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DRIVE V1011 PROJECT A7.2

THE DEVELOPMENT OF A REAL-TIME CONTROL STRATEGY TO REDUCE BLOCKING-BACK DURING OVERSATURATION USING THE MICROSIMULATION MODEL NEMIS

S.P. Shepherd

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1.0 Introduction - Objectives Of The Study

This report summarises two months work carried out in Turin, in collaboration with MIZAR AUTOMAZIONE. The objective was to develop further the control strategies initialised in the DRIVE CAR-GOES project (DEL 24), also reported in the form of a technical note by Shepherd. This project simulated a part of the A41 Finchley Road in London, using the microsimulation model TRAFFICQ.

The aim of the control strategy is to reduce the effects of blocking back during oversaturated periods, by in effect responding to the traffic conditions and metering the traffic back upstream. The benefits should be, elimination of first order effects, such as wasted green time in the main direction and also second order effects, such as disruption to opposing and cross street traffic.

2.0 The London Study Using TRAFFICQ (Shepherd 1990)

The first part of this project was to model part of the A41 Finchley Road in London using the event based model TRAFFICQ and calibrate against a set of data collected in a previous study. The A41 is an inbound signalised arterial with problems of blocking back during the morning peak. Four main intersections were modelled with connecting links varying between 230-530 metres. The furthest downstream junction was critical, causing a bottleneck and was therefore modelled as a fixed junction.

Next two traffic responsive control strategies were implemented and tested. Both these methods have the aim of metering traffic upstream by using information about the queues on the links in the main direction and reducing the upstream green allocation accordingly.

The first strategy was called "The Indicator Strategy" and produced an indicator from information about the queues on the examined link, the upstream link and the downstream link. It was found that this strategy became unstable during oversaturated periods.

The second was called "The α Strategy" and relied only on information about the queues on the downstream links. The strategy used an estimate of the space left downstream at the start of GREEN to calculate the new green time. If the space was considered to be more than adequate then the green time was set to its maximum value. As the space downstream decreased then the green allocation decreased. Rapid changes in green time were avoided by smoothing the process over four cycles. The term α was a constant determined from the saturation flow per second and the average vehicle length, the value of α basically controlled the "Critical Space downstream", below which the green time would be reduced, and the rate of response of the ensuing control.

Initial results for this strategy suggested that blocking back had been reduced in the main direction, while increasing the average speed on the main route by 17%. The whole system benefitted by an increase in average speed of some 6.8%. While these results looked promising, it should be noted that an artificial bottleneck had been used to produce the blocking back effect. This was necessary because of the way in which TRAFFICQ modelled queues. TRAFFICQ models queues as vertical stacks of vehicles placed on the stop line, when the light changes to GREEN, all the vehicles in the queue drop or move forward at the same time (i.e there is no starting wave as in real life and a vehicle which is at the back of the queue moves forward instantaneously). This may not be so important during medium traffic conditions but is thought to be necessary when modelling long saturated queues.

To overcome this problem it was deemed necessary to change simulation model, therefore the following work was carried out using NEMIS.

3.0 The Turin Study Using NEMIS

This study was carried out in collaboration with MIZAR AUTOMAZIONE in Turin as part of the DRIVE V1011 CAR-GOES project.

3.1 NEMIS

NEMIS is a Network Microsimulation Package developed by MIZAR in Turin. It is a time increment model capable of tracing the movement of every vehicle, step by step through a network defined by the user. The vehicles are moved along lanes within links according to a CAR-FOLLOWING LAW, which also holds across a junction (i.e when a vehicle leaves a link it follows the nearest vehicle in its destination lane within its destination link). The advantage over TRAFFICQ is that a true horizontal queue is formed from the knowledge of the position and speed of every vehicle within the lane.

3.2 The Turin Network

A Sub-Network of TURIN, (Fig 1), with problems of blocking back, has been modelled using NEMIS. The network is similar to that used in the London study in that it has a main flow towards a critical intersection (Node 5) and associated blocking back problems on link 11. It then differs by having four lanes on the main links (as opposed to three) and much shorter links (varying between 100-230m).
The Turin network is also further into the centre of the city and so has a greater relative opposing flow. Also it should be noted here that the network chosen does not have large cross flows, infact Nodes 6 and 7 do not have cross flows.

3.3 The Control Strategy

Next the α control strategy used in London was programmed into the model and tested on the network with a similar demand profile. The strategy was developed to take account of link lengths, as the links in the Turin network were considerably shorter than the London network, and renamed the MX strategy.

The principle of the MX strategy was basically the same as for the α strategy, but now reacted to the percentage space left downstream at the end of red. The response could be set using a pre-defined critical space, Xc (e.g Xc=40%) of the link.

The first tests of the MX strategy were performed using values of Xc equal to 40 and 50% of the link, considering only what happened to the main direction i.e Bidirectional control was used.

Bidirectional control is where the main flow and the opposing flow receive the same "controlled" green time, and any wasted green is passed to the cross-streets flow. In all cases the cycle time and the starting offsets remain constant.

On the other hand Unidirectional control (developed and used later), is when the green times of the cross streets and of the opposing flow remain constant, the controlled green in the main direction being "capped", thus producing an overlapping green. Again the cycle time and starting offsets remain constant.

3.4 Performance Indicators

The initial results showed that the blocking back had been reduced in the main direction. The problem was how to show what the benefits were to the network. For this a measure of performance of the main green time was defined as follows:-

$$ETA = NP / (S*G)$$

where

NP is the number of vehicles exiting the link during the green time

S is the total saturation flow for the link in vehicles per second

G is the corresponding green time for the link

ETA has a range of 0-1 for all links.Thus ETA defines a measure of efficiency for the link (the number of exiting vehicles must be the same or higher when reducing the green times to account for a true rise in efficiency).

It is also necessary to consider the effects on the rest of the network. In order to do this the following data was collected per cycle for every link :-

a) The number of vehicles leaving the link in a cycle

b) The total travel time for these exiting vehicles on the link in that cycle (hence the average travel time per cycle per link can be calculated)

c) The number of stops on each link during each cycle

d) The total delay on each link per cycle.

Delay is defined as the time spent by a vehicle queueing on the link; thus total delay is the sum of the delay over all vehicles in a queue during the cycle. Delay defined in this way, depends on the definition of a queue. Since this is rather subjunctive, total travel time in the system should be used as the main performance index.

Also, to be comparable, the number of vehicles exiting the system must be the same or similar over the whole simulation period.

3.4 Tests Conducted

For the ETA tests MX Bidirectional control with a value for Xc of 40% was used (where Xc is the "critical space" on the downstream link). For these initial tests the offsets for the main route were set to zero.

Next a series of tests was conducted collecting the above defined performance indices as follows :-

For all the following cases Xc was set equal to 40%

1) The zero offset scenario as base
   No control vs MX Bidirectional control
   No control vs MX Unidirectional control

2) The testing of offsets only NO CONTROL
   Forward Progression vs Zero Offsets
   Reverse Progression vs Zero Offsets

3) Best scenario tests with Unidirectional control
   Reverse Progression No Control vs Reverse Progression plus Unidirectional Control
   Zero Offsets No Control vs Reverse Progression plus Unidirectional Control

4.0 RESULTS

4.1 The ETA Results

Graphs 1 to 4 depict the queues (at the end of red) and releases per cycle for the main "controlled" links (8-11), for no control versus MX Bidirectional control throughout the simulation period.(For No control queues and releases are marked by MAXQN and RELN respectively, and for the controlled results by MAXQC and RELC).

For link 11, the critical fixed link, it can be seen that the number of releases per cycle has been maintained whilst the queues have been reduced considerably, thus avoiding blocking back. For the "controlling" links 8,9,10 it is sufficient to note that the number of releases has been maintained with slightly shorter queues.

Graphs 5 to 8 depict the above defined index of efficiency ETA for with and without control for the same links. Note that for the critical fixed link 11, the efficiency remains high (saturated, with variations due to turning movements) during the peak. However, for links 8,9 and 10 the efficiencies rise during the blocking back period. This is due to the "shortening" of their green times, forming a funnel or "flared green" progression; but as shown above the number of releases per cycle is similar. Thus in the main direction, blocking back has been reduced and the green times are used more efficiently.

4.2 Zero Offsets :Bidirectional Control

The simulation was run first with no control then with MX Bidirectional control (i.e giving wasted green to the cross flows and reducing the main and opposing green times). The value used for Xc was 40 and the results were processed using LOTUS. The following table summarises the percentage differences between the two situations, a positive number indicates a saving with control, a negative number is a loss.

Percentage Savings No Control vs Bidirectional Zero Offsets

	Total Travel Time	Total Stops	Total Delay
All Links	-2.63	-7.90	1.04
Links 2-5	-26.32	-30.06	-49.60
Links 8-11	-0.43	-1.41	5.30

Figure 2 gives a plan of the network with the distribution of the percentage savings in delays and total travel times. Note that the cross flows do benefit but the flows are in this case relatively low compared to the main and opposing flows. The opposing flow has been greatly disrupted by reducing the green times and as this flow is approximately half the main flow the benefits to link 11 and the cross flows are out weighed.

4.3 Zero Offsets :Unidirectional Control

Unidirectional control aims to give benefits to both the main and opposing flows. The same MX control is used in the main direction, reducing the green times to avoid blocking back, however no extra green is given to the cross flows and the opposing green time remains constant throughout. This is done by ending the main green early and merely overlapping the opposing green. Both the cross and opposing flows are expected to benefit due to the lack of blocking back. So again for Zero Offsets :-

Percentage Savings No Control vs Unindirectional MX

	Total Travel Time	Total Stops	Total Delay
All Links	-0.24	-3.67	3.18
Links 2-5	0.83	0.69	1.05
Links 8-11	-0.75	-1.65	4.19

Figure 3 gives a more detailed view of the delay and total travel time percentage savings. It can be seen that now the main flow transfers delay and travel time further upstream whilst maintaining the saturated condition of link 11. Also the opposing flow is not disrupted, in fact it benefits slightly due to the lack of blocking back easing turning movements. Here any benefits to the cross flows are due to those movements which join the main flow. The model is still 'Blind' to blocking back for cross traffic. Even if this effect is modelled in the future the example network is not a good one, as the first two points of blocking back have not got any cross traffic. (A grid structure should be tested).

4.4 Offsets Without Control

First of all it is necessary to study the effects only of the offsets. Two cases were considered, forward progession (downstream activated after the upstream to create a green wave), and reverse progression (downstream activated before the upstream to clear queues). The offsets were based on a free speed of 10m/s .

The results are not shown in full detail but are summarised in the following tables (both are compared to the zero offset scenario) :-

Percentage Savings - Forward Progression vs Zero Offsets

	Total Travel Time	Total Stops	Total Delay
All Links	0.95	3.4	0.34
Links 2-5	-29.90	-60.0	-57.85
Links 8-11	6.60	17.9	5.04

Percentage Savings - Reverse Progression vs Zero Offsets

	Total Travel Time	Total Stops	Total Delay
All Links	1.06	2.8	6.69
Links 2-5	7.13	49.0	50.00
Links 8-11	0.70	-2.7	4.00

From these tables it can be seen that forward progression improves the main direction as expected but causes considerable disruption to the opposing flow. However reverse progression has considerably improved the situation for the opposing flow whilst also improving slightly the main direction. The overall performance of the system is better with reverse progression in terms of delay, stops and travel time. This is perhaps because reverse progression is designed for use in congested situations.

In order to prove this GRAPH 9 depicts the performance of the saturated link (link 11) for no control forward progression versus reverse progression. It depicts the average travel times and the number of exits per cycle for both methods over the whole simulation (reverse progression marked r, forward progression marked f).

Firstly the number of exits is virtually identical. However it can be seen that the forward progression functions better than the reverse progression during the build up to oversaturation, with a lower average travel time,but worse during the oversaturated period, with a higher average travel time. It is therefore important that the MX control strategy can improve on the reverse progression scenario, as it was designed to improve congested periods.

4.5 Reverse Progression As Base With Unidirectional Control

Here the No Control situation is with the offsets calculated for a reverse progression. As before, with Unidirectional control the first part of the two simulations will be identical and the control can only improve the congested situation. The results are summarised in the folowing table :-

Percentage Savings - MX versus Reverse Progression

	Total Travel Time	Total Stops	Total Delay
All Links	1.62	-1.4	8.28
Links 2-5	0.19	1.87	1.07
Links 8-11	2.69	-1.98	10.59

The distribution of the benefits can be viewed in more detail in figure 4 and GRAPH 10 which illustrates the saving in average travel time for link 11. In this case the Unidirectional control plus reverse progression gives positive lower bound benefits to nearly all the network, the following table compares the benefits to the original zero offsets and no control :-

Percentage Savings - UNI MX + RP vs Zero Offsets No Control

	Total Travel Time	Total Stops	Total Delay
All Links	2.65	1.36	14.4
Links 2-5	7.32	34.50	50.6
Links 8-11	3.37	-4.95	14.2

These lower bound benefits are considerable in terms of delay and also number of stops, the saving in total travel time is relatively low but an upper bound would be much higher, depending on the amount of blocking back which takes place without control.

What is more important is the distribution of the travel times on the main route, the strategy reduces environmental intrusion in the centre (link 11), by reducing the travel time (8%) and delay (24%). (Also the number of stops has been reduced significantly but has not been recorded for individual links.)

When the control was tested with progressive offsets as a base it actually made the situation slightly worse. When looked at in more detail it was seen that the green times were being reduced from links 7+8 before links 9+10, opposite to the required effect.

4.6 Summary

In terms of the total travel time in the system, over the whole simulation period, the results can be summarised as follows (using No Control and Zero Offsets as a base):-

% Changes in Travel Time from No Control Zero Offsets

+ 2.60	Bidirectional Control Zero Offsets
+ 0.24	Unidirectional Control Zero Offsets
0.00	No Control Zero Offsets (Base)
- 0.95	No Control Forward Progression
- 1.06	No Control Reverse Progression
- 2.70	Reverse Progression + Unidirectional Control

5.0 Modelling Blocking Back In NEMIS

Finally blocking back was modelled in NEMIS, this section describes how blocking back during oversaturated periods was modelled and the results.

Figure 5 is a plan view of a four-armed intersection. The link lengths are defined between the middle of two intersections or nodes, therefore for the four-armed case, the intersection is divided into four regions as shown. The 8 links are labelled as E1-E4 for entry links and Q1-Q4 for exit links.

The four regions can be used to define when a movement is blocked or not. The regions contain the following queues and entrances :-

1 = Q1 or E4
2 = Q2 or E1
3 = Q3 or E2
4 = Q4 or E3

Now it is considered that blocking back depends upon the turning movement or which regions the vehicle must cross. Consider as an example the vehicle entering the junction from E4. There are of course 3 cases, Right, Straight and Left turns.

Right turn	Must cross region 1 only Therefore check Q1 only
Straight ahead	Must cross regions 1 + 2 Therefore check Q1,Q2 + E1 Note that E1 need only be checked if there is a queue blocking from Q3
Left turn	Must cross regions 1,2 + 3 Therefore check Q1,Q2,Q3 + E1,E2 Note that E2 is already dealt with separately as a conflict, and E1 need only be checked if there is a queue blocking from Q3 and if so then it will already have blocked the turn

5.1 Link Level

Again considering a vehicle entering the junction from entrance 4, the first check need only be at the link level. If there is any lane blocking back then the link is considered as blocking back. The figures 6,7+8 for cases 1 to 3 show which turning movements are blocked by each of the blocking links. For example case 1, queue 1 blocks all turning movements, case 2 queue 2 blocks left and straight movements and case 3 queue 3 blocks only left turns.

5.2 Lane Level

In the case where the blocking link is also the vehicle's destination link then a more detailed view of the lanes is required. The three cases are depicted in figures 9,10+11. For right and left turns, only the lanes which the vehicle must cross to reach its destination lane need be checked. For straight ahead only the destination lane is checked. Of course the lane level is not required if another link blocks the movement as defined above for the link level.

5.3 Placement of "Ghost" Vehicles

In order to "stop" a vehicle using the car following model, a dummy or "Ghost" vehicle is placed on the network with zero velocity. Figure 12 shows the placement of the "Ghost" vehicles for each turning movement. For straight and left turns they are placed in the middle of the junction i.e at the end of the present link. For right turns it is placed on the stop line.

5.4 Criteria For Blocking Back

For this case blocking back was defined when a queue in any lane on the link was greater than or equal to the storage length minus five metres.

5.5 Results for the MX Unidirectional Strategy

As explained above the model has been adapted to not only record the blocking back but also to model the effects for all turning movements.

The model was run for the case Reverse Progression with No Control and Reverse Progression with MX Unidirectional Control (Xc=40). First of all the No Control scenario was compared to the same No Control scenario without the effects of blocking back modelled. The general results in terms of travel time are the following :-

Links	%Savings Total Travel Time
All	-1.11
2-5	0.23
8-11	-0.75
13-28	-3.00

As expected in general the total travel time has increased by 1.11%. When viewed in more detail the cross links are seen to be affected, just as expected, note in particular that total travel time for links 21 and 23 increases by 14 and 10 percent respectively. Links 21 and 23 are the first set of "True" cross links (i.e the first four armed intersection upstream), and that the results would be similar for nodes 6 and 7 if there had been "True" cross flows also.

No Control vs MX Unidirectional Control

This time both cases have blocking back modelled and both are based on a Reverse Progression. The general network results are :-

Links	%Savings Travel Time	%Savings Delay
All	1.85	6.25
2-5	2.19	3.59
8-11	2.00	7.78
13-28	1.09	0.30

The strategy has improved the whole system in terms of travel time by 1.85% from the best No Control situation. In more detail (Figure 13) the travel time was reduced on the main critical link 11 by 4.8% and delay by 16.5%, also the travel time was reduced on the cross links 21 and 23 by 5.9 and 3.3 percent respectively.

Possible Blocking Back

In both cases there were only three links which blocked back, namely links 9,10 and 11, the three main links leading to the critical intersection as expected. The number of seconds that each of these links blocked back was recorded as a measure of possible disruption upstream. The results are as follows :-

Blocking Link	Number Of Seconds Blocked No Control	With Control	%Reduction
11	859	417	51
10	686	186	73
9	582	253	57
Total	2127	856	60

In this simulation the blocking back period is from about t=1800 secs to t=3600 secs, therefore link 11 blocks back for almost 50% of the oversaturated period without control.

With blocking back modelled, it is also possible to record the links actually affected and for how many seconds. The results are as follows :-

Affected Links	(Blocked Link)	Number Of Seconds Affected No Control	With Control	%Reduction
8	(9)	549	197	64
9	(10)	671	115	83
10	(11)	844	388	54
17	(11)	53	20	62
19	(10)	91	17	81
21	(9)	360	156	57
23	(9)	438	189	57
Total		3006	1082	64

So not only have the possibilities been reduced by 60% but also the actual number of events has been reduced by a similar amount (according to which link caused the blockage, in brackets).

When viewed in greater detail it can be seen that links 8,21 and 23, are all blocked by link 9. Infact there is some overlapping of the times at which they are blocked, this happens as the lights change, and any vehicles which were beyond the stopline must complete their movement in effectively red time. This is not considered a problem as it often happens in real life situations.

6.0 Conclusions

Taking in to account all the above effects it seems that the following can be concluded :-

i) During the build up to congestion Progressive Offsets should be used (see GRAPH 9).

ii) During oversaturation Reverse Progression plus Unidirectional MX control should be used.

iii) During the decay it should revert to Progressive Offsets.

More research should be done investigating the integration of the control strategy with a strategy to optimise the offsets during congestion as proposed above.

Also the use of "Floating Car" data (from guided vehicles), to improve queue estimates from detector loops will be investigated using this model. This is important as in reality the control would depend on a good queue estimator.

The system should be developed further for Grid systems, perhaps using overlapping greens to control both main and opposing flows in the same manner.

Currently a strategy based on similar principles to the above is being developed and tested using the SPOT - UTOPIA system developed by MIZAR AUTOMAZIONE. Here the strategy will be defined in terms of a cost function within the local controller during oversaturation.

References

TN267 Shepherd S.P (May 1990) Drive V1011 Project A7.2 Advanced Real-Time Control Strategies To Minimise Day To Day Travel Time Variability - Part 2:Initial Results

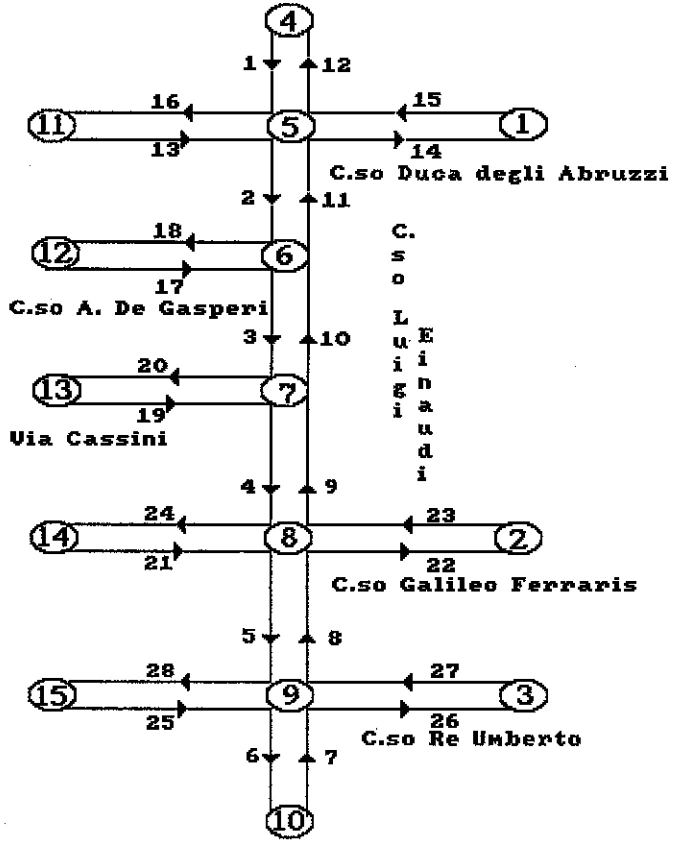


FIGURE 1 A SUBNETWORK OF TURIN

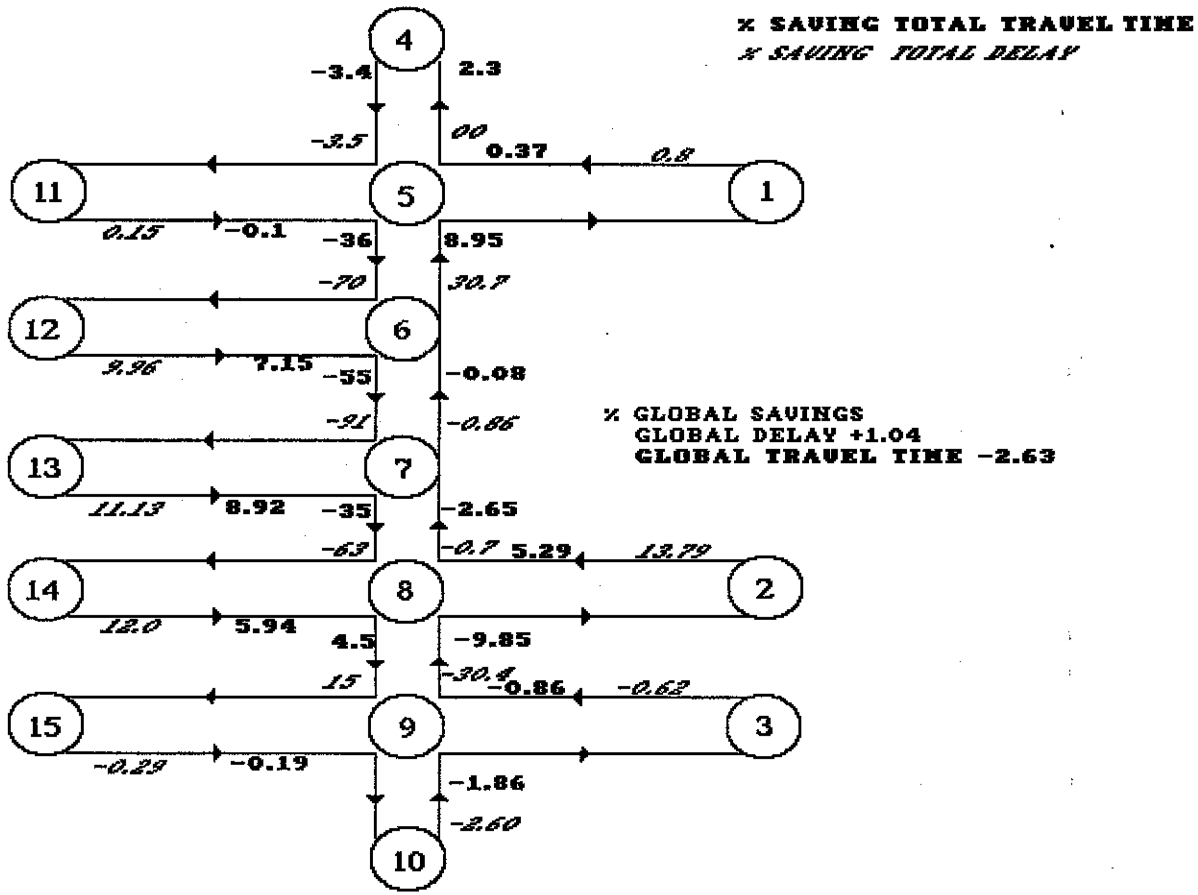


FIG. 2 BIDIRECTIONAL - CONGESTED + RECOVERY - ZERO OFFSETS

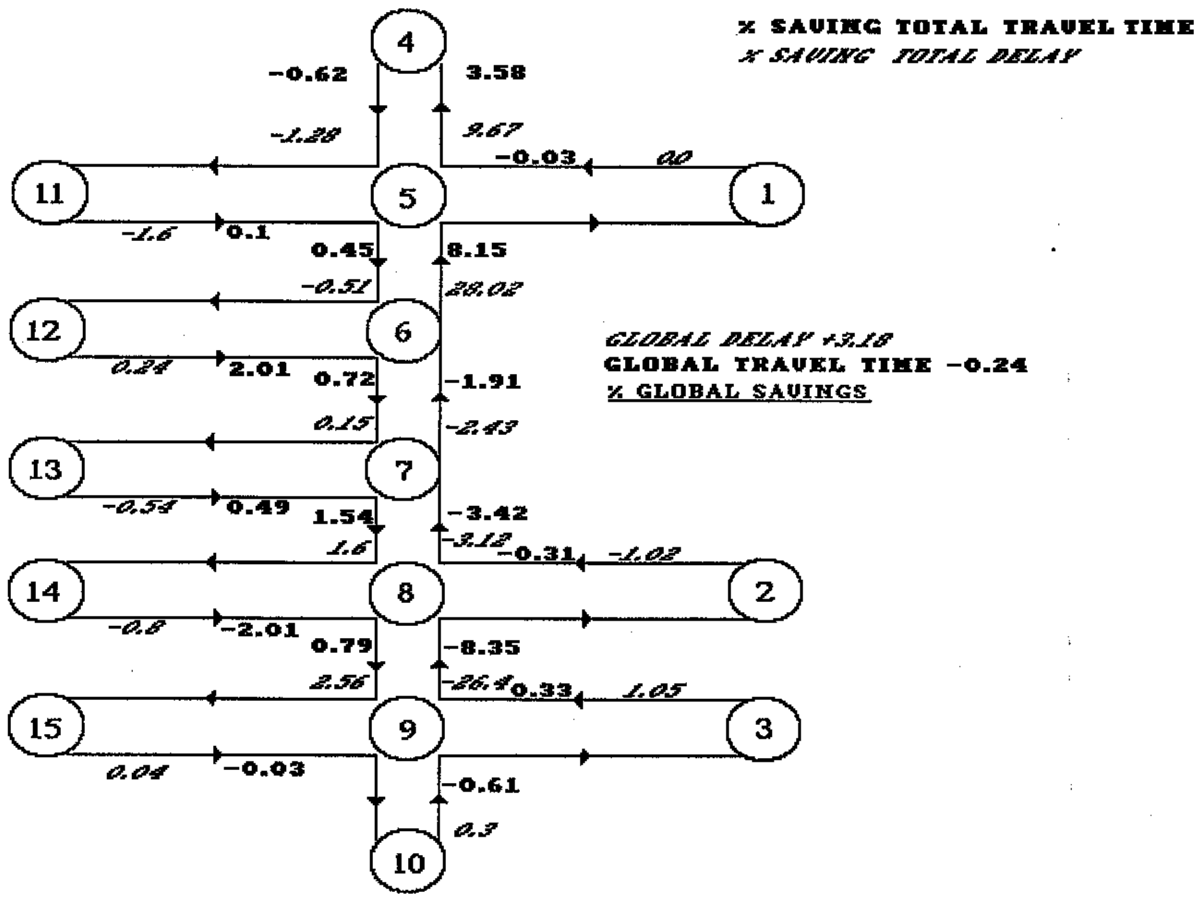


FIG. 3 UNIDIRECTIONAL - CONGESTED + RECOVERY - ZERO OFFSETS

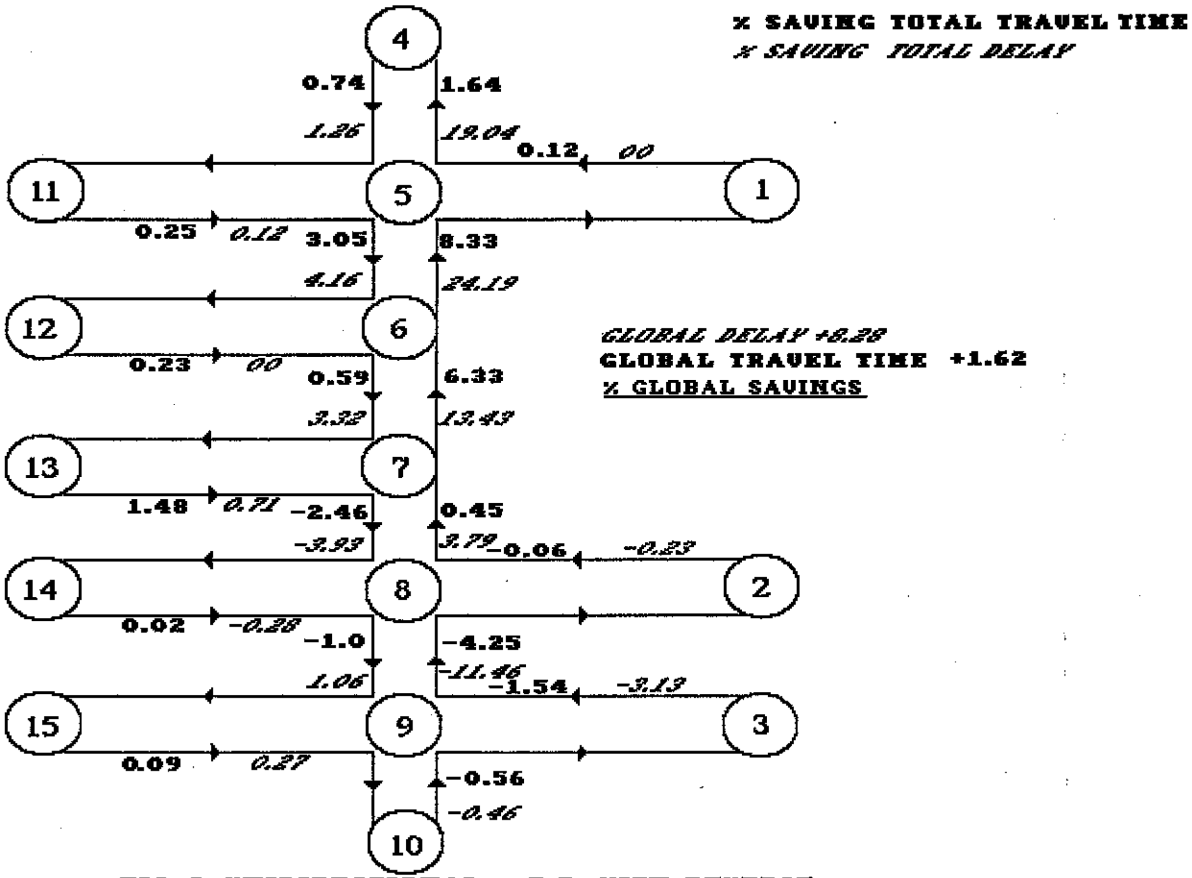


FIG. 4 UNIDIRECTIONAL + R.P. WITH REVERSE PROGRESSION AS THE NO CONTROL SCENARIO

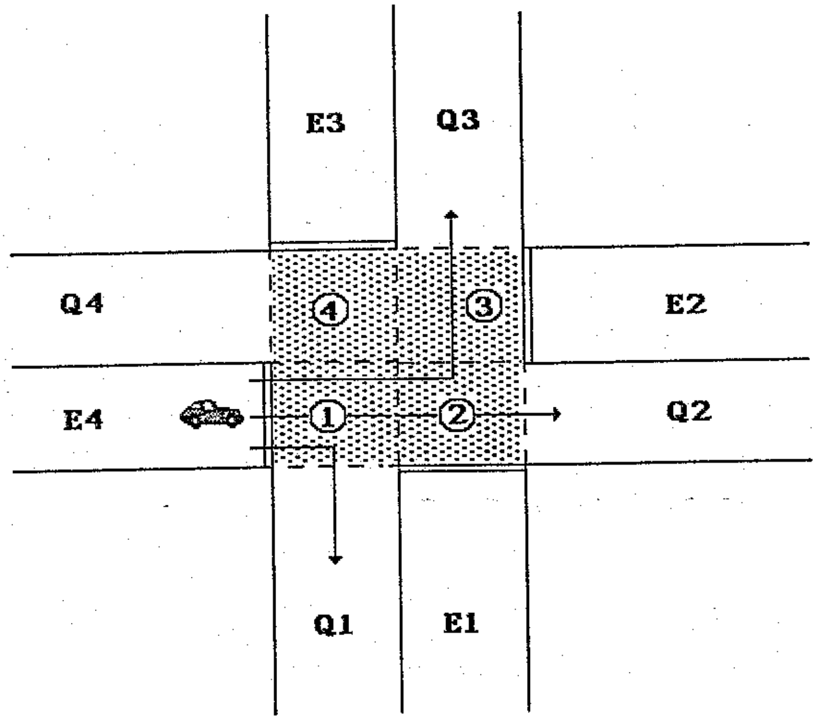


FIG. 5 - A VIEW OF THE INTERSECTION

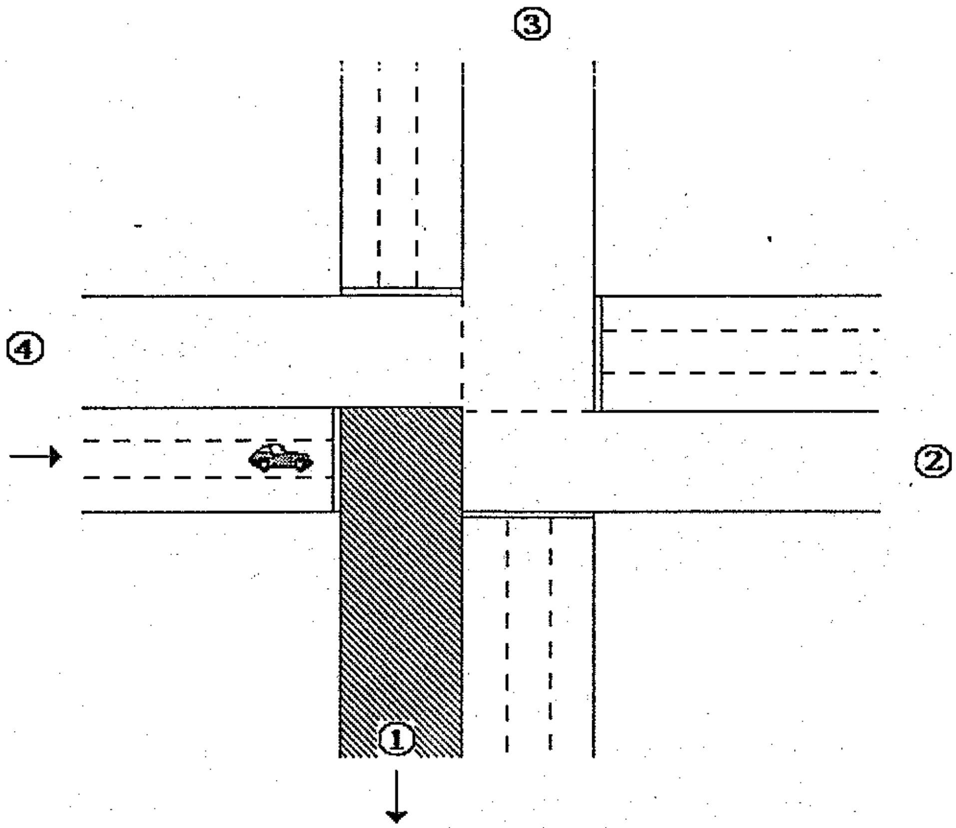


FIG. 6 - Case 1 blocked by exit (1) right, left + straight

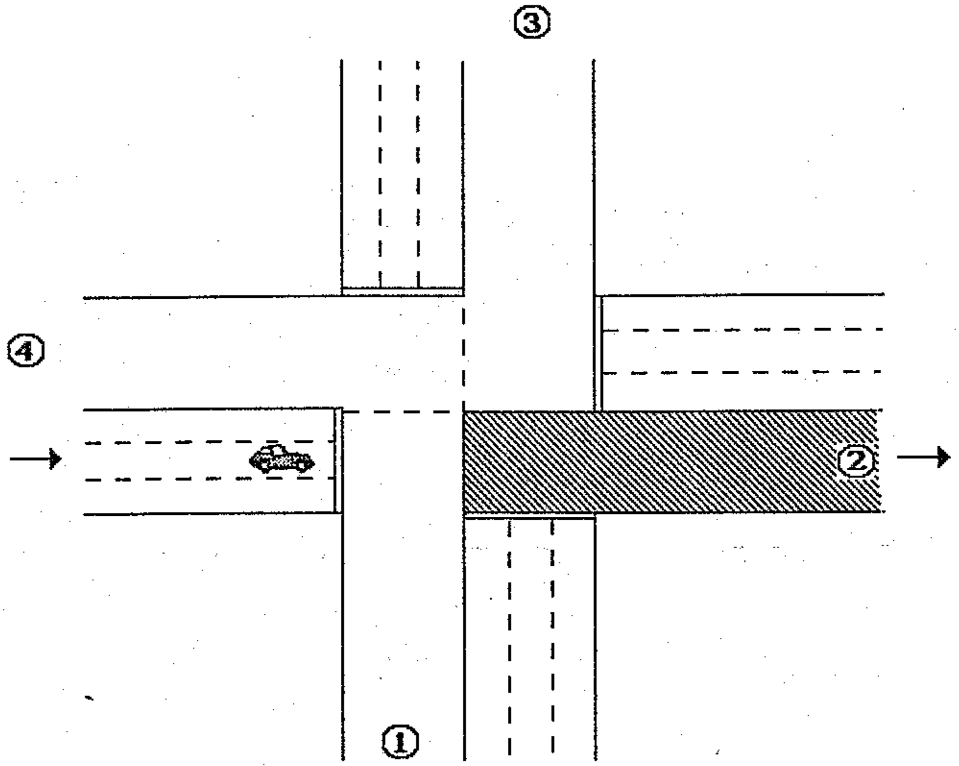


FIG. 7 - Case 2 blocked by exit ② left + straight

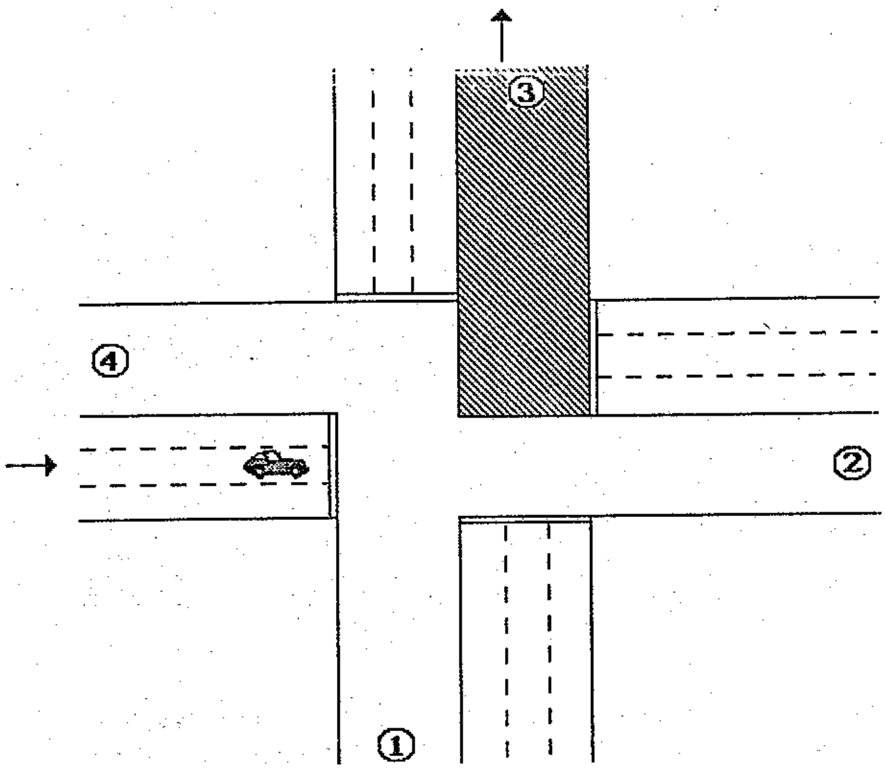


FIG.8 - Case 3 blocked by exit ③ left

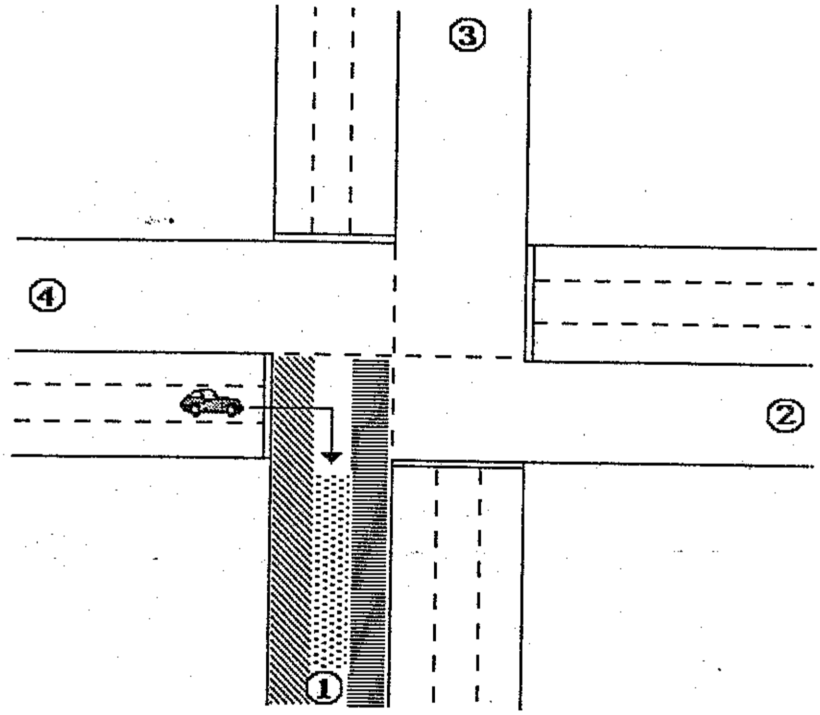


FIG. 9 – Blocking Link = Next link – Right Turn

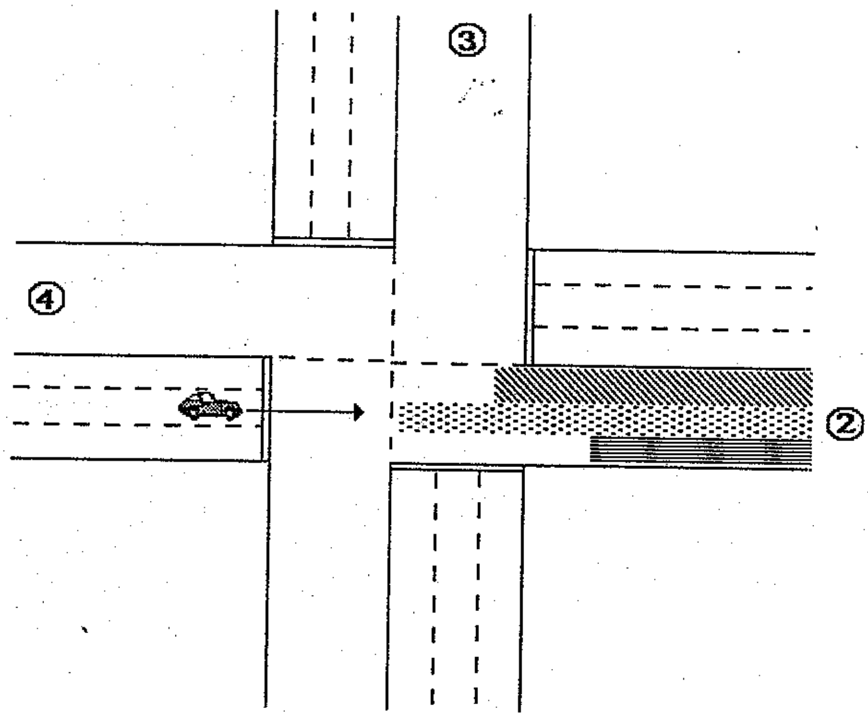


FIG. 10 – Blocking Link = Next link – Straight Ahead

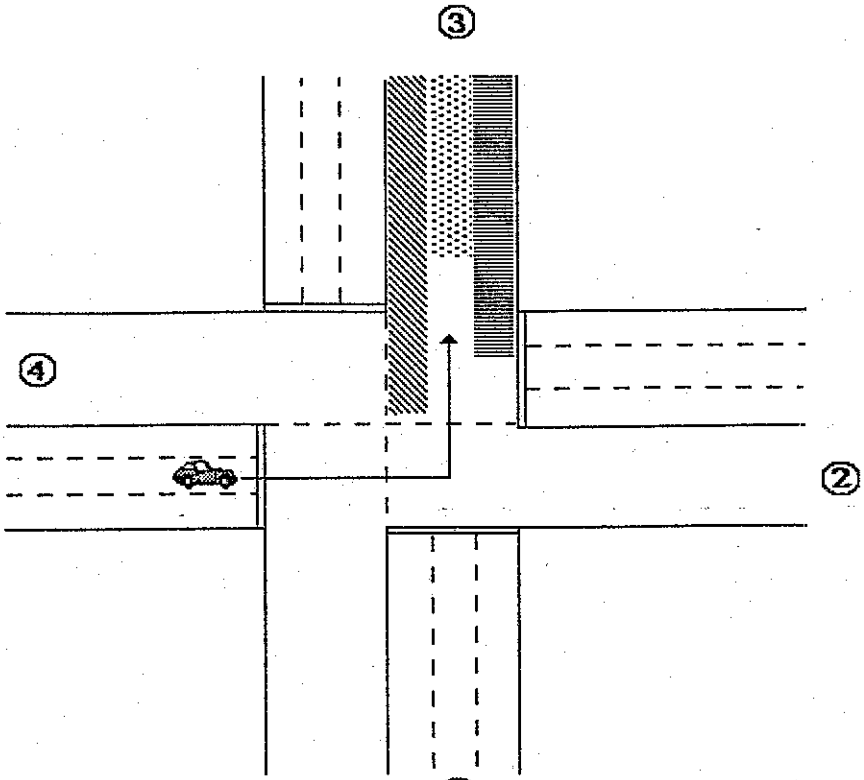


FIG. 11 - Blocking Link = Next link - Left Turn

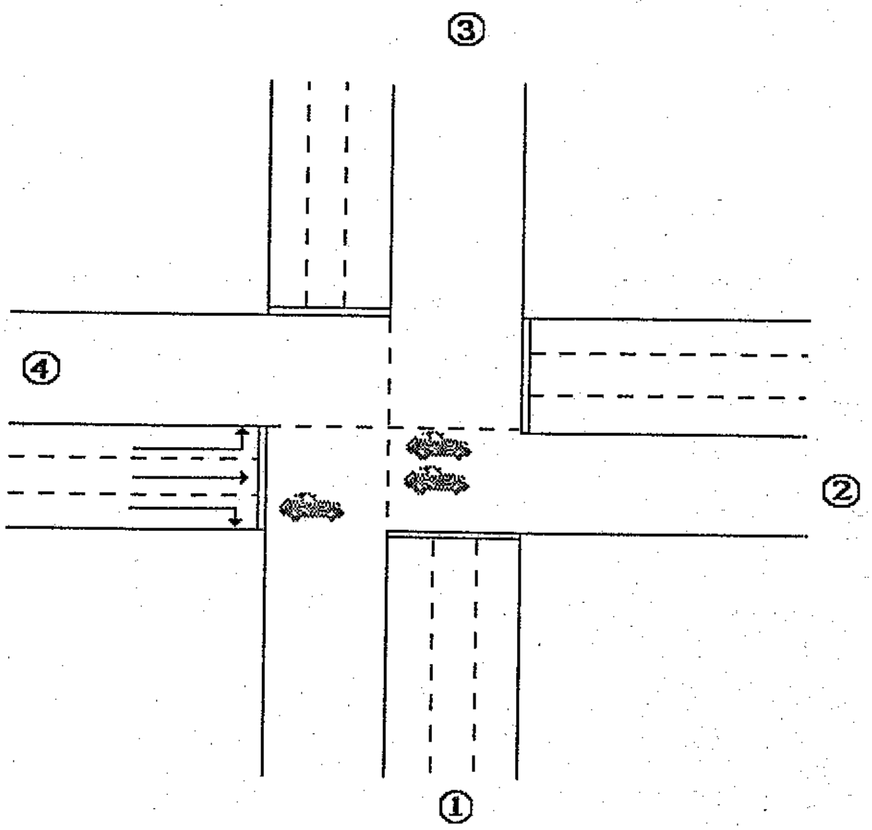


FIG. 12 - Placement of "Ghost" vehicles for different turns

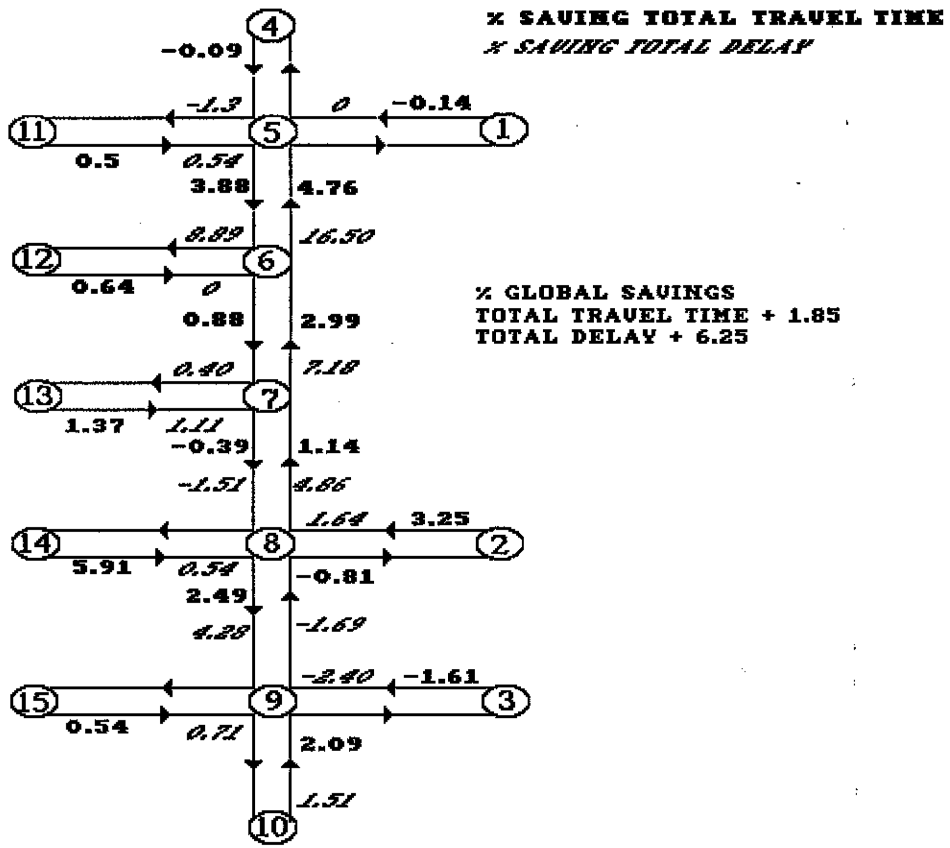
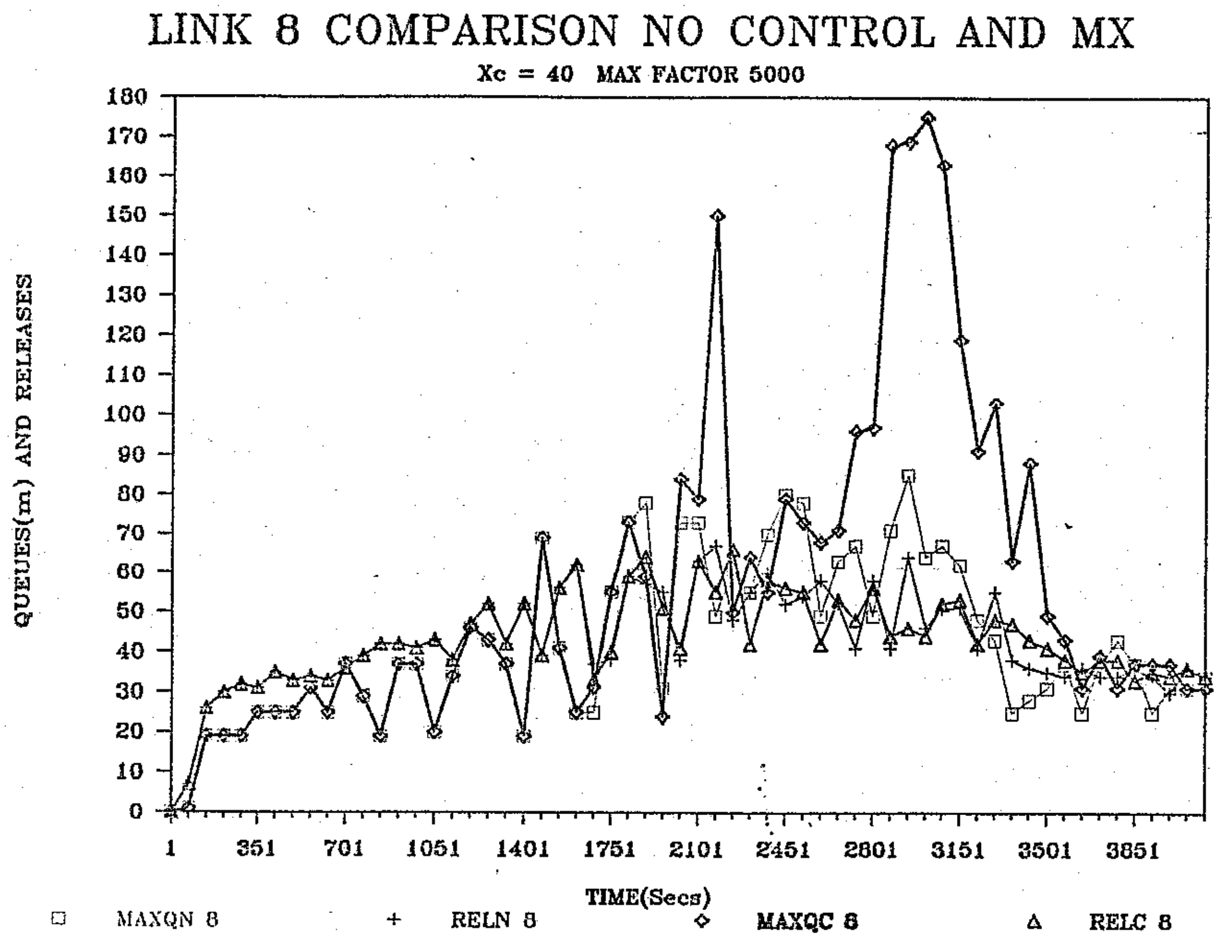
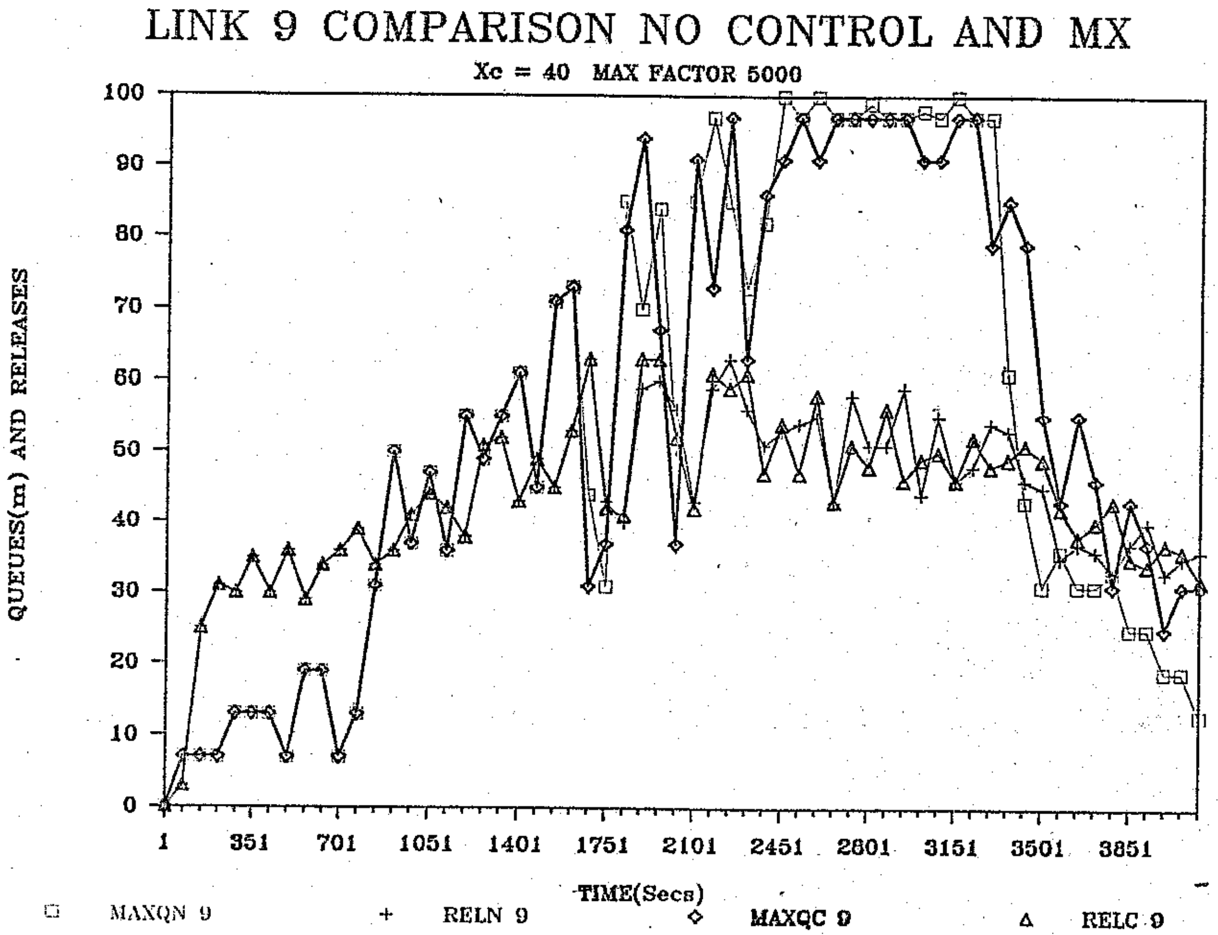


FIG.13 - NO CONTROL REVERSE PROGRESSION VS MX UNIDIRECTIONAL CONTROL WITH REVERSE PROGRESSION (BLOCKING-BACK MODELLED)

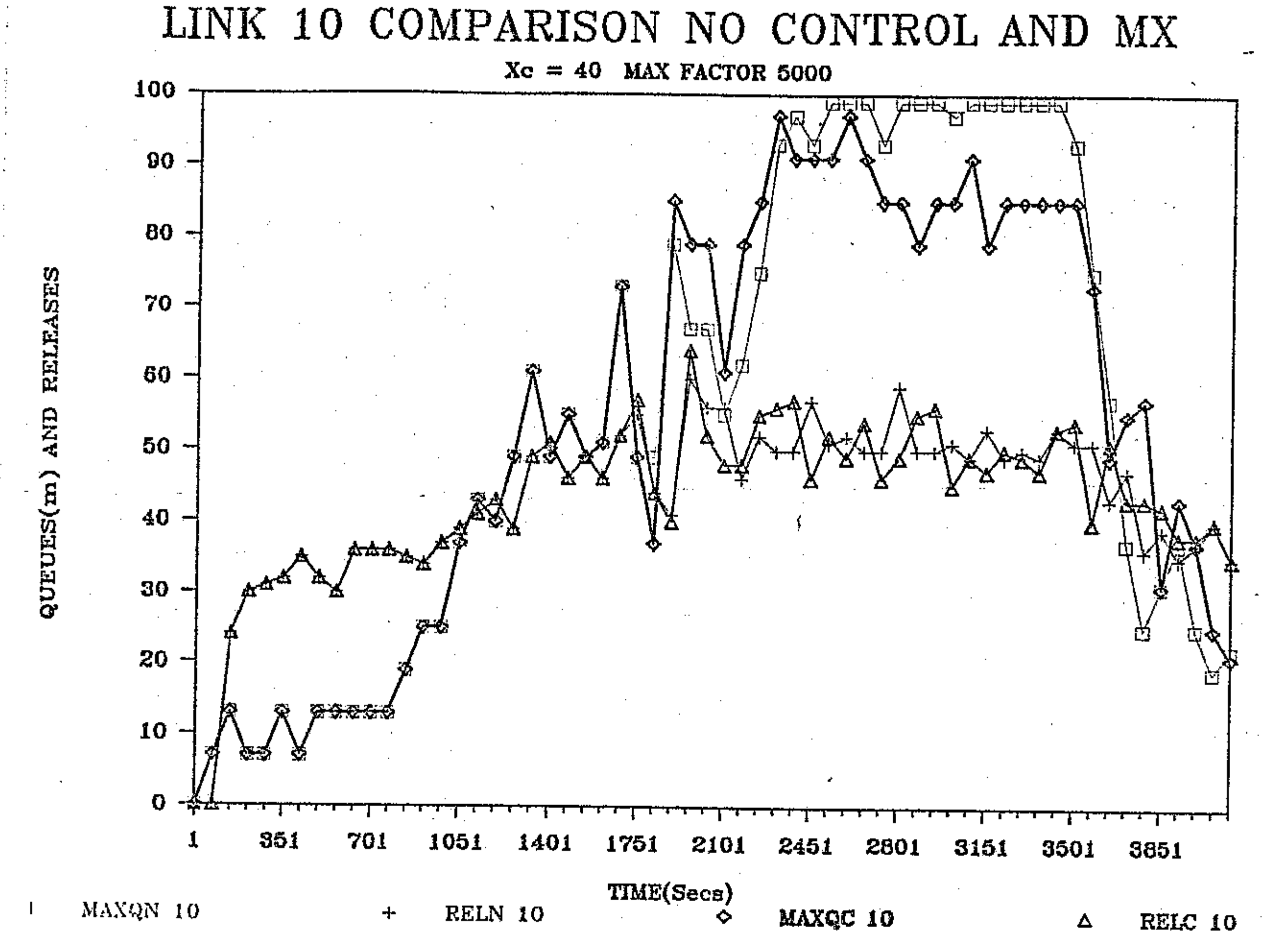
GRAPH 1



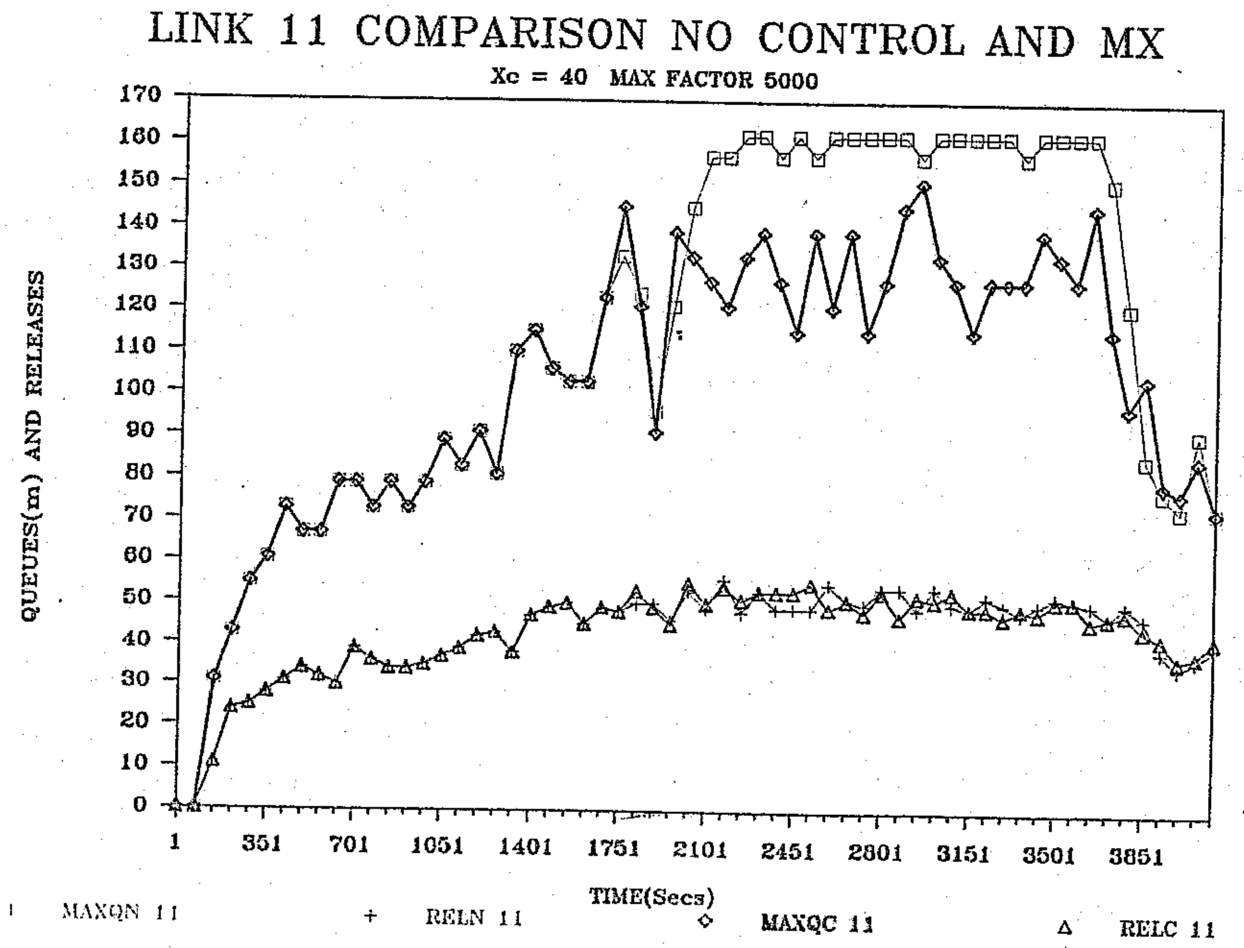
GRAPH 2



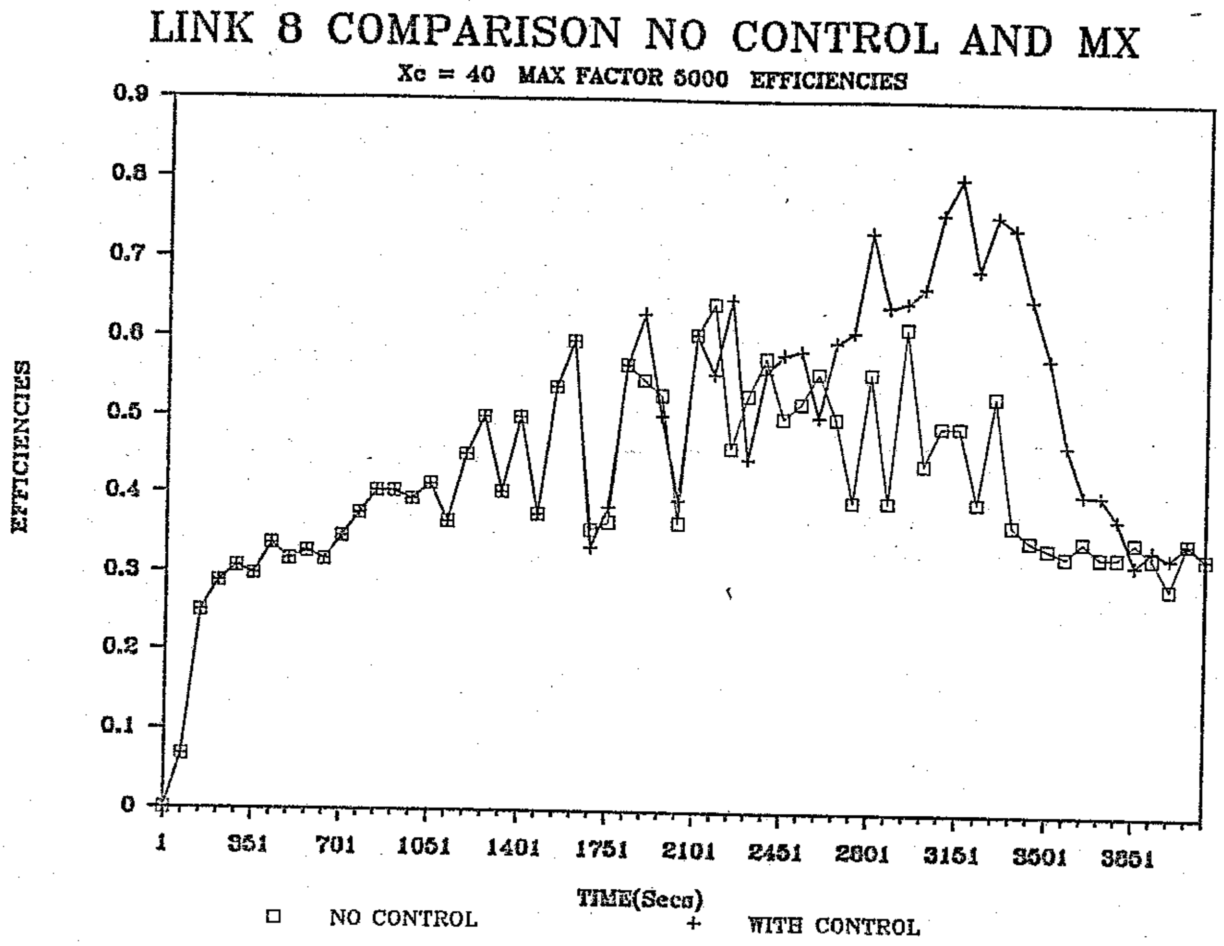
GRAPH 3



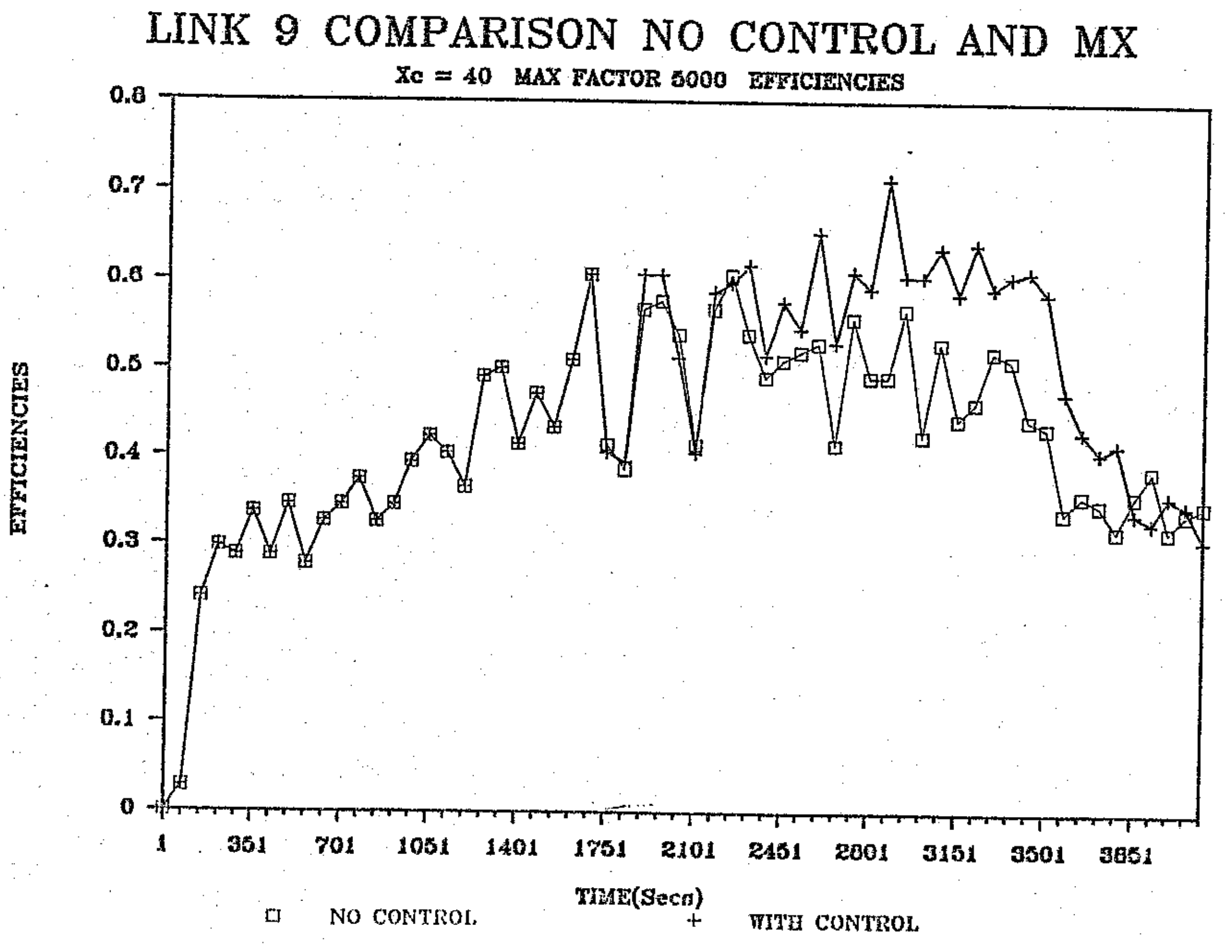
GRAPH 4



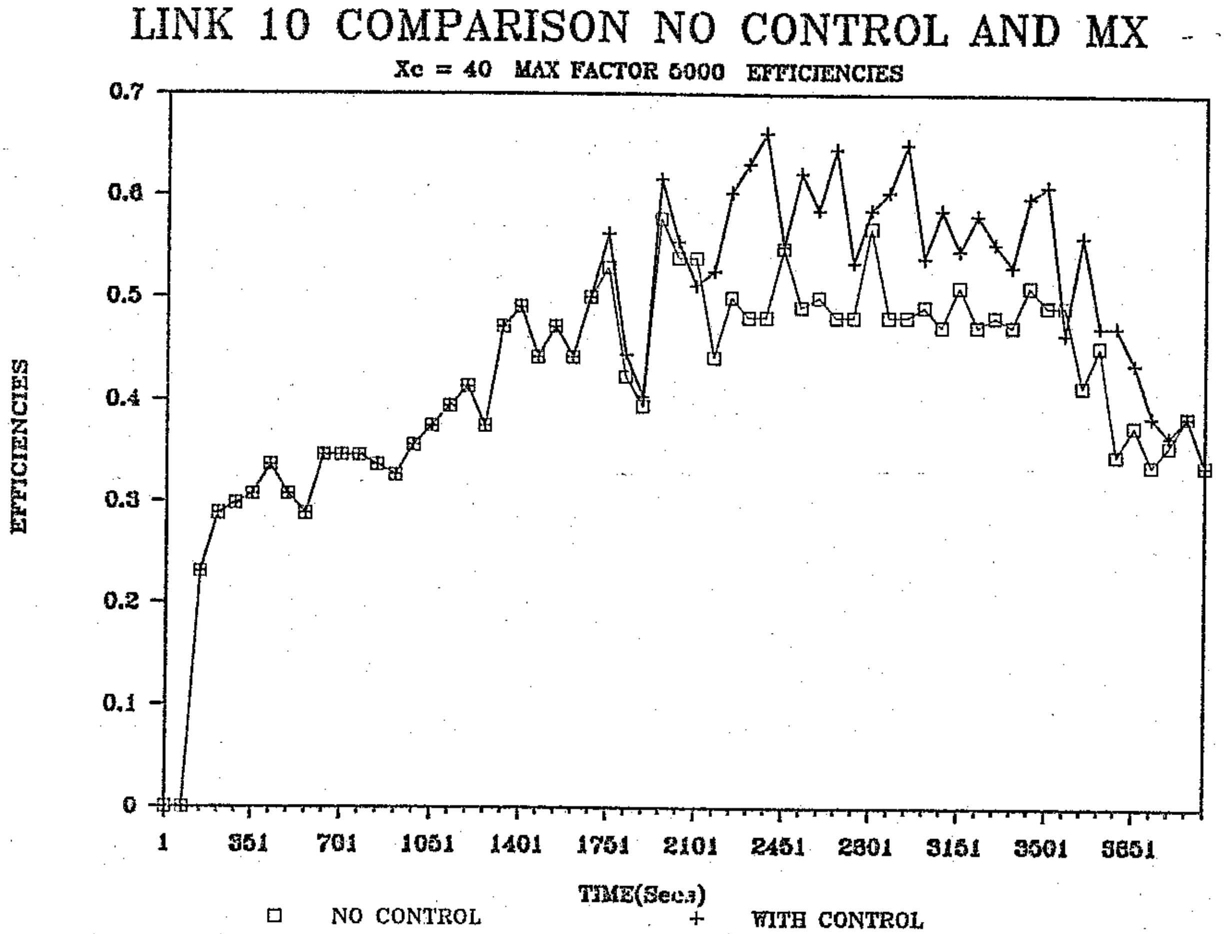
GRAPH 5



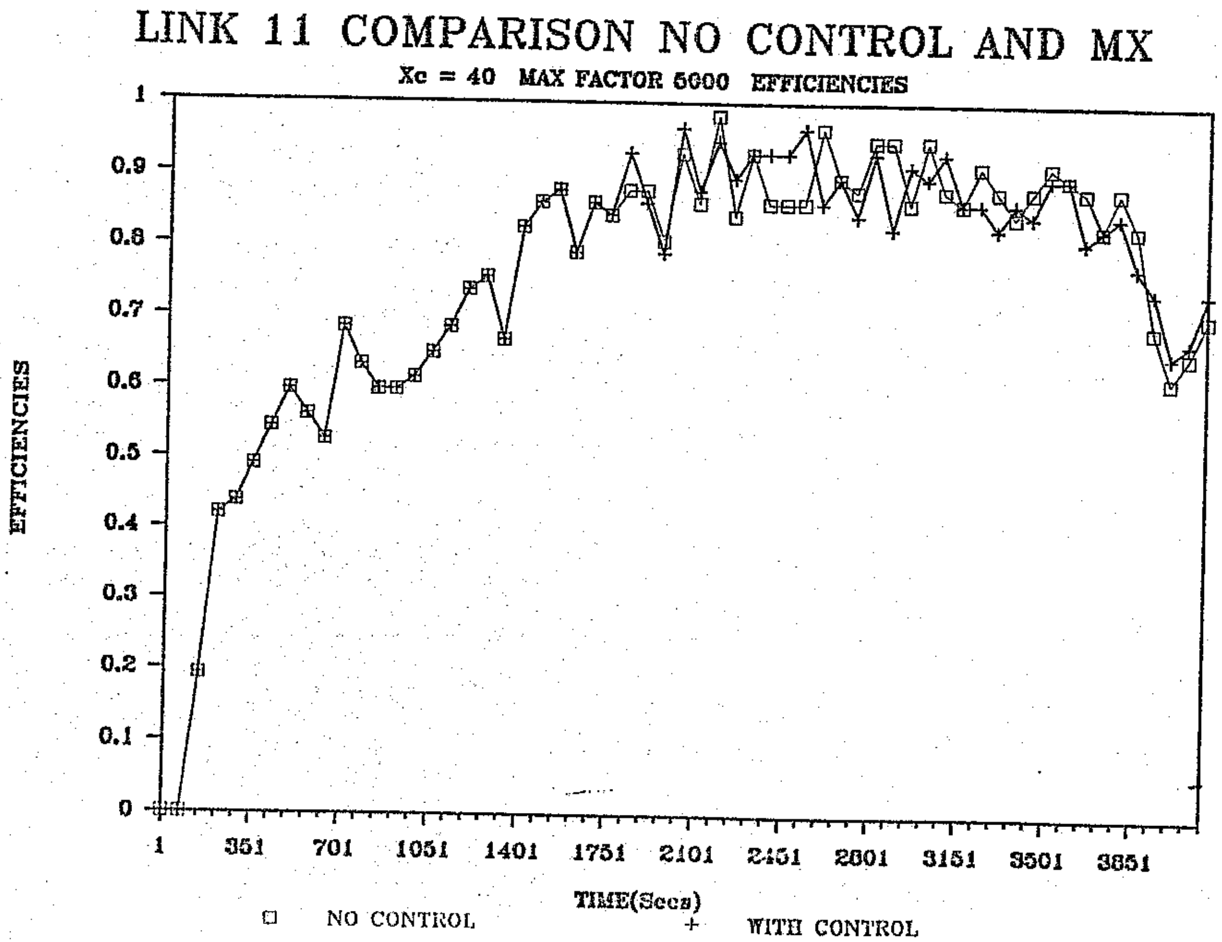
GRAPH 6

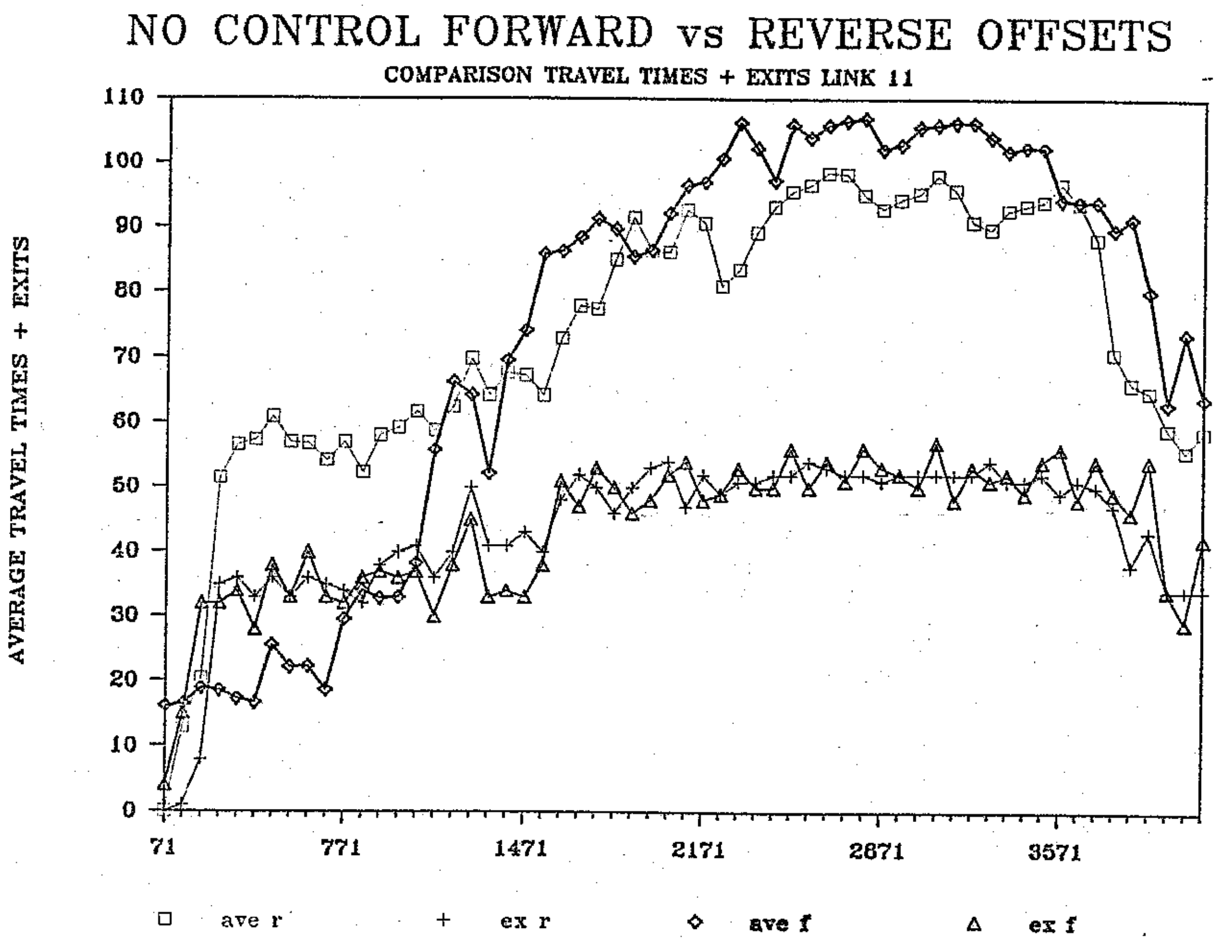


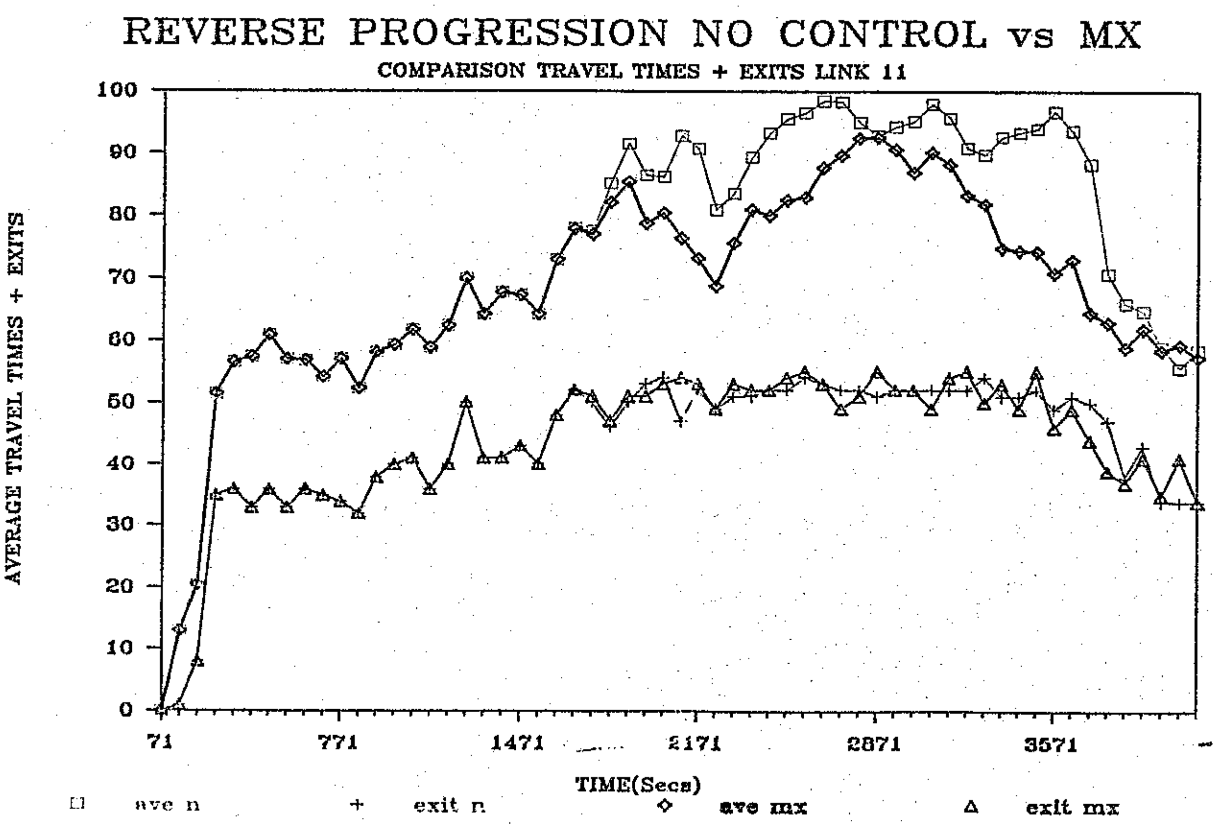
GRAPH 7



GRAPH 8




NO CONTROL FORWARD vs REVERSE OFFSETS
COMPARISON TRAVEL TIMES + EXITS LINK 11
AVERAGE TRAVEL TIMES + EXITS
0
10
20
30
40
50
60
70
80
90
100
110
71
771
1471
2171
2871
3571
ave r
ex r
ave f
ex f


REVERSE PROGRESSION NO CONTROL vs MX
COMPARISON TRAVEL TIMES + EXITS LINK 11
AVERAGE TRAVEL TIMES + EXITS
0
10
20
30
40
50
60
70
80
90
100
71
771
1471
2171
2871
3571
TIME(Secs)
ave n
exit n
ave mx
exit mx