URBAN CONGESTION REDUCTION USING VARIABLE MESSAGE SIGNS

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1. INTRODUCTION

Variable Message Signs (VMS) are becoming increasingly attractive as a means of providing useful traffic information to drivers. When appropriately sited, such signs can affect a large proportion of road users and, particularly in 'incident' conditions, have a potentially substantial effect on traffic distribution within a network. This is recognised in Southampton, for example, where new VMS are being installed at key urban locations as part of the ROMANSE and ENTRANCE projects.

This paper will discuss a number of factors which are likely to influence the effectiveness of VMS; these include the proportion of drivers reacting to the VMS message, timely implementation of the VMS message, the 'normal' level of congestion within the network and whether pre-trip information (via mediums such as the radio or television) is also available.

2. METHOD OF APPROACH

A major aim of the ROMANSE project (Tarrant et al, 1992) has been to improve the detail and timeliness of traffic and travel information in the Southampton area. This information is collected by a comprehensive network monitoring system and disseminated to the travelling public via such methods as the radio, television, teletext, electronic displays at bus stops, TRIPlanner terminals and electronic messages displayed on route guidance VMS. In addition, a parking guidance system exists within Southampton city centre which provides drivers with current parking availability information via a network of VMS.

As part of the ROMANSE project, integrated traffic management strategies have been developed and evaluated off-line. The lack of repetition of incidents means that in order to achieve any understanding of the network implications of potential interventions, the various incident scenarios must first be simulated off-line. A strategy log has also been established at the ROMANSE Office to accommodate the families of scenarios developed for use in response to potential incident scenarios. This includes a series of output files which display the expected traffic conditions under potential incident scenarios, the recommended VMS messages (and portable sign locations) and the UTC adjustments to be undertaken.

However, this paper reports the findings of new research which has aimed to develop a more generic understanding of issues relating to the effectiveness of VMS information. The 'single day' (SD) version of the route guidance model RGCONTRAM (Route Guidance CONTRAM) (Leonard and Taylor, 1989) has been used to undertake the modelling work. RGCONTRAM is based on CONTRAM (CONtinuous TRaffic Assignment Model) (Njoze, 1995) and has been developed at the University of Southampton during the previous six years.

Two CONTRAM networks have been developed and used in this research. This paper reports the results of a small, symmetric, artificial radial 'test' network which was used initially to identify potentially generic issues. A second, more detailed, calibrated network for Southampton was then used to substantiate these findings (Richards et al, 1996).

3. MODEL

CONTRAM is a computer based traffic assignment model for use in the design of traffic management schemes. The assignment process uses "packets" of vehicles and their progress through the network can be monitored and evaluated. A key feature of CONTRAM is that traffic conditions can be varied with time; other advantages of the model are the modelling of all junction types, the modelling of bus services by assigning selected classified O-D movements to prescribed fixed routes and the detailed simulation of traffic signals. A vast number of statistics are output, including traffic flows, delays, queues, journey time and average speeds for each link in the network.

In order to run the CONTRAM model, three input files are required:

- a network file which describes the link-based topology, junctions, signals and link capacities of the road network being modelled.
- an Origin-Destination (O-D) matrix which provides the time-varying traffic demands.
- a control file for running the program.

The CONTRAM model is run using the 'normal' (i.e. non-incident) network in order to generate the normal base routes of all the packets (5 iterations were used in the study described in this paper). These routes are then used as a basis for subsequent RGCONTRAM runs which specifically model route guidance operations. The emphasis in RGCONTRAM is on 'single-day' modelling with enhanced traffic incident and driver behaviour sub-models. Inter-relationships between system operation, network performance and driver response can be explored in a way which is not possible with a traditional equilibrium model.

Within RGCONTRAM, there are a number of user-specified driver behaviour functions. These are being updated as more findings from parallel research into driver behaviour become available For the modelling work described in this paper, the following assumptions were used:

- In the base incident scenario (i.e. no VMS in operation), there are no diversions; all drivers use their normal route.
- In the VMS scenarios, the drivers which are diverted are randomly selected from those familiar drivers passing a VMS sign and whose original route would have passed through the site of the incident.
- The drivers who pass the VMS and do not divert remain on their normal routing as in the base incident scenario.
- The proportion of drivers which divert at the VMS is user-defined.
- Drivers divert via user-defined diversionary routes. The actual route chosen depends upon the destination of the diverted driver.
- Once the diverted drivers have reached the end of their user-specified route, they reassign to their destinations using an imperfect knowledge of the current network conditions.
- When more than one VMS is used, the same proportion of drivers divert at each sign.

Previous modelling research within the ROMANSE project measured the success of the VMS strategy in terms of journey time savings. The benefits of a strategy relate to a number of contributory factors such as the severity, duration and location of an incident, the VMS location(s), the suitability of diversionary routes and the proportion of drivers which divert at these routes.

The research described in this paper aimed to build upon this understanding. The factors investigated within this research include:

- incident location
- incident severity
- the number of VMS used
- the level of normal congestion within the network (by factorising the O-D matrix to vary the base demand)
- varying the duration of the VMS flag (to simulate the effects of delaying the implementation / cancellation of the VMS message
- the effects of pre-trip information

4. NETWORK

4.1 Description of Test Network

A radial 'test' network was developed which was symmetrically divided into six segments (see Figure 1). The outer cordon represents an orbital motorway split into six junctions (labelled 1-6) an equal distance (6 km) apart. From each junction, a two lane dual carriageway (of length 3 km) leads to a signalised junction. The six signalised junctions (labelled 7-12) are 3 km apart and are located on an inner ring road (which has 1 lane in each direction). These junctions form the main bottleneck in 'normal' conditions (the signal plans used have a cycle time of 100 secs with a green split of 60 sec for the arterial route and 30 sec for the ring road). The dual carriageway (length 2.8 km) then continues from the signalised junction to a central roundabout (consisting of the six junctions labelled 13-18). Symmetry enables the entire network to be assessed by only considering potential incident locations (and corresponding strategies) occurring within one segment.

4.2 Description of O-D matrix

An artificial O-D matrix was also created. This was also symmetrical, and was divided into 1 x 30 min time slice from 07:00-07:30, 8x 15 min time slices from 07:30-09:30, and 1 x 60 min time slice from 09:30-10:30. Since this O-D matrix represents the a.m. peak period, the majority of the trips are inbound towards the city centre.

4.3 Assumptions

For all modelling runs using this test network, the following assumptions were used:

- In order to simplify the results, all vehicles were assumed to have 'perfect' knowledge of current traffic conditions within the network; no distortion was used.
- No adjustments of the signal plans were made.
- VMS were allowed to be located on the outer zone connectors.
- The incident duration was 0800-0900.

There are 54 links (and therefore 54 potential incident locations) within the test network. However, since the network is symmetric, it is only necessary to consider the 9 different incident locations within one of the triangular segments. For each incident location, strategies were developed (which identified where to locate the VMS and which diversionary route to use). A number of physically possible diversionary routes exist. However, the nature of the network was such that a subset of realistic diversionary routes was easily identified and modelled. The small number of zones meant that the diverted packets could be accurately assigned to their destinations via the 'obvious' diversionary routes.

These strategies were run for one segment of the network and considered the 9 possible incident locations at links 61, 52, 63, 124, 122, 182, 181, 121 and 113 (see Figure 1). Results from the corresponding modelling runs were then used to produce collective sets of results for the whole network. The results are arranged in order to convey the relative benefits generated by the use of different sets of VMS (a set consists of the equivalent locations in all six segments of the network). It is assumed that an incident is equally likely to occur on any link in the network and hence the tables below show the aggregate network benefits if an incident occurs successively at all incident locations. The results are for 'current' demand levels (i.e. 100% demand). Table 1 presents the total network benefits while Table 2 shows the corresponding results for incident drivers only.

For this network and O-D matrix, the major benefits of VMS occur when they are sited to provide information to drivers as early as possible i.e. when the VMS are located on the outer edges of the network. This is intuitively sensible since early warning allows drivers a greater (and potentially more effective) choice of diversionary routes.

For some scenarios, the benefits to the incident drivers are substantially greater than the benefits to the network as a whole. As a consequence, non-incident drivers must be collectively incurring substantial disbenefits. This raises the issue of whether total network benefits or incident driver benefits is a better measure of effectiveness of a VMS strategy. The former must clearly be the underlying objective of traffic management; however, 'perceived' effectiveness of VMS and future driver behaviour is likely to be governed by the latter.

It should be noted that although the test network retains the spatial magnitude of a real network, the density of links is deliberately reduced. Consequently, a problem of using this network is that the length of the diversionary route can sometimes be much greater than the normal route of the driver. This means that an incident (of one hour's duration) usually has to be very severe before diversions provide any significant benefits.

5. FACTORS INFLUENCING VMS BENEFITS

5.1 Incident Location with varying base demand

The O-D matrix for the preceding runs was assumed to represent the base year (i.e. 100% base traffic demand in the network). All strategies were rerun, for base demands of 60%, 110%, 120% and 140%. The network remained unchanged, although a uniform increase in demand to the O-D matrix does not mean that the new assignment (and hence the base routes) will increase uniformly.

From plots of total network and incident drivers benefits for varying base demand levels, for each incident location, the following comments can be made:

For this network and O-D matrix, increasing the base demand does not lead to comparable increases in the network benefits of VMS. Above a certain level of demand, the congestion on the diversionary routes outweighs the benefits to the incident route (partly due to the lack of 'attractive' diversionary routes). Figure 2 illustrates this point using the results for an incident located at link 113; the network benefits decrease once the base demand reaches about 110%.

The benefits of VMS depend on the incident location. For instance, in contrast to an incident on link 113, an incident on the motorway (link 52) does not provide any network benefits at all above about 120% demand. This implies that it is better to store vehicles on the motorway rather than divert them through an already congested urban network (see Figure 3).

When the incident is less severe, optimal benefits are attained at lower proportions of diversion (see Figure 4). This is because a lower incident severity results in more capacity being available on the incident link which means that less vehicles need to be diverted in order to achieve optimal benefits. This illustrates the point that it is important to identify the severity of the incident being monitored before the strategy is implemented.

When the subset of incident drivers only is considered, the graphs show that the subset of incident drivers always benefit from the strategies (although other drivers in the network could be delayed as a result). This is because a diverted incident driver benefits by diverting (rather than remaining on the incident route for up to 1 hour), and an undiverted driver benefits because the congestion on the incident route is eased by diverting the other drivers. This can be observed from Figures 5, 6 and 7 which illustrate the incident driver benefits for incident locations 113, 52 and 182 respectively.

5.2 Varying the duration of the VMS Flag

The preceding runs assumed the VMS to be activated from 0800-0900 (exactly matching the incident duration). However, in practice, there will be a delay in activating the VMS if the incident is unforeseen. There may be extra benefits to be attained by extending the duration of the VMS message, and continuing to divert drivers after the incident has ended (because network recovery from a congested state after an incident has 'ended' is not instantaneous).

Therefore, four sets of runs were repeated, but assuming durations of the VMS flag of 0815-0900, 0830-0900, 0800-0915 and 0800-0930. (The demand level assumed was 100%, and the incident remained from 0800-0900).

Figures 8 to 10 present the results in terms of network benefits for incident locations 113, 52 and 182 respectively, while Figures 11 to 13 illustrate the incident driver benefits.

It appears that extending the duration of the flag does not increase the benefits (even when just the subset of incident drivers is considered), and delaying the activation of the VMS reduces the benefits approximately linearly. For instance, if the flag is set from 0815-0900, then (compared to the 0800-0900 case) the benefits are reduced by about 25%. This illustrates the importance of timely incident detection.

5.3 Pre-trip Information

The use of VMS (which provide driver information en route) combined with pre-trip information (which could be broadcast to the driver via a variety of mediums such as radio, television or the internet before the start of the journey) was next considered. If drivers were notified about an incident before they set off, it is possible that those whom would be affected by the incident would delay or even cancel their trip. The demand level assumed was 100% and four scenarios were tested:

i) Assume 20% of relevant drivers cancel their trip:

For each incident location, this involved determining the O-D's of the vehicles normally using the incident link between 0800 and 0900. For a specific O-D, if 50% or more vehicles normally used the incident link, then the O-D was deemed to be 'affected' by the incident and would be decreased by 20% between 0800 and 0900. The O-D's between 0900 and 0930 remain unchanged. This process meant that a new demand matrix (and hence a new routes file and assignment) must be generated for each incident location.

ii) Assume 20% of drivers delay their trip

Instead of cancelling their trip, this scenario now assumes that 20% of all drivers affected by the incident would choose to delay their trip. Again, this involves generating a new demand matrix for each incident location. For each O-D 'affected' by the incident, 20% of the demand between 0800 - 0900 is now delayed until the time slices 0900 - 0930. In effect, this means decreasing the demand for each time slice between 0800 - 0900 by 20% and increasing the demand for each time slice between 0900-0930 by 40%. Again, this means that a different base routes file is needed for each incident location.

iii) Assume 10% of drivers delay their trip

iv) Assume 5% of drivers delay their trip

Figures 14 to 16 illustrate the network benefits for incident locations 113, 52 and 182 respectively. Generally, it can be observed that the benefits due to pre-trip information are linear in proportion to the percentage of driver delaying their trip For instance, if 10% of drivers delay their trip then the corresponding benefits are approximately half those attained when 20% of drivers delay their trip. It can also be seen that the extra benefits attained when drivers cancel their trip (as opposed to merely delaying their trip) are not particularly substantial.

5.4 Vary Pre-trip Information and VMS flags

The pre-trip information scenarios investigated in Section 5.3 assumed that the pre-trip information was received immediately the incident occurred. However, in reality, there would be a delay in receiving and transmitting this information. So the '20% delay trip' cases were rerun; this time assuming that there would be an offset in the provision of the information. Two cases were considered.

i) Delay of 15 minutes: These runs assumed that 20% of the demand from time slices 0815-0900 was transferred to time slices 0900-0930. For consistency, these runs also assumed that the duration of the VMS flag was from 0815-0900.

ii) Delay of 30 minutes: These runs assumed that 20% of the demand from time slices 0830-0900 was delayed until time slices 0900-0930. Again, the VMS flag was also set to 0830-0900.

Figures 17 to 19 illustrate the network benefits for incident locations 113, 52 and 182 respectively. It can be seen that the benefits of the pre-trip information reduce approximately linearly as the delay in implementing the pre-trip information increases: e.g. consider the results in Figure 19. When the flag for the pre-trip information exactly coincides with the incident duration (0800-0900), savings of about 700 vehicle hours can be achieved from pre-trip information alone (i.e. with no additional vehicles diverting at the VMS). These benefits reduce to about 450 vehicle hours when the pre-trip information flag is delayed by 15 minutes. A further delay of 15 minutes reduces the benefits still further, to about 230 vehicle hours.

6. CONCLUSIONS

The findings from the modelling activity can be summarised as follows:

- As the base demand increases, then the VMS benefits are maximised at about 110% to 120% demand. When demand is greater than this level, the benefits reduce since congestion on diversionary routes outweigh the reduced congestion on the incident route.
- It is crucial to specify which subset of drivers are being investigated, since the 'optimal' proportion of drivers to divert varies according to whether it is the total network or just the incident drivers being considered.
- Timely incident detection is very important since the VMS benefits reduce approximately linearly in proportion to the delay in detecting the incident.
- Even with a relatively small proportion (10-20%) of drivers acting on pre-trip information, the benefits of pre-trip information (with 0% diversion at the VMS) can outweigh the VMS benefits attained for large proportions of diversion. As base demand increases, pre-trip information becomes increasingly important and can extend the 'shelf life' of VMS.

Although the results presented in this paper have been obtained from a somewhat artificial CONTRAM network, they have been verified using a much larger, and realistic, Southampton CONTRAM network.

7. REFERENCES

Leonard, D.R. and Taylor, N.B., (1989). CONTRAM - Structure of the model, TRL report RR178.

Njoze, S.R. (1995). The development and application of an assignment model for dynamic route guidance, PhD thesis, TRG, University of Southampton.

Richards, A., Lyons, G. and McDonald, M, (1996). Network Routing Effects of Variable Message Signs, to be presented at 3rd Annual World Congress on Intelligent Transport Systems, Orlando, USA.

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Table 1: Benefits (veh-hrs) for total network: demand = 100%

VMS Set	Incident Link	Percentage of drivers diverted						
		5%	10%	20%	40%	60%	80%	100%
19, 29, 39, 49, 59, 69	113	18	23	50	85	139	175	204
	121	16	26	55	93	145	180	211
	122	24	28	45	378	490	362	66
	124	13	19	39	59	100	126	148
	181	-144	229	-101	515	576	339	716
	182	81	167	329	792	824	870	787
	52	23	36	62	100	42	9	-56
	61	22	37	60	98	124	84	35
	ALL	**318**	**3390**	**3234**	**12720**	**14640**	**12870**	**12666**
124, 114, 104, 94, 84, 73	63	28	58	72	127	184	214	235
	ALL	**168**	**348**	**432**	**762**	**1104**	**1284**	**1410**
182, 172, 162, 152, 142, 131	124	8	13	22	46	64	64	63
	ALL	**48**	**78**	**132**	**276**	**384**	**384**	**378**
123, 74, 113, 121, 103, 111, 93, 101, 83, 91, 72, 81	113	4	11	10	17	23	22	27
	121	7	6	10	17	25	29	27
	ALL	**66**	**102**	**120**	**204**	**288**	**306**	**324**

Table 2: Benefits (veh-hrs) for incident drivers: demand = 100%

VMS Set	Inc. Link	Percentage of drivers diverted						
		5%	10%	20%	40%	60%	80%	100%
19, 29, 39, 49, 59, 69	113	17	26	50	85	135	169	197
	121	17	26	52	87	141	176	204
	122	95	177	355	1007	1570	2146	2361
	124	13	20	38	61	104	135	164
	181	12	44	49	130	186	212	267
	182	116	231	458	957	1247	1538	1788
	52	52	102	200	369	465	572	657
	61	54	101	197	364	526	644	745
	ALL	**2256**	**4362**	**8394**	**18360**	**26244**	**33552**	**38298**
124, 114, 104, 94, 84, 73	63	18	29	72	101	162	206	247
	ALL	**108**	**174**	**336**	**606**	**972**	**1236**	**1482**
182, 172, 162, 152, 142, 131	124	8	12	25	48	77	91	108
	ALL	**48**	**72**	**150**	**288**	**462**	**546**	**648**
123, 74, 113, 121, 103, 111, 93, 101, 83, 91, 72, 81	113	6	8	14	23	36	42	46
	121	7	8	13	23	35	40	48
	ALL	**78**	**96**	**162**	**276**	**426**	**492**	**564**

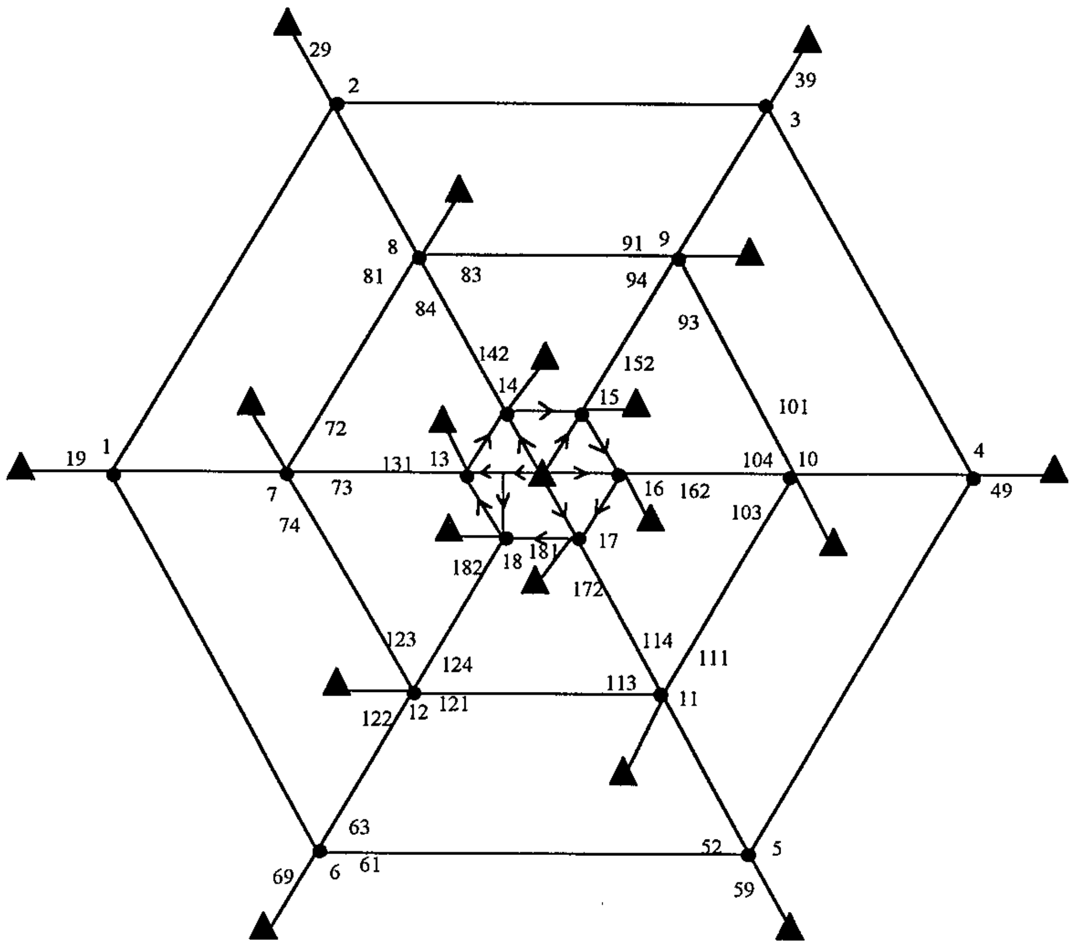

Figure 1: Description of the CONTRAM network used.

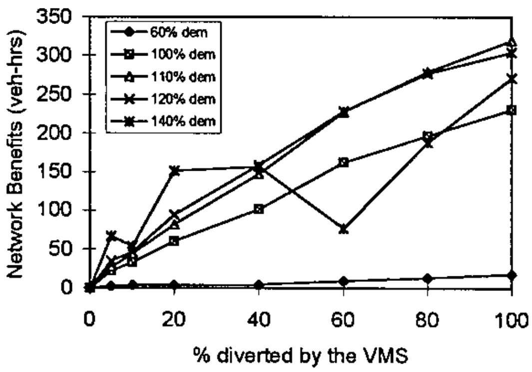

Figure 2: Network benefits for an incident (total closure) at link 113, with varying base demand.

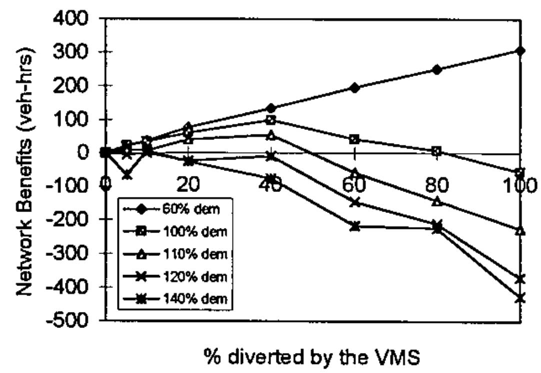

Figure 3: Network benefits for an incident (total closure) at link 52, with varying base demand.

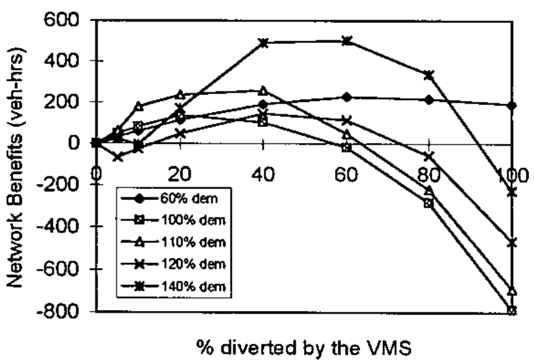

Figure 4: Network benefits for an incident (1 lane closure) at link 182, with varying base demand.

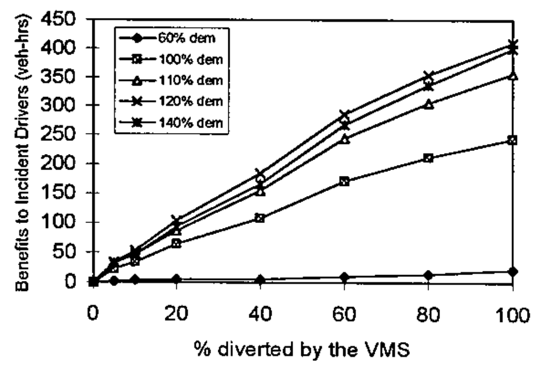

Figure 5: Incident drivers' benefits for an incident at link 113, with varying base demand..

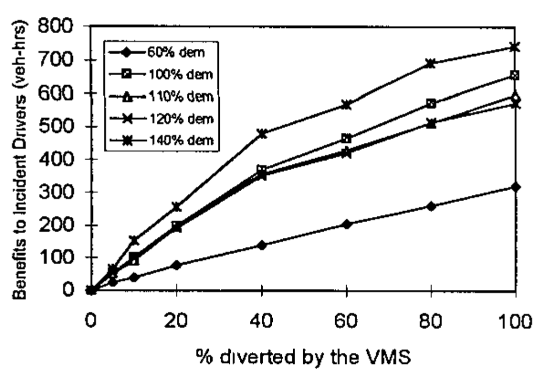

Figure 6: Incident drivers' benefits for an incident (total closure) at link 52, with varying base demand.

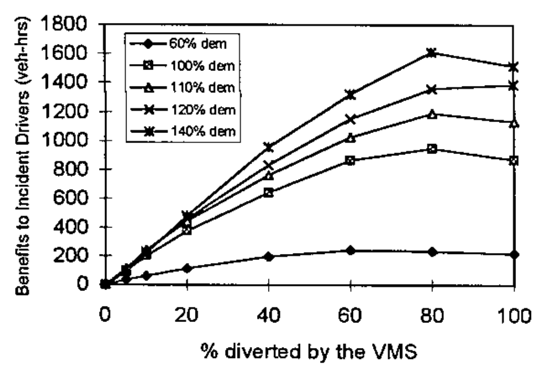

Figure 7· Incident drivers' benefits for an incident (1 lane open) at link 182, with varying base demand

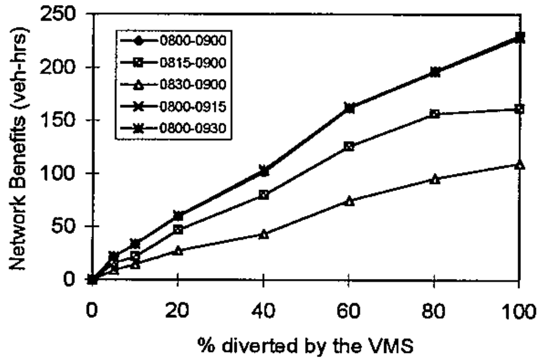

Figure 8: Network benefits for an incident at link 113, with varying VMS durations.

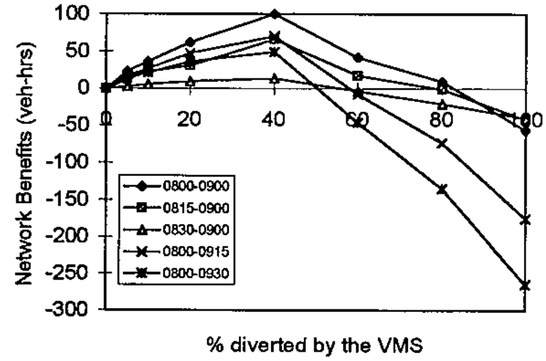

Figure 9: Network benefits for an incident at link 52, with varying VMS durations.

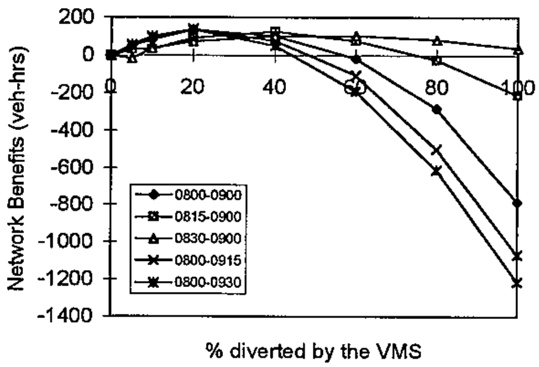

Figure 10: Network benefits for an incident at link 182, with varying VMS durations.

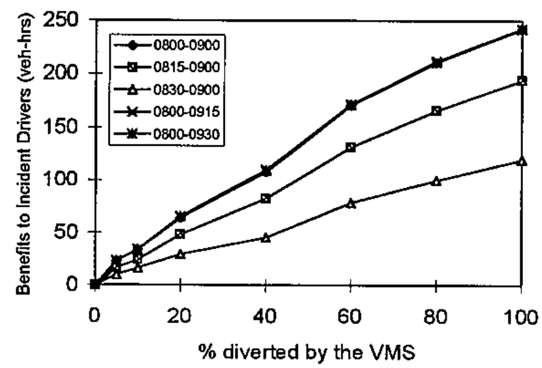

Figure 11: Incident drivers' benefits for an incident at link 113, with varying VMS durations.

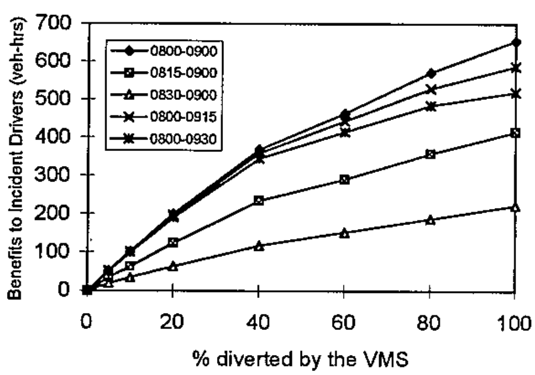

Figure 12: Incident drivers' benefits for an incident at link 52, with varying VMS durations.

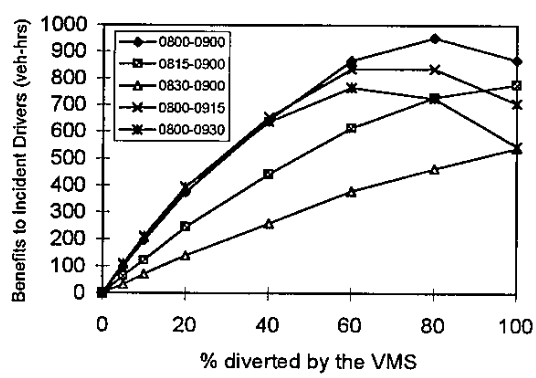

Figure 13: Incident drivers' benefits for an incident at link 182, with varying VMS durations.

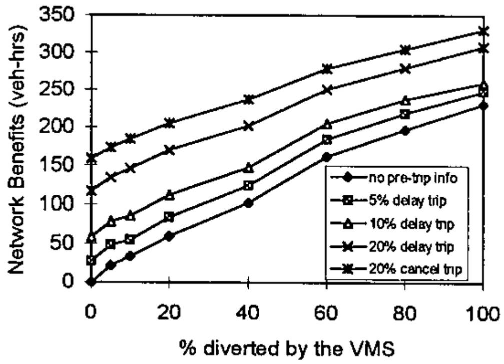

Figure 14: Network benefits for an incident at link 113, with varying responses to pre-trip information.

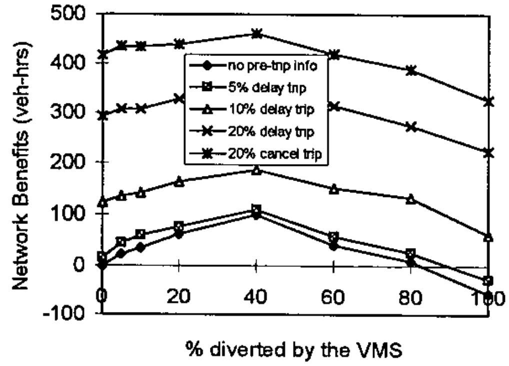

Figure 15: Network benefits for an incident at link 52, with varying responses to pre-trip information.

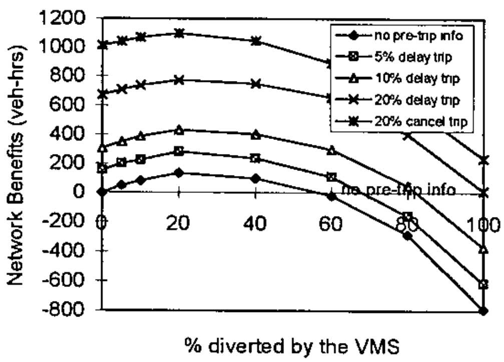

Figure 16: Network benefits for an incident at link 182, with varying responses to pre-trip information.

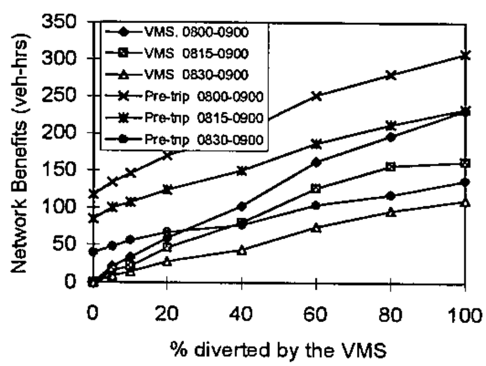

Figure 17: Network benefits for an incident at link 113, with varying durations of VMS and pre-trip information.

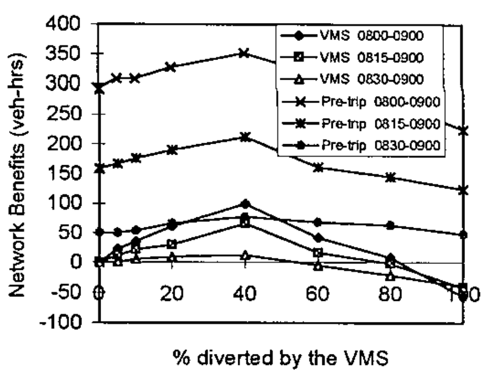

Figure 18: Network benefits for an incident at link 52, with varying durations of VMS and pre-trip information.

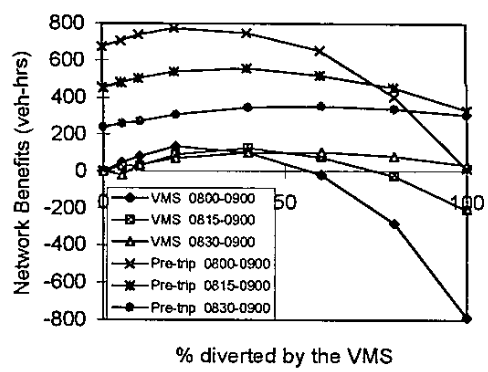

Figure 19: Network benefits for an incident at link 182, with varying durations of VMS and pre-trip information

Table 1: Benefits (veh-hrs) for total network: demand = 100%

VMS Set	Incident Link	Percentage of drivers diverted						
		5%	10%	20%	40%	60%	80%	100%
19, 29, 39, 49, 59, 69	113	18	23	50	85	139	175	204
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	122	24	28	45	378	490	362	66
	124	13	19	39	59	100	126	148
	181	-144	229	-101	515	576	339	716
	182	81	167	329	792	824	870	787
	52	23	36	62	100	42	9	-56
	61	22	37	60	98	124	84	35
	ALL	**318**	**3390**	**3234**	**12720**	**14640**	**12870**	**12666**
124, 114, 104, 94, 84, 73	63	28	58	72	127	184	214	235
	ALL	**168**	**348**	**432**	**762**	**1104**	**1284**	**1410**
182, 172, 162, 152, 142, 131	124	8	13	22	46	64	64	63
	ALL	**48**	**78**	**132**	**276**	**384**	**384**	**378**
123, 74, 113, 121, 103, 111, 93, 101, 83, 91, 72, 81	113	4	11	10	17	23	22	27
	121	7	6	10	17	25	29	27
	ALL	**66**	**102**	**120**	**204**	**288**	**306**	**324**

Table 2: Benefits (veh-hrs) for incident drivers: demand = 100%

VMS Set	Inc. Link	Percentage of drivers diverted						
		5%	10%	20%	40%	60%	80%	100%
19, 29, 39, 49, 59, 69	113	17	26	50	85	135	169	197
	121	17	26	52	87	141	176	204
	122	95	177	355	1007	1570	2146	2361
	124	13	20	38	61	104	135	164
	181	12	44	49	130	186	212	267
	182	116	231	458	957	1247	1538	1788
	52	52	102	200	369	465	572	657
	61	54	101	197	364	526	644	745
	ALL	**2256**	**4362**	**8394**	**18360**	**26244**	**33552**	**38298**
124, 114, 104, 94, 84, 73	63	18	29	72	101	162	206	247
	ALL	**108**	**174**	**336**	**606**	**972**	**1236**	**1482**
182, 172, 162, 152, 142, 131	124	8	12	25	48	77	91	108
	ALL	**48**	**72**	**150**	**288**	**462**	**546**	**648**
123, 74, 113, 121, 103, 111, 93, 101, 83, 91, 72, 81	113	6	8	14	23	36	42	46
	121	7	8	13	23	35	40	48
	ALL	**78**	**96**	**162**	**276**	**426**	**492**	**564**

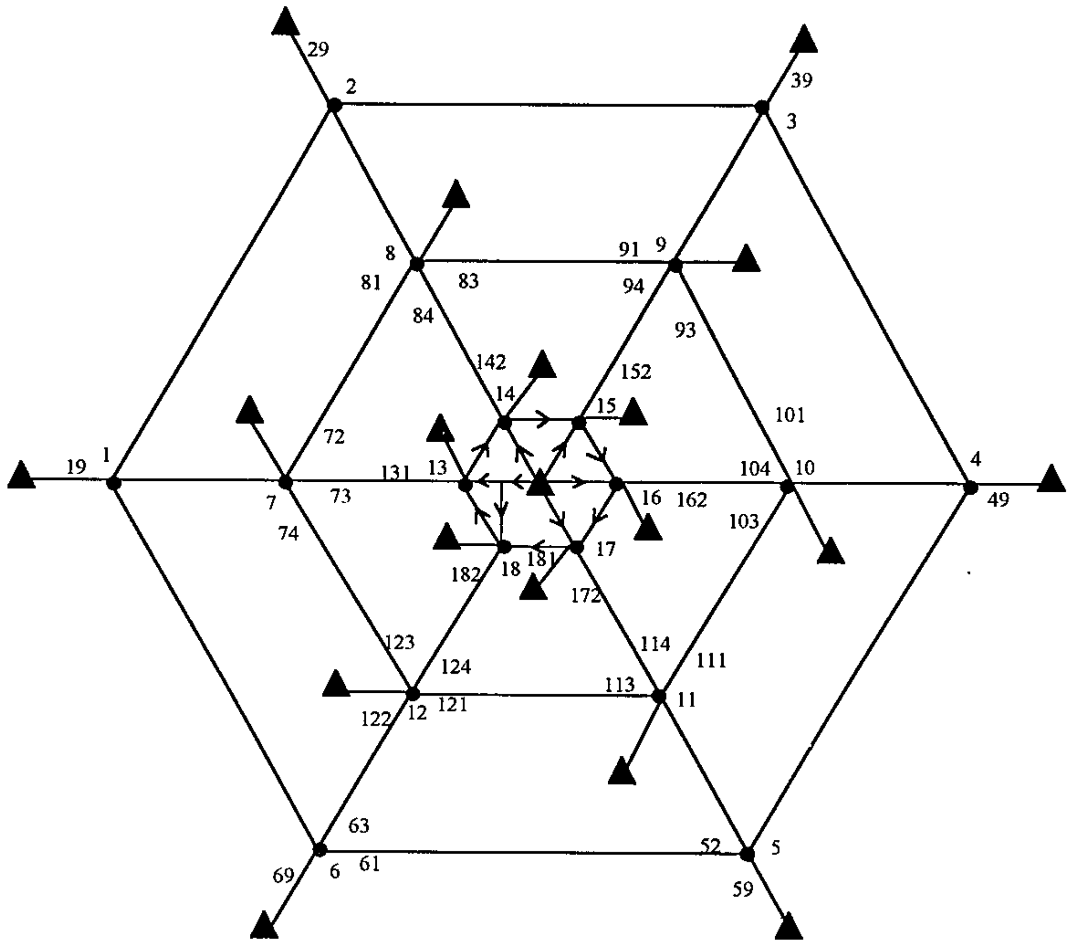

Figure 1: Description of the CONTRAM network used.

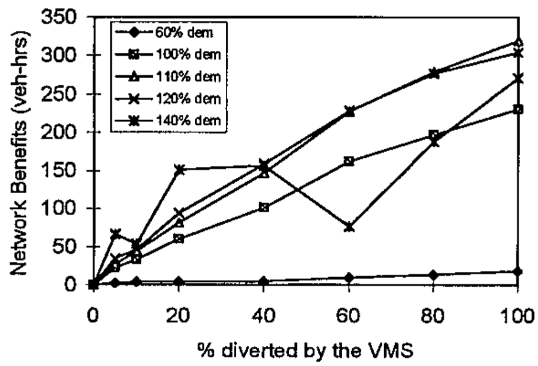

Figure 2: Network benefits for an incident (total closure) at link 113, with varying base demand.

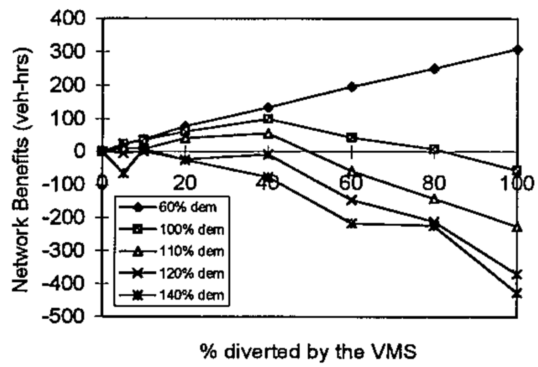

Figure 3: Network benefits for an incident (total closure) at link 52, with varying base demand.

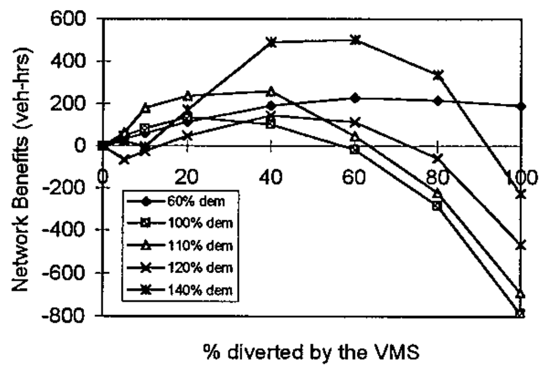

Figure 4: Network benefits for an incident (1 lane closure) at link 182, with varying base demand.

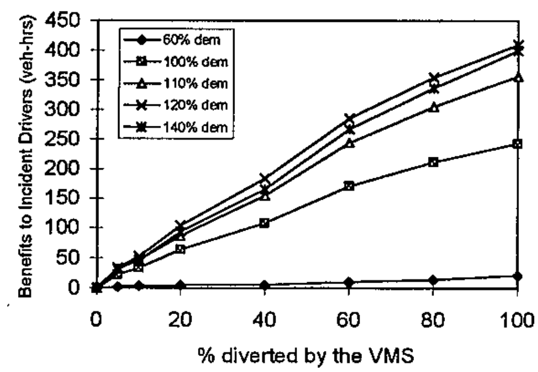

Figure 5: Incident drivers' benefits for an incident at link 113, with varying base demand..

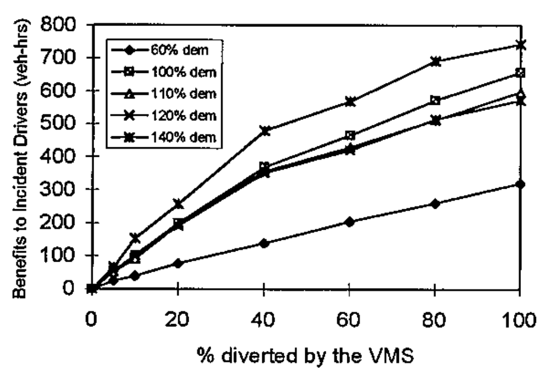

Figure 6: Incident drivers' benefits for an incident (total closure) at link 52, with varying base demand.

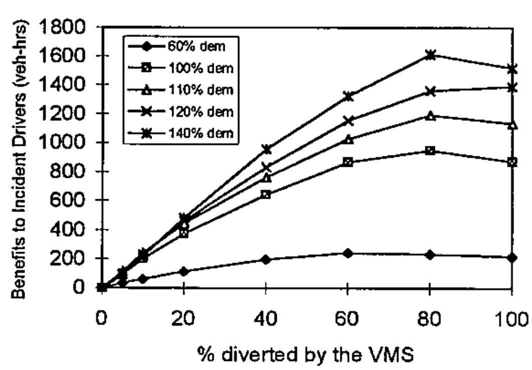

Figure 7: Incident drivers' benefits for an incident (1 lane open) at link 182, with varying base demand.

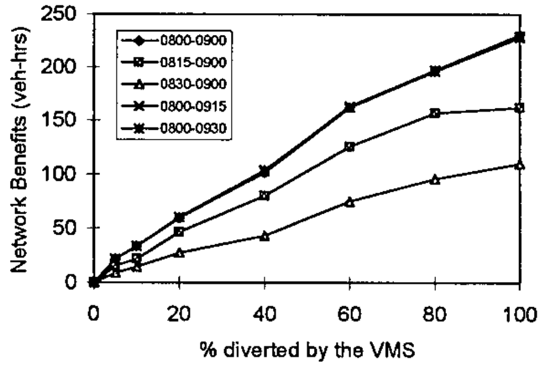

Figure 8: Network benefits for an incident at link 113, with varying VMS durations.

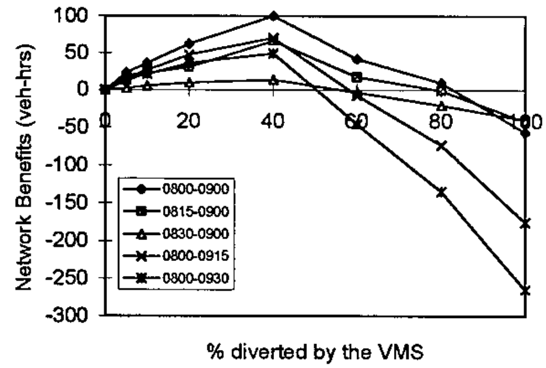

Figure 9: Network benefits for an incident at link 52, with varying VMS durations.

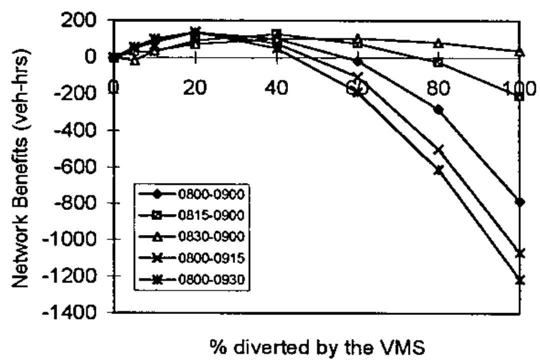

Figure 10: Network benefits for an incident at link 182, with varying VMS durations.

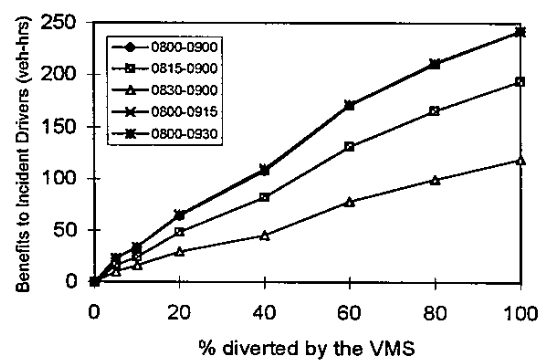

Figure 11: Incident drivers' benefits for an incident at link 113, with varying VMS durations.

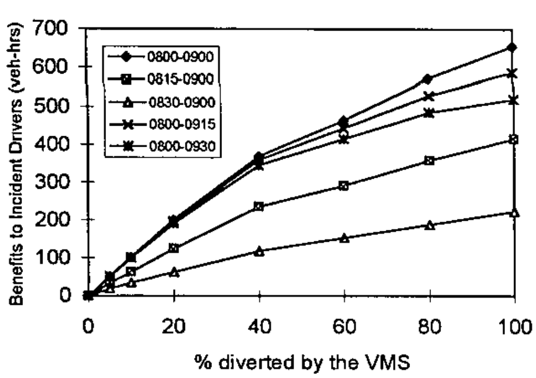

Figure 12: Incident drivers' benefits for an incident at link 52, with varying VMS durations.

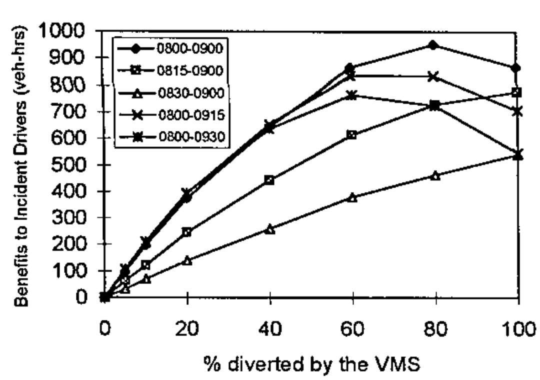

Figure 13: Incident drivers' benefits for an incident at link 182, with varying VMS durations.

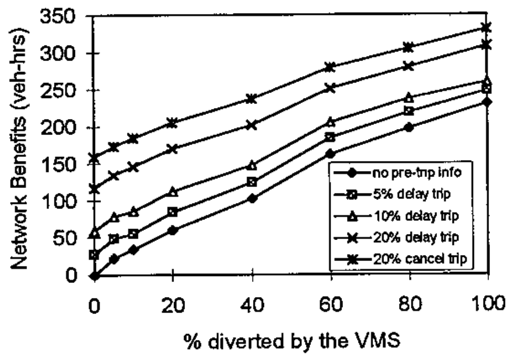

Figure 14: Network benefits for an incident at link 113, with varying responses to pre-trip information.

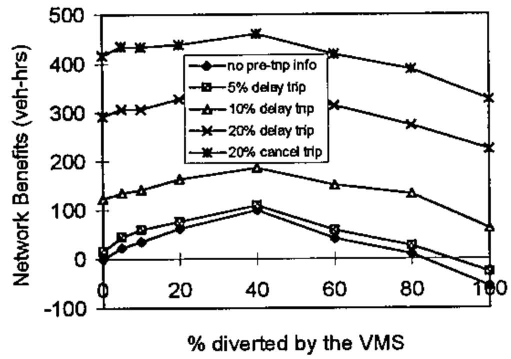

Figure 15: Network benefits for an incident at link 52, with varying responses to pre-trip information.

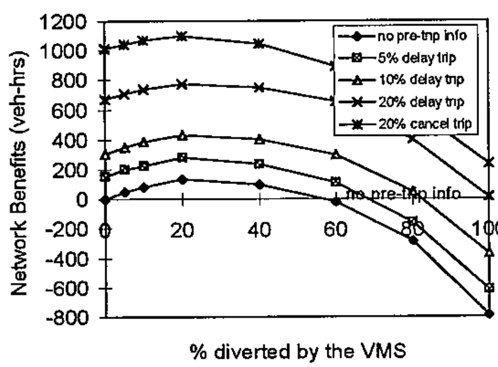

Figure 16: Network benefits for an incident at link 182, with varying responses to pre-trip information.

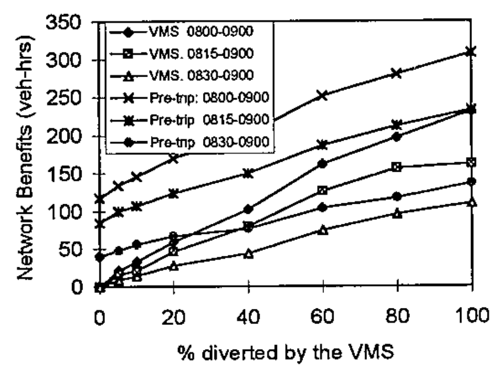

Figure 17: Network benefits for an incident at link 113, with varying durations of VMS and pre-trip information.

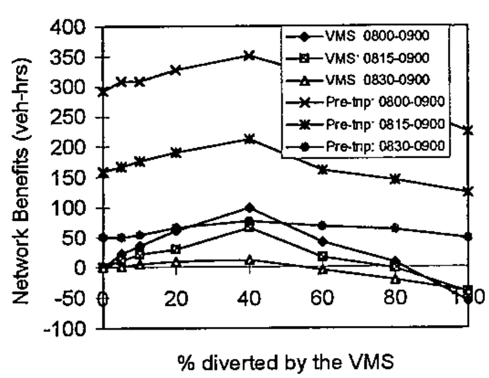

Figure 18: Network benefits for an incident at link 52, with varying durations of VMS and pre-trip information.

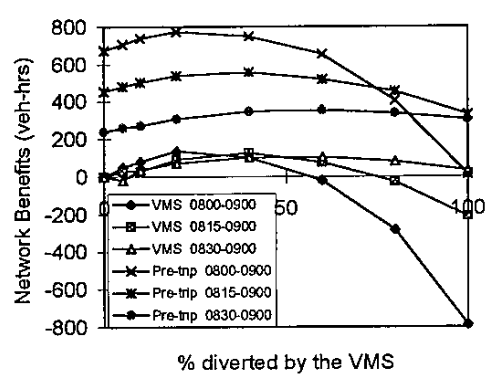

Figure 19: Network benefits for an incident at link 182, with varying durations of VMS and pre-trip information.

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