineering Research Council (Grant Ref:)
Project title: Gating for Traffic Signal Control: The Application of State-Space Control Theory.

CONTENTS

Page

Abstract

Appendix

ABSTRACT

SHEPHERD, SP (1993). Metering strategies applied to signalized arterial networks. *ITS Working Paper* ***404***, Institute for Transport Studies, University of Leeds, Leeds.

KEY-WORDS:

Contact: Simon Shepherd, Institute for Transport Studies (tel: 0532-335353)

METERING STRATEGIES APPLIED TO SIGNALIZED ARTERIAL NETWORKS

1. INTRODUCTION

This paper describes the development and adaptation of ramp metering strategies for use in signalized arterial networks. The strategies were developed in a simulation environment using the micro-simulation model NEMIS. The paper concentrates on the adaptation of the strategies for signalized arterials, producing real time control strategies which can deal with the problems of over-saturation and blocking back. The basic philosophy behind the strategies is to formulate the problem as a regulator problem, regulating the average link densities to a pre-specified level.

The NEMIS model is used to represent the real world, providing simulated detector loop data. This simulated loop data feeds another model developed by Cremer and Schoof, which estimates flows, queues, and link densities. This sub-model represents the UTC model which is present in systems such as SCOOT and SPOT, its only purpose being to introduce measurement errors similar to those which would occur in reality. These estimates are used to determine the control strategy for the immediate future, which is then enacted within NEMIS.

The paper presents detailed results for four algorithms with various parameters and draws conclusions about the effects of the parameters.

2.THE AUTO-GATING PRINCIPLE

The objectives of all the following methods are :-

i) to reduce total travel time and delay in the system;
ii) to reduce the amount of blocking-back in the system caused by an over-saturated intersection;
iii) to improve safety along the length of the arterial via queue relocation;
iv) to reduce vehicle emissions especially towards the centre of the city.

The above objectives can be met by formulating the problem as a regulator problem, regulating the average link densities to a pre-specified or desired level. This concept has been termed **Auto-Gating**, whereby each control point or intersection meters the traffic into the downstream links. As the inbound flow increases and queues form, then the inbound green times are cut gradually at each control point which has the desired effect of queue relocation, avoiding blocking-back.

This is in stark contrast to the traditional approach of gating, which selects one control point and uses a crude on-off logic with a harsh cut in green time to store the traffic on a pre-determined link.

3. THE SIMULATION ENVIRONMENT

The strategies were tested on a sub-network of Turin using the micro-simulation model NEMIS (Mauro 1991), developed by Mizar Automazione SpA. NEMIS is an incremental model and simulates individual vehicles according to a car-following law, lane changing rules, junction regulations and traffic light status. NEMIS can simulate up to six different classes of private vehicles, specified by different car-following parameters, buses and trams, thus giving a mix of traffic. NEMIS has been modified to represent the blocking-back of upstream junctions and hence the disruption caused to the traffic including cross-flow movements (Shepherd 1991a).

Here NEMIS was chosen to represent the real world for this study. However, in the real world, traffic control systems use data from detector loops to form their own model of the traffic , which in turn determines the control implemented in the form of signal settings. Therefore a simple model developed by Cremer and Schoof (1989) was programmed into NEMIS, which uses simulated detector loop data to provide estimates of various parameters such as flows, queues and link densities, for use in the control strategies/algorithms.

This sub-model represents the U.T.C model which is present in systems such as SCOOT and SPOT, its only purpose being to introduce measurement errors similar to those which occur in reality.

4.1Method 1 The Adapted MX Strategy

This method is basically the MX strategy which was developed in DRIVE 1 (Shepherd 1991b), but adapted to use the Cremer and Schoof model. Instead of using the percentage space left downstream, it now uses the average percentage space left downstream given by the Cremer and Schoof model to determine the green time as follows :-

$$g(k) = \frac{[\, g_{des}(k) + 2g(k-1) + 2g(k-2) + g(k-3)]}{6}$$

where

$$g_{des}(k) = \mathrm{Max}\,(\,\mathrm{Min}(\frac{g_{\max} X}{X_c}, g_{\max}), g_{\min})$$

$g(k)$ is the green time for the main direction at cycle k
$g_{des}(k)$ is the desired green time for cycle k bounded by maximum and minimum values
g_{max} is the maximum permissible green time
X is the percentage average space left downstream per cycle
X_c is the critical percentage average space left downstream

The only variables which influence this control method are the maximum and minimum green times and the value of X_c. For this study, the maximum and minimum green times were considered fixed for all junctions; only the critical space downstream was varied. The values for X were taken from the Cremer and Schoof model during the simulation runs.

4.2 METHOD 2 Local Feedback Control

The following set of methods have been adapted from ramp metering strategies described by Papageorgiou et al (1989).

This first method uses the link densities from the next link downstream only to determine the green time in the main direction. The strategy aims to regulate the average link density over a period to a pre-specified desired density, which can be varied according to conditions. The control is as follows :-

$$g_i(k+1) = \frac{q^i_{desout}(k+1)\, g_i(k)}{q^i_{out}(k)}$$

where

$$q^i_{desout}(k+1) = q^i_{out}(k) - K\,[\,\overline{\rho_j}(k) - \overline{\rho^d_j}\,]$$

$g_i(k)$ is the green time for link i at cycle k
$q^i_{out}(k)$ is the modelled number of vehicles leaving link i in cycle k
$q^i_{desout}(k)$ is the desired number of vehicles to leave link i during cycle k

$\overline{\rho_j}(k), \overline{\rho^d_j}$ are the average density on link j over cycle k and the desired average density for link j.

K is a gain feedback which determines the response of the control.
Link i feeds traffic into link j.

The control is again bounded by the same maximum and minimum green times. The values for the average density over the cycle and the number of vehicles leaving a link per cycle are taken directly from the Cremer and Schoof model. The variables which influence the control system are the gain feedback and the desired average density. The latter determines the steady state solution and, given a constant demand high enough to sustain the desired density, the system would settle to this value. The value of K determines the response to the deviations from the desired density.

Although the above equations are written in terms of densities in vehicles per metre, it was easier to program the control in terms of numbers of vehicles present on a link. This is possible because to convert from densities to number of vehicles present requires only a multiplication by a constant. This constant can be divided into the gain term K.

For this study the desired density and the gain feedback term were varied and the responses noted.

4.3METHOD 3 Linear Quadratic Co-ordinated Feedback Control

This method basically extends the local feedback control method, by using information from all links both upstream and downstream. The feedback term becomes a feedback matrix and the control law is written as follows :-

$$q_{desout}$$

where the notation is as before only in vector terms.

4.4METHOD 4 Linear Quadratic Integral LQI Control

This method is yet another extension of the control law, and brings in an integral term, which basically means that any changes in link densities from one cycle to the next are penalised. The control is written as follows :-

$$q_{desout}(k+1) = q_{out}(k) - K_1[\overline{\rho}(k) - \overline{\rho}(k-1)] - K_2[\overline{\rho}(k) - \overline{\rho^d}]$$

This time there are two gain matrices to define and the desired link densities. In the associated ramp metering strategy tested by Papageorgiou et al (1989), the desired densities were given for selected bottleneck sections only. In the signalised arterial case all densities are given as there is a control point leading into each link; however it was recognised that as the last junction inbound was critical and therefore a fixed bottleneck, the gain terms associated with this junction could be increased.

Various values were tested for both the gain matrices and the desired densities. As usual the resulting green times were bounded by maximum and minimum values.

5.SIMULATION RESULTS

All the following results are for a sub-network of Turin with no route choice (Figure 1a), using a fixed cycle as a base plan. The control strategies limit the amount of in-bound green time at each intersection using an **early cut-off** approach, i.e throwing away green at the end of the phase for the main inbound flow whilst maintaining the outbound green. This has the advantage of keeping the cycle time and the starting offsets fixed.

Each strategy was simulated for one hour plus a recovery period with a zero demand which served to empty the network ensuring that the same number of vehicles were serviced and tested the strategy's properties of recovery from congestion.

First of all the effects of the various parameters for each method will be discussed, followed by a more detailed comparison of the best results for each of the four methods.

The summary tables (1-4) in Appendix A give the distribution of vehicle-hours and the percentage benefits for each method and various parameters tested.

5.1Method 1

The only parameter which has been varied here is X_c, the critical percentage average space left downstream of a control point.

It can be seen from Table 1 that for all cases the outbound traffic has hardly been affected. This is due to the early cut-off approach keeping the outbound timings constant together with a strong outbound flow (ie. there are not many turning movements blocked).

However, for the inbound traffic which is being controlled or metered into the area then the disbenefit increases as the value of X_c increases as expected. The higher the value of X_c the more each link is protected from inbound traffic, the earlier the response and the harsher the response. To balance this disbenefit there is an increase in the benefits to the cross flow or turning traffic due to the reduction in blocking-back at each intersection.

There comes a point where the disbenefits to the inbound traffic outweigh the benefits to the cross traffic, ie. the control is too harsh.

The first three columns in Table 1 were for a fixed value of X_c applied at all the controlled junctions. Column four has different values of X_c for each link, found by trial and error and intuition through simulation. Generally, the shorter links were given a higher value of X_c ie. they were protected more. This results in a higher overall benefit to the system in terms of total travel time.

5.2Method 2

In this method the desired density and the gain feedback parameters were varied. In Table 2, D represents the desired percentage average density, D = 80% is directly comparable to the MX method with a value of $X_c = 20\%$.

It can be seen that the desired density and the value of K combine to determine the control action. The desired density determines the steady-state solution of the regulator problem whilst the gain feedback K determines the rate of response to deviations from the desired state.

Table 2 shows that as D changes from 80% to 75% there is a significant change in the inbound and cross traffic. In fact with D = 80% the control is only slightly different from the fixed plan case, but as the desired density is decreased then the control action becomes harsher. With the desired density set to 70% the gain feedback term must be lowered to K = 0.25 to dampen the response. Again the desired densities for each link were varied by trial and error to give more protection to the shorter links.

Note that reducing the gain feedback element not only dampens the rate of response to increasing congestion but it also dampens the response rate during recovery from congestion.

5.3Method 3

This method requires the specification of a gain feedback matrix as well as the desired densities. The elements k_{ij} where $j = i + 1$ correspond to the local feedback terms in Method 2, so these values were used as a starting point in the matrix. It was found that the elements should decrease in magnitude as the associated distance from the control point increases, as in the study by Papageorgiou et al (1989). However, a significant difference is that the gain elements for upstream links and the current link should be negative, ie. an upstream link which is above the desired density requires the green time downstream to be increased.

These negative elements counteract the gating strategy, hence the positive elements dominate, however, they are useful during the recovery period in bringing the greens back up to maximum green time.

The method achieves similar results to Method 2, although the increase in the number of variable parameters makes it more difficult to see what is influencing the control. One advantage of the matrix formulation is obviously the look-ahead principle and extra benefits can be obtained during the build-up and recovery periods.

5.4 Method 4

This method brings in an integral term which penalises changes in density from one cycle to the next; this means the introduction of another gain matrix. Also in Papageorgiou's study K_2 was applied to selected bottleneck densities only, obviously in the arterial case here link 11 is acting as a bottleneck and this information can be fed to all upstream links by changing the right hand column of K_2 from 0.0 to 0.25 for example. The results in Table 4 are for with and without such a bottleneck.

The introduction of these extra variables makes the results difficult to interpret. Adding the bottleneck term can give more protection to link 11 and greater benefits to the cross movements immediately upstream of link 11 but at the expense of other cross movements and inbound links further upstream.

The introduction of the integral term which penalises changes in density causes a more sluggish response in build up to and recovery from congestion.

5.5 Comparison of Methods

Table 5 gives a summary of the total travel times in vehicle-hours and the percentage benefits for the best of each method. It has been shown that all four methods can reduce the amount of blocking-back in the network by relocating queues upstream. The methods provide a means of protecting certain links or areas from excessive queues and hence protection against vehicle emissions, which is a problem in the centre of Turin.

Table 6 gives a global view of percentage reductions in other impacts simulated; namely carbon monoxide, nitrous oxides, unburned hydro-carbons, fuel consumption and amount of blocking back for each of the four methods.

Each of the four methods produce significant reductions in vehicle emissions, fuel consumption and the amount of blocking-back in the network.

5.6 Distribution of Benefits for Method 1

A more detailed view of where the benefits and disbenefits occur for method 1 can be seen from Figure 1(b), the distribution of travel time benefits along the network and Table 7; which gives the percentage benefits in travel times by O/D movements.

In this case as there is no route choice then the O/D movements correspond to routes. In Table 7 there is a zero if no vehicles took that route, the route was impossible or there was no significant change in travel times.

It can be seen from both these sources that the main benefits are to vehicles entering the network from the side streets, whether turning on to the arterial or crossing the arterial. This result is due to the large reduction in blocking-back at each junction. The disbenefits are mainly to the inbound traffic as expected, with a large proportion of the extra delay on link 8 which is the longest link. The method has automatically found the link with the available storage capacity to hold the traffic on. The outbound traffic is hardly disrupted.

5.7 Differences in Control

There is little to choose between the four methods in terms of impacts on travel times, emissions and fuel consumption. However, in terms of the control or green times derived by each method there is a huge difference.

The first four graphs in Appendix A depict the green times used by each method throughout the simulation period for the four main controlled green times downstream of links 7-10.

Recall that there is a demand profile which peaks at about 2500 seconds and drops off to zero at 3600 seconds to clear the network.

As expected the first green time to be cut is that for link 10, for all methods, this is a reaction to the build up of queues on link 11. Next the green times for links 9, 8 and 7 are gradually cut. However, the reaction of the four methods is completely different. In general the first method is the most stable in terms of range of green times used and smoothness of response. The other three methods oscillate at differing levels. Method 2 oscillates the most, due to the fact that it is based on local feedback only plus the number of vehicles leaving in the previous cycle only to determine the green time. When blocking-back occurs then this number of vehicles leaving in the previous cycle can become unpredictable and produces oscillation in the desired green time. All of the last three methods suffer from this problem to varying degrees.

The effect can be seen for link 7 method 2, as the link is blocked, the number of vehicles leaving in the previous cycle can drop to almost zero which is used as the denominator in determining the next green time.

Some of the oscillations are smoothed out by the look-ahead principle of method 3, but method 4 seems to be less predictable.

These patterns are mirrored by the plots of average density per cycle for the regulated links (8-11) as depicted by graphs 5-9 in the appendix.

The first density graph shows the average densities for the base fixed plan. Link 11 dominates with a prolonged period with an average density above 85%, which is equivalent to a period of queues blocking-back. Links 9 and 10 also have long periods of blocking-back.

Method 1 reduces the maximum levels of density for links 9, 10 and 11, transferring the traffic to link 8. However, the levels are stable and at such a level that the blocking-back effect is reduced by 53%.

Method 2 also reduces the maximum levels for links 9, 10 and 11 but there are strong oscillations present, which indicate an over-reaction or a bang-bang control mechanism where the "gate" is on for a short period and then off and so on.

With methods 3 and 4 again the overall maximum densities have been limited and the oscillation is less marked. In fact in both cases link 11 can be seen to be oscillating around the desired density of

75%.

Altering the gain values in the last 3 methods can produced more "damped" responses, but finding the correct values is a matter of trial and error at the moment. Also these methods suffer from their dependence on the number of vehicles leaving in the previous cycle, which can fluctuate wildly during periods of blocking-back.

A better method may be to combine the look-ahead principle of method 3 with the weighted average approach of method 1.

6.CONCLUSIONS

The auto-gating principle has been demonstrated via four different methods, all of which show reductions in total travel times and blocking-back. Obviously the benefits gained depend on the original disruption caused by the blocking-back in the first place. However, it has been shown that it is possible to protect some links more than others, which may be desirable for environmental reasons. This decision could be taken by the traffic engineer and can be implemented simply by changing the desired density for that link.

From a traffic engineering point of view, method 1 would be the most desirable, as the range of green times used is smaller, the response is smoother, and there are less parameters to specify. It also has the traditional UK viewpoint about plans changing gradually over time built-in to the algorithm.

7. ACKNOWLEDGEMENTS

This paper is the result of work undertaken in the following project:

Gating for Traffic Signal Control: The Application of State-Space Control Theory, Sponsored by the Science and Engineering Research Council (SERC); Grant holders F.O.Montgomery and D.Van-Vliet.

8.REFERENCES

MAURO, V. (1991) Evaluation of Dynamic Network Control : Simulation Results Using NEMIS Urban Microsimulator. Paper presented at Transportation Research Board annual meeting, Washington DC, January (1991).

SHEPHERD, S.P. (1991a) The Development of a Real-Time Control Strategy to Reduce Blocking-Back During Over-saturation using the Micro-simulation Model NEMIS. ITS Working Paper 320, Institute for Transport Studies, University of Leeds, Leeds.

SHEPHERD, S.P. (1991b) The Development of a Real-Time Control Strategy to Reduce Blocking-Back During Over-saturation using the Micro-simulation Model NEMIS. Proceedings 24th ISATA International Symposium on Automotive Technology and Automation, Florence, Italy, 20th-24th May 1991 pp.151-158.

PAPAGEORGIOU, M., HADJ-SALEM,H., BLOSSEVILLE,J.M. and BHOURI,N. (1989) Modelling and Real-Time Control of Traffic Flow on the Boulevard Peripherique in Paris. IFAC Control, Computers, Communications in Transportation, Paris, pp.205-211.

APPENDIX A

SUMMARY TABLES VEHICLE-HOURS (% BENEFIT)

Method 1 MX Strategy

Links	No Control	$X_c = 20$	$X_c = 25$	$X_c = 30$	X_c = Variable
Outbound	65.3	64.2 (2)	65.0 (0)	65.4 (0)	65.6 (0)
Inbound	224.3	227.4 (-1)	245.9 (-10)	257.2 (-15)	263.5 (-17)
Cross	371.6	303.8 (18)	215.7 (42)	197.2 (47)	163.4 (56)
Total	661.2	595.4 (10)	526.6 (20)	519.8 (21)	492.5 (26)

Method 2 Local Feedback Control

Links	No Control	D = 80 K = 0.5	D = 75 K = 0.5	D = VAR[1] K = 0.5	D = 70 K = 0.25	D = VAR[1] K = 0.25
Outbound	65.3	64.0 (2)	65.4 (0)	65.3 (0)	64.8 (1)	65.3 (0)
Inbound	224.3	231.1 (-3)	285.6 (-27)	278.5 (-24)	296.2 (-32)	290.2 (-29)
Cross	371.6	359.9 (3)	179.9 (52)	184.9 (50)	216.2 (42)	216.4 (42)
Total	661.2	655.0 (1)	530.9 (20)	528.7 (20)	577.2 (13)	571.9 (14)

Method 3 Linear Quadratic Co-Ordinated Feedback Control

Links	No Control	D = 75 $\underline{K} = K_1$	D = VAR[1] $\underline{K} = K_1$	D = VAR[1] $\underline{K} = K_2$	D = VAR[2] $\underline{K} = K_1$
Outbound	65.3	65.6 (0)	65.8 (-1)	64.6 (1)	65.3 (0)
Inbound	224.3	259.4 (-16)	271.0 (-21)	282.0 (-26)	259.8 (-16)
Cross	371.6	251.8 (32)	187.5 (50)	182.7 (51)	174.4 (53)
Total	661.2	576.8 (13)	524.3 (21)	529.3 (20)	499.5 (24)

Method 4 Linear Quadratic Integral LQI Control

Links	No Control	D = VAR^2	D = VAR^2 + Bottleneck	D = VAR^3	D = VAR^3 + Bottleneck
Outbound	65.3	65.0 (0)	64.7 (1)	65.1 (0)	64.8 (1)
Inbound	224.3	281.4 (-25)	283.1 (-26)	275.3 (-23)	271.1 (-21)
Cross	371.6	208.8 (44)	252.2 (32)	246.9 (34)	238.0 (36)
Total	661.2	555.2 (16)	600.0 (9)	587.3 (11)	573.9 (13)

Variable % desired densities used for links (11, 10, 9, 8) respectively were:-

VAR^1 = (75, 75, 70, 80)
VAR^2 = (75, 70, 65, 80)
VAR^3 = (75, 70, 70, 70)

Method 3

$$K_1 = \begin{matrix} 0.0 & 0.5 & 0.3 & 0.2 & 0.1 \\ 0.0 & 0.0 & 0.5 & 0.3 & 0.2 \\ 0.0 & 0.0 & 0.0 & 0.5 & 0.3 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.5 \end{matrix}$$

$$K_2 = \begin{matrix} -0.02 & 0.5 & 0.3 & 0.2 & 0.1 \\ -0.01 & -0.02 & 0.5 & 0.3 & 0.2 \\ -0.001 & -0.01 & -0.02 & 0.5 & 0.3 \\ 0.0 & -0.001 & -0.01 & -0.02 & 0.5 \end{matrix}$$

For Method 4 the matrices used were as follows:-

$$K_1 = \begin{matrix} -0.5 & 0.25 & 0.0 & 0.0 & 0.0 \\ 0.0 & -0.5 & 0.25 & 0.0 & 0.0 \\ 0.0 & 0.0 & -0.5 & 0.25 & 0.0 \\ 0.0 & 0.0 & 0.0 & -0.5 & 0.25 \end{matrix} \qquad K_2 = \begin{matrix} 0 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0.5 & 0 \\ 0 & 0 & 0 & 0 & 0.5 \end{matrix}$$

Bottleneck for Link 11 is achieved by adding 0.25 to the right hand column of Matrix K_2.

Table 5Total travel times in the network in Vehicle-hours and percentage benefits

Links	No Control	Method 1	Method 2	Method 3	Method 4
Outbound	65.3	65.6 (0)	65.4 (0)	65.3 (0)	65.0 (0)
Inbound	224.3	263.5 (-17)	285.6 (-27)	259.8 (-16)	281.4 (-25)
Cross	371.6	163.4 (56)	179.9 (52)	174.4 (53)	208.8 (44)
Total	661.2	492.5 (26)	530.9 (20)	499.5 (24)	555.2 (16)

Table 6 Percentage reductions in emissions, fuel consumption and blocking-back

	Method 1	Method 2	Method 3	Method 4
CO	16	13	14	10
NO_x	11	10	11	8
HC	19	16	18	13
Fuel	10	9	10	7
Blocking-back	53	51	52	47

Table 7 Percentage Benefits by O/D Movements for Method 1

Destination →												
Origin ↓	1	2	3	4	10	11	12	13	14	15	16	17
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	52	77	0	0	0	74	0	0	0
3	0	0	0	-12	1	0	0	0	0	0	0	0
4	1	9	-2	0	1	-4	-2	0	1	1	0	0
10	-17	-73	-7	-17	0	-16	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	42	50	0	0	0	0	0	0	63
13	0	0	0	37	25	0	0	0	0	0	36	0
14	0	24	0	17	17	0	0	0	0	0	0	0
15	0	0	0	-12	0	0	0	0	0	0	0	0
16	0	0	0	59	72	0	0	80	0	0	0	0
17	0	0	0	5	9	0	12	0	0	0	0	0

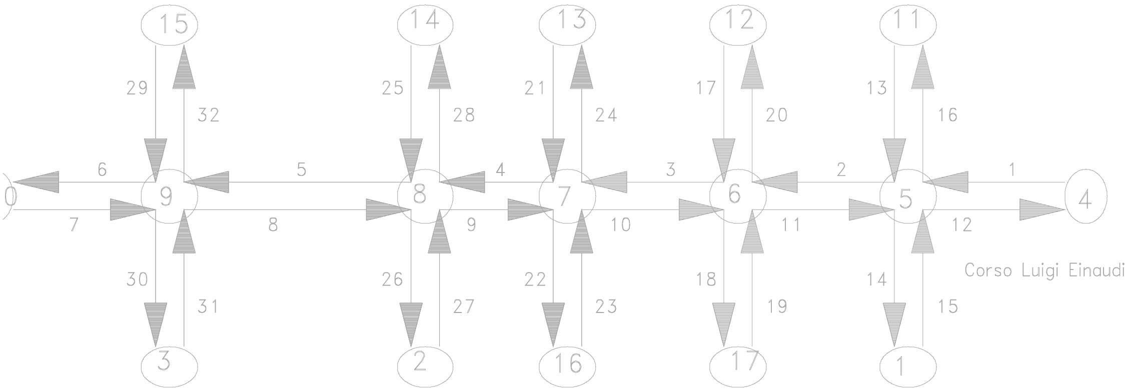


Figure 1 a Sub-Network of Turin, node and link numbers

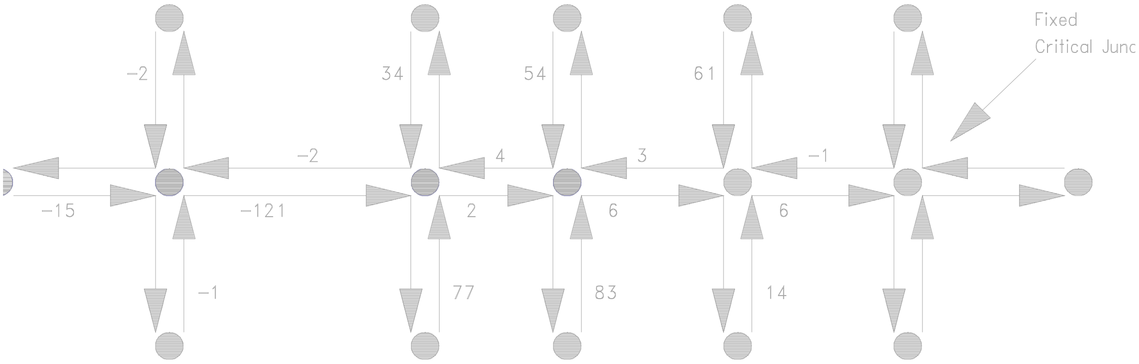
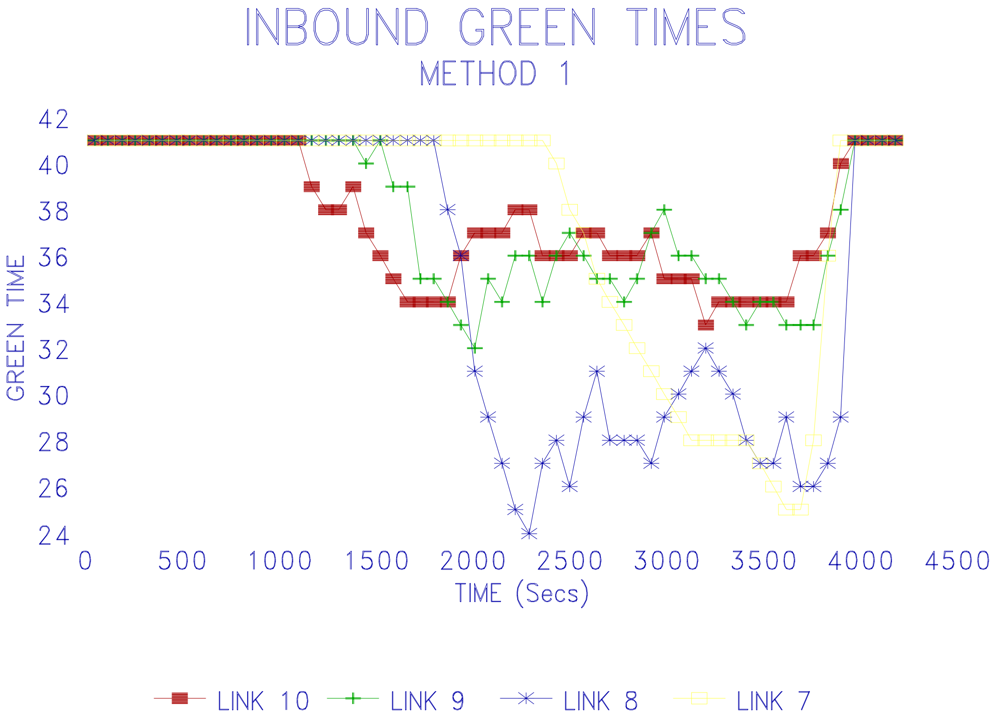
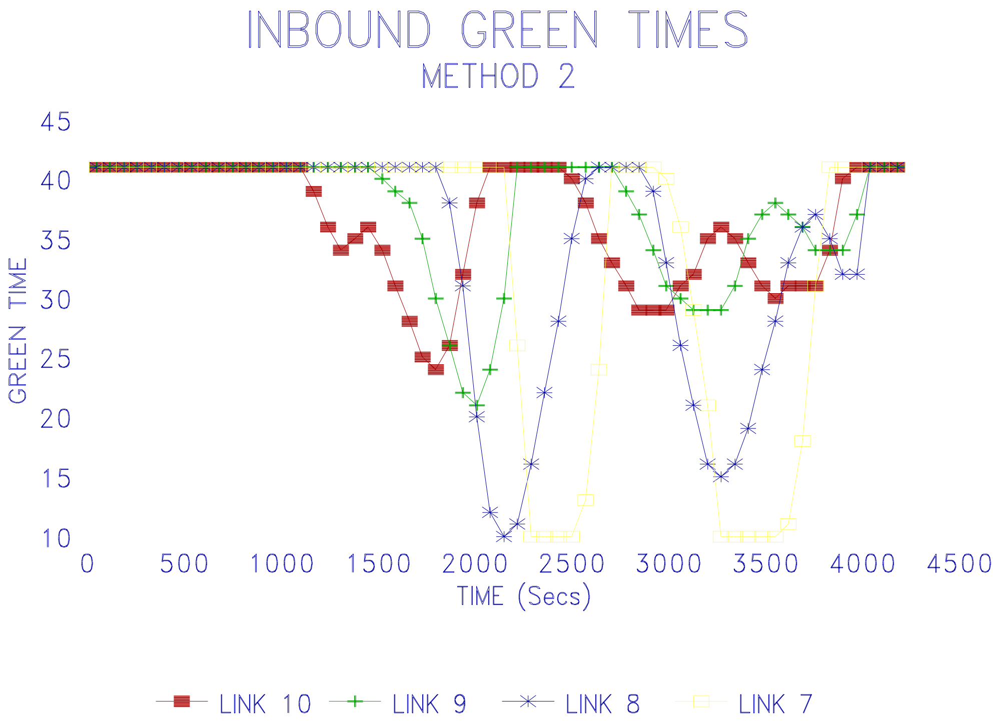
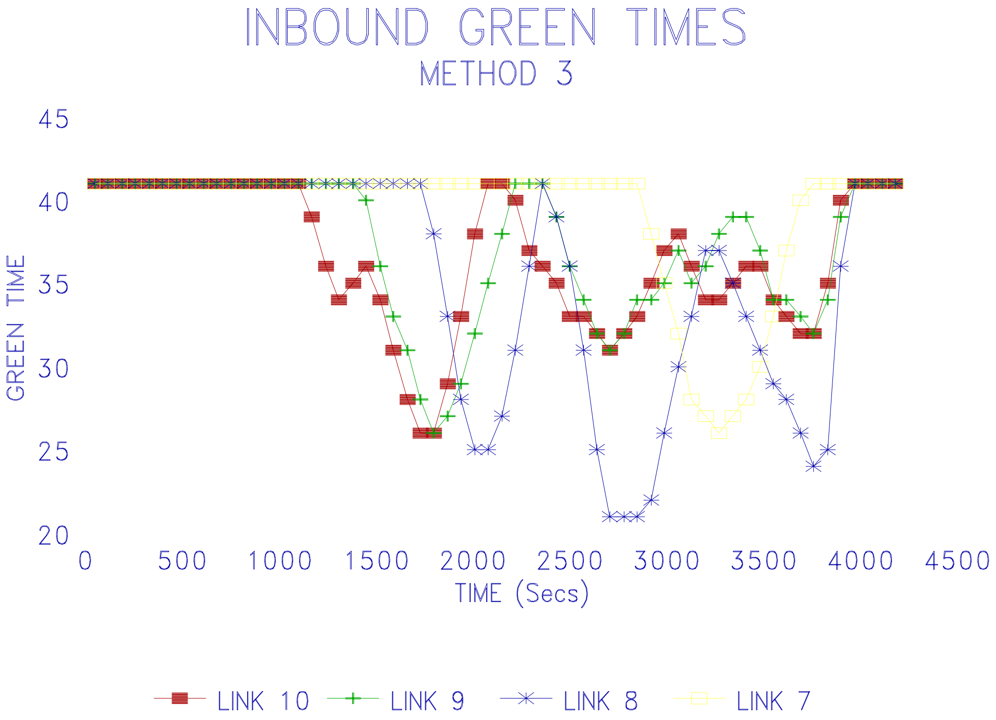
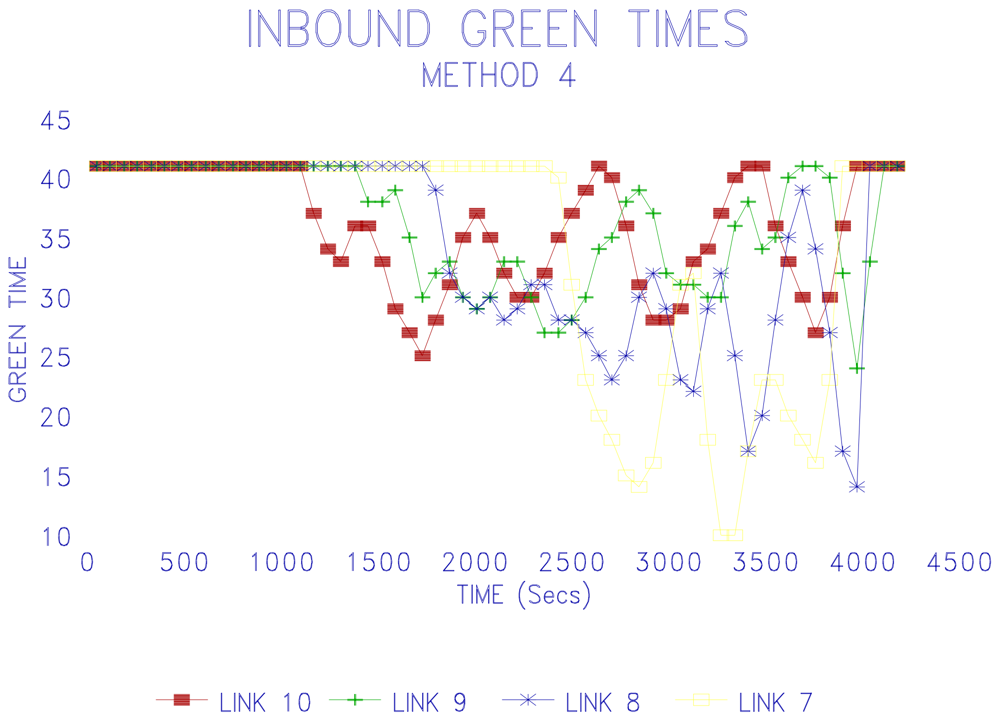


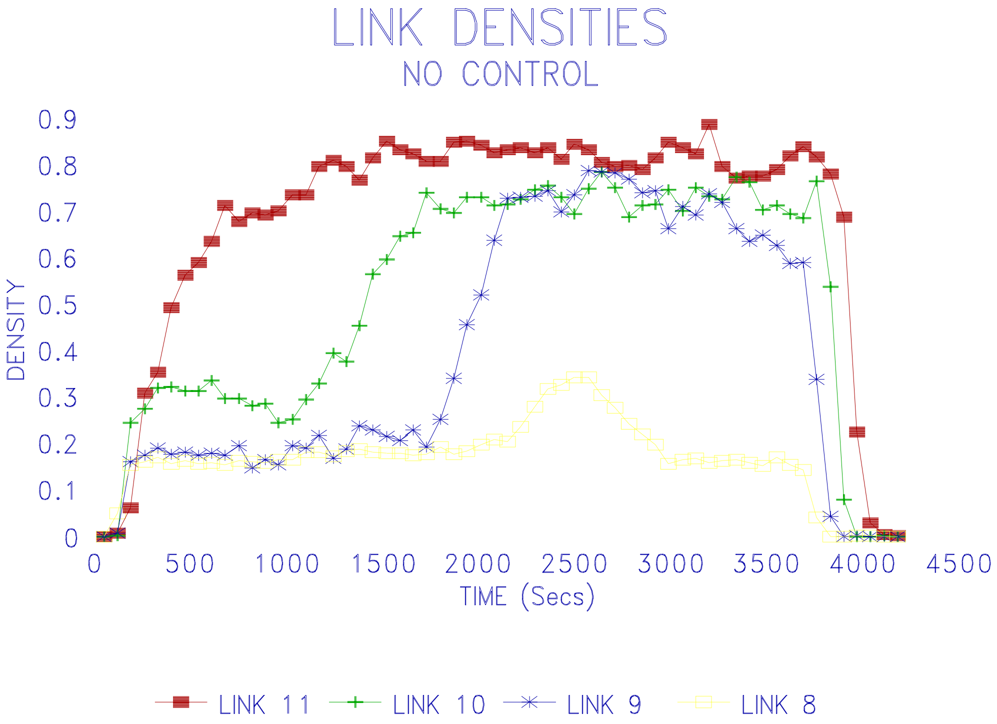
Figure 1b Method 1 % Benefits in Total Travel Times

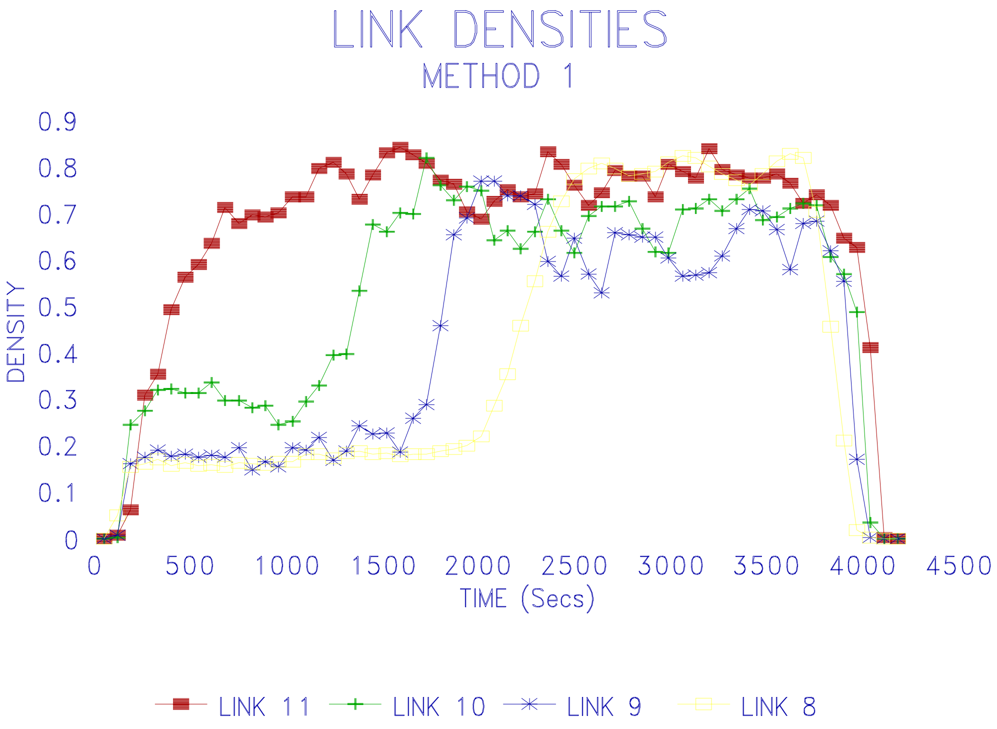

INBOUND GREEN TIMES
METHOD 1
GREEN TIME
42
40
38
36
34
32
30
28
26
24
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (Secs)
LINK 10
LINK 9
LINK 8
LINK 7

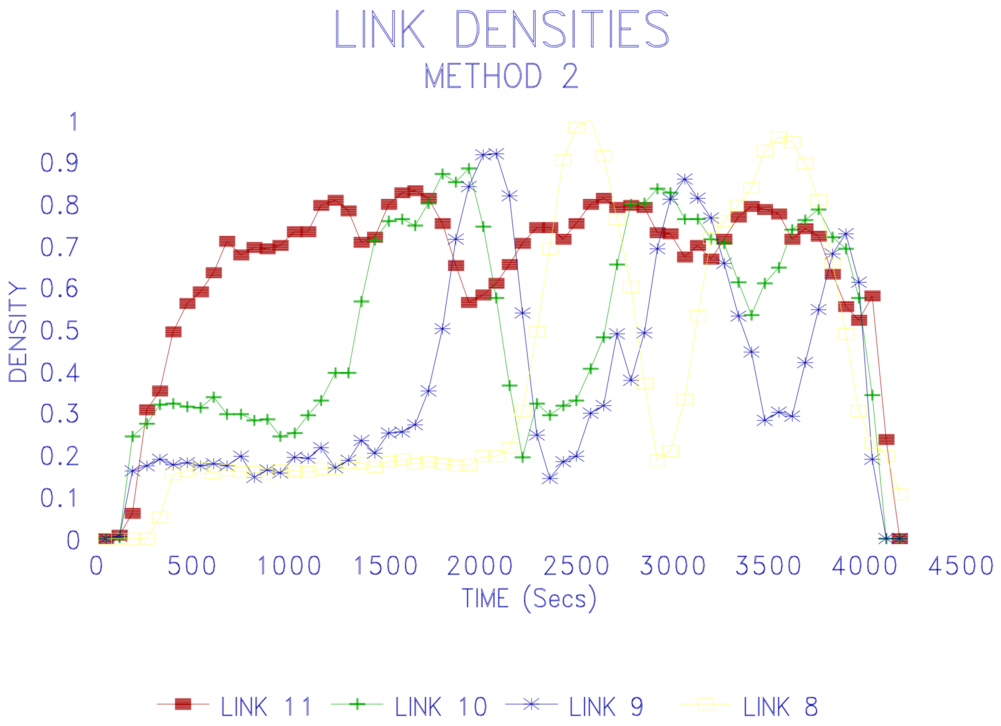

INBOUND GREEN TIMES
METHOD 2
GREEN TIME
45
40
35
30
25
20
15
10
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (Secs)
LINK 10
LINK 9
LINK 8
LINK 7

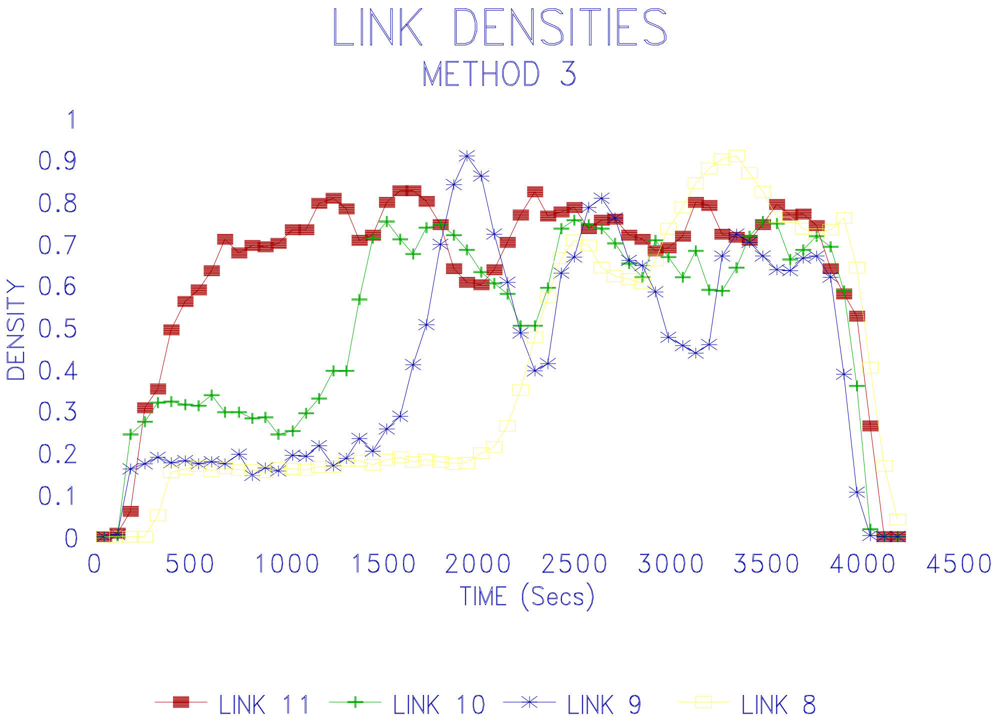

INBOUND GREEN TIMES
METHOD 3
GREEN TIME
45
40
35
30
25
20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (Secs)
LINK 10
LINK 9
LINK 8
LINK 7

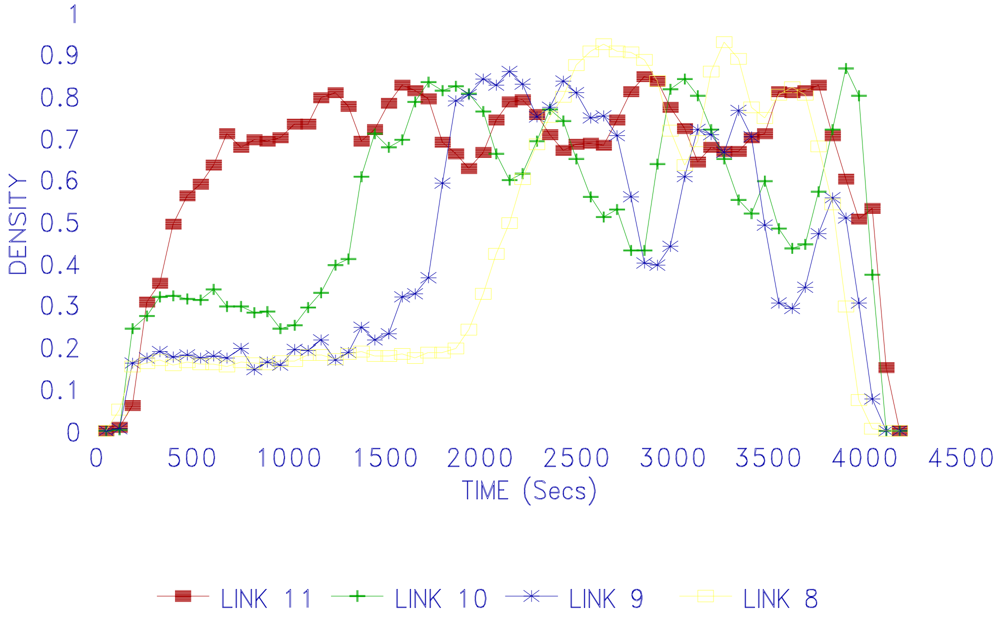

INBOUND GREEN TIMES
METHOD 4
GREEN TIME
45
40
35
30
25
20
15
10
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (Secs)
LINK 10
LINK 9
LINK 8
LINK 7


LINK DENSITIES
NO CONTROL
DENSITY
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
TIME (Secs)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
LINK 11
LINK 10
LINK 9
LINK 8


LINK DENSITIES
METHOD 1
DENSITY
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (Secs)
LINK 11
LINK 10
LINK 9
LINK 8


LINK DENSITIES
METHOD 2
DENSITY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (Secs)
LINK 11
LINK 10
LINK 9
LINK 8


LINK DENSITIES
METHOD 3
DENSITY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (Secs)
LINK 11
LINK 10
LINK 9
LINK 8



LINK DENSITIES

METHOD 4