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AREA SPEED-FLOW RELATIONSHIPS BY MICRO-SIMULATION : SENSITIVITY ISSUES AND PROBLEMS WITH THE TRACKING APPROACH WHEN EXTENDED TO MULTI-ZONE NETWORKS

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Preface

This paper is one of a series of ITS working papers and technical notes describing the methodology and results of the EPSRC funded project "The definition of capacity in urban road networks : The role of area speed flow relationships". The objectives of the project were to investigate the interaction between vehicle-hours and vehicle-km within a network as the demand for travel increases; to develop improved area speed flow relationships; to use the relationships to explain the process by which networks reach capacity; and to assess the significance for the evaluation of road pricing policies.

The approach used was to collect the vehicle-hours and the vehicle-km directly from a simulation model and thus create relationships between supply and demand in terms of veh-hours/hr and veh-km/hr demanded and also between times per trip and trips demanded.

During the project two models were used. The first was a micro-simulation model called NEMIS. This model was used on hypothetical networks ranging from single link to a six by six grid and finally a ring-radial network. The networks were used to study the effects of changes in OD pattern and the effects of varying capacity on the resulting speed flow measures.

The second model used was SATURN. This model was used to study the same ring-radial as before and a full SATURN model of Cambridge. The SATURN results were then taken one step further in that they were used to create an aggregate model of each network using SATURN in buffer only mode. The related papers discuss issues such as network aggregation. Note that the methodology and terminology was developed as the study progressed and that in particular the method varies between application of the two distinct models.

The reader is directed to the attached appendix A for a full list of publications arising from this project.

Abstract

This working paper is the third in a series relating to the EPSRC funded project, " The definition of capacity in urban road networks : the role of area speed-flow relationships". The paper looks at the sensitivity of the results to the process of modelling blocking-back in NEMIS, for the same 6x6 grid network described by May and Shepherd (1994b).

First of all the blocking-back logic implemented in NEMIS is described. This logic was developed by Shepherd (1990) for use on an arterial network with the intention of blocking cross flows at signalised junctions. When implemented on grid networks with high demands and certain turning ratios this logic can lead to gridlock conditions. The logic implemented in NEMIS caused an irrecoverable gridlock condition i.e. once gridlock occurs it cannot be cleared. Although gridlock conditions may exist for short periods of time in the real world driver behaviour and or external factors combine to relieve the condition eventually. The results will be discussed with and without the blocking-back model implemented in NEMIS for matrix B - heavy inbound traffic.

This work also revealed some problems with the tracking approach described by May and Shepherd (1994a) and the definition of demand when extended from single link/zone networks to multi-zone networks. One of the main problems was that of overlapping in the space-time domain, the amount of overlap increasing as demand is increased.

1. Introduction

The blocking-back logic in NEMIS was implemented by Shepherd (1990) for use on an arterial sub-network of Turin. The aim of the logic was to block cross movements when queues extended into the upstream junction. When implemented on grid networks with extremely high demands and high turning percentages this logic can lead to irrecoverable gridlock conditions i.e. once gridlock occurs it cannot be cleared. Although gridlock conditions may exist for short periods of time in the real world driver behaviour and or external factors combine to relieve the condition eventually. The sensitivity of the results to the implementation of blocking-back in NEMIS will be discussed for the 6x6 grid network in figure 1 for the matrix B - heavy inbound traffic.

This work also revealed some problems with the tracking approach described by May and Shepherd (1994a) and the definition of demand when extended from single link/zone networks to multi-zone networks. One of the main problems was that of overlapping in the space-time domain, the amount of overlap increasing as demand is increased. Another problem with the tracking approach occurs when gridlock prevents data being collected in a zone for a particular generating time slice as no vehicles can reach the zone from that generating time slice. This results in free-flow speeds being reported for this zone and generating time slice as there are no vehicle-kms and no vehicle-hours. These problems will be discussed with reference to the 6x6 grid results.

2. The NEMIS Blocking-back Model

The previous work described for this network by May and Shepherd (1994b) used the standard NEMIS car-following logic. This logic automatically blocked only those vehicles wishing to enter a full link or lane. It did not block any other cross movements thus allowing vehicles to cross over the back end of queues in the junction area.

The later blocking-back logic implemented in NEMIS is described in more detail by Shepherd (1990). The logic was introduced during a study of metering strategies for an arterial in Turin. The purpose of the logic was to block any cross flowing vehicles when the junction area was blocked by excessive queues.

The logic basically looks at the last five metres in each lane which the subject vehicle must cross to determine if it is taken up by a stationary vehicle. If it is blocked then the subject vehicle will wait at the stop line. This process is carried out for all turning movements.

When implemented on grid networks the blocking-back logic can give rise to irrecoverable gridlock conditions, depending on the demand level and upon turning movements. This irrecoverable gridlock is thought to be unrealistic and the purpose of this paper is to investigate the sensitivity of the results with respect to the logic implemented. Although the gridlock conditions are more common when blocking-back is implemented other simulations by Shepherd (1994) have shown that for certain turning movements and OD patterns gridlock can occur without modelling blocking-back.

3. Comparison of Results For Matrix B - Heavy Inbound

This section discusses the results for the 6x6 grid network shown in figure 1 using matrix B - heavy inbound, with and without the blocking-back logic implemented in NEMIS.

Figures 2-13 refer to the simulations without blocking-back modelled. Figures 14-25 are the equivalent figures with blocking-back modelled indicated by the letter B in front of the 6x6 in the main titles. Figures 26-28 are extra graphs required to explain the differences for zone 1 inbound links.

3.1 Total Network Measures

The total network figures are for slices 2+3 or the mid-peak periods. When comparing the four standard measures (figures 2-5 with figures 14-17) the two curves are almost identical for low demand levels as expected. At higher demand levels the blocking-back results produce lower speeds, lower flows and higher travel times per km (also expected).

The first and most obvious question from these graphs is how close to gridlock should we accept ? The network travel times for the highest demand level are 7 hours/km with blocking-back and nearly 2 hours/km without blocking-back. The latter would be equivalent of 0.5 km/h which seems a reasonable lower limit on speed (even though some vehicles may cross over each other in the simulation).

The two approaches diverge from the 6th demand level onwards. This point is already beyond capacity and heading towards the gridlock condition. In terms of supply, results are very similar until demand exceeds capacity; beyond capacity the slope of the supply curve increases dramatically with blocking-back modelled.

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Figure 1. The 6*6 grid network

3.2 Time/km : Zone 1

Figures 6-9 and figures 18-21. For the no blocking-back approach the different link types seem to act over the same range of travel times/km as demand is increased. The drops in travel time at very high demands may be due to a lack of vehicles at entrance links as the NEMIS limit for vehicles present is reached e.g. for outbound links (figure 8) or it may be that the links have reached a capacity and are full. This is the case for inbound links (figure 7); the time levels off as the link becomes full and there are no external queues associated with zone 1 inbound links (see figure 1) to increase the travel time.

Figures 18-21 are more difficult to explain. At first sight it seems as though the inbound links become free moving as demand is increased beyond capacity. It is in fact a problem with the tracking approach.

The problem is due to the way in which the data is collected. The slice 2 data for inbound links in zone 1 is for vehicles which set off from any origin in the network in slice 2. However for the flow and vehicle hours to be collected the vehicle must actually pass along the links considered. Unfortunately as demand is increased then more vehicles from slice

1 fill the central area and stop vehicles from slice 2 entering that area. At high demands some vehicles from slice 2 may get into an inbound link in zone 1 from an internal origin, they may then move to another link and hence contribute a high speed for slice 2 just before gridlock sets in.

Figures 26-28 show the situation more clearly for zone 1 inbound links in terms of speed versus demanded flow. Figures 26+27 show the 4 slices and 2+3 for the tracking approach whilst figure 28 shows all 4 slices for the time slice approach. The time slice approach shows what the state of the inbound links is in each time slice. It is obvious from this graph that the links are actually becoming blocked as demand is increased.

The slice 2 result for the tracking approach gives a speed somewhere in between the slice 1 and slice 2 of the time slice approach.

Perhaps the most illuminating graph is for slices 3 and 4 of the tracking approach (figure 27). This shows the speeds on inbound links associated with slice 3+4 shooting up to 70 km/h (free-flow) as demand is increased. This is not an anti-queue it is merely demonstrating the fact that no vehicles generated in slices 3 or 4 reached this type of link in zone 1 at high demands. This could be because of gridlock or because they were displaced in time so that they would have completed the trip beyond the simulation period.

This is a reason to consider the time-slice approach (with external queues added) to give the supply measures. This will be discussed further in section 4.

3.3 Time/km : Zone 2

Figure 10-13 and figures 22-25.

Figures 10-13 for the no blocking-back simulations are reasonable. From figure 1 it can be seen that only the inbound links in zone 2 are origins and have external queue time associated with them. This explains the difference in magnitude between the times/km 5 hours for inbound links compared to 0.25 hours for outbound and orbital links.

The inbound link times/km increase as the external queue increases and input to zone 1 is reduced by congestion within zone 1. The outbound and orbital links reach a capacity and travel time becomes constant as a flow is maintained. The total network flow curve (figure 5) indicates that this flow is lower than demanded. Again the tracking approach could be suffering from flow displacement in time and in space. A slice approach would indicate the state of the network.

Figures 22-25. Figure 23 for the inbound links shows the effect of modelling blocking-back by increasing the time/km to unrealistic levels (35 hours/km) as gridlock sets in. The other link travel times may be more realistic as no external queues contribute but again they suffer from the same problem as described in zone 1 results i.e. the tracking approach can break down.

3.4 Blocking-back Conclusions

The no-blocking-back simulations produce reasonable curves even if the tracking approach is maintained. The speeds within the physical network drop to a range of 2-4 km/hour;

where origin links contribute the speed may drop to 0.3 km/hour with no blocking-back modelled. The disadvantage is that some vehicles will be crossing over one another in the junction area.

The blocking-back results can give closer to gridlock scenarios. The speeds within the network drop to between 0.3-0.5 km/hour; where origin links contribute the speed may drop to 0.03 km/hour.

The tracking approach seems fundamentally flawed in gridlock situations for 2-dimensional networks with more than one zone. Free-flow may be predicted for some generating time periods. This is discussed further in section 4. If blocking-back is to be modelled then a new data collection approach may be required.

4. Problems With The Tracking Approach

The tracking approach used for collecting supply measures was described for single link and single origin-destination networks by May and Shepherd (1994a). The approach basically tracked all vehicles through the space-time domain and aggregated the speed flow data by generating sub-periods or time slices. The method worked well and produced consistent results apart from in the very high demand scenarios when the flow could be displaced beyond the end of the simulation period.

For the tracking approach the demand in veh-km per hour was defined as the generation rate or factor multiplied by the veh-km/h recorded at the lowest level of demand simulated. This definition of demand assumes that there are no supply constraints.

When demand exceeds capacity the excess is stored within the network as queues and finally in queues external to the network. As seen above when this definition was carried forward to a multi-zonal network problems arose.

4.1 Overlap Of Data

Consider the space time diagram for a general multi-zone network for trips from the outer zones to the central zone as shown in figures 29 and 30 for an uncongested and congested case respectively. The outer zone acts in a similar fashion to the single network definition i.e. there is no overlapping of data and the slices are merely displaced in time as congestion increases. The central zone contains overlapping data even for the uncongested case. This is because the data is related to the generation of demand at origins which can be different distances from the central zone or even within the central zone itself.

This overlap may not be too problematic for small uncongested networks, but as can be seen from figure 30 as congestion increases then the amount of overlap increases. For larger networks the different travel times required to reach the central zone would imply even greater overlap of data.

As congestion increases, the slices will merge together, with the data relating to the internal origins being concentrated at the start of a time slice, and the data relating to the outer origins being concentrated at the end of the time slice.

The extension of the slices for the central zones as shown in figure 30 also implies an increase in the divisor used to determine the flow rate in veh-km/h (May and Shepherd, 1994a). This increase in the divisor produces a decrease in actual flow compared to the actual flow in the central zone as defined by the time slice approach. The flow is also under-estimated due to the overlapping data.

One method of reducing the amount of overlapping data would be to aggregate the data by origin-destination pair. However this would require greater detail and more speed flow curves as each OD pair would need three link types per zone per time slice. This is heading towards a full network model and in any case does not remove the problem of overlap completely.

Alternatively the approach could be to aggregate the data based on entry time to the zone in question. Although this would solve the overlap problem it is difficult to see how the data in the central zone could be related to demand at the origins.

4.2 Lack Of Data In Central Zones

This problem was described for zone 1 inbound links in section 3.2 relating to figures 26-28. The problem is due to the way in which the data is collected. The slice 2 data for inbound links in zone 1 is for vehicles which set off from any origin in the network in generating slice 2. However for the flow and vehicle hours to be collected the vehicles must actually pass along the links considered. Unfortunately as demand is increased then more vehicles from slice 1 fill the central area and stop vehicles from slice 2 entering that area. It may be that the vehicles will never enter the central zone under gridlock conditions or that the flow has been displaced in time and would eventually occur beyond the simulation period.

This lack of vehicle-km and vehicle-hours results in a free-flow speed giving the impression of anti-queues or spaces within the central zone. Figure 28 shows the actual speed in the central zone based upon the time slice approach, confirming the effect of the jam.

4.3 Data Collection And Definition Of Demand In Central Zones

As can be seen from the previous sections the current tracking approach causes problems in multi-zone networks best illustrated by considering the central zones. With the current definition of demand and the tracking approach, trips in the central zone are aggregated by entry time in the network irrespective of where the origin is with respect to the central zone. This means that data from nearer origins is collated with data from more distant origins in terms of the time required to reach the central zone.

This mixing of data may give reasonable results for small networks at low demand levels, but as network size and congestion increase then the times to reach a central zone increase for certain OD pairs and not for others. The demand is defined on the basis of the uncongested network factored by a generation rate with an assumption of infinite capacity. However in reality the demand for trips through central zones must be related back to the origins by the time taken to reach the zone. That is to say drivers from outer origins expect to reach a central zone later in congested periods than in uncongested periods, whereas those travelling from internal origins may still expect to enter the zone immediately. It therefore does not seem logical to relate the demand in the central zone to generating sub-periods over all origins.

An alternative method which solves all the above problems is proposed and depicted in figure 31. The method is simply based on the time-slice approach described by May and Shepherd (1994a) used to collect speed flow performance curves. The method would be adapted to collect supply measures by including external queues on the origin links. Each time slice would produce reliable speed flow data for the current state of that particular part of the network aggregated simply by the usual three link types per zone.

The relationship between origins and demand at origins would then be dealt with in the strategic model. The model would be able to calculate an average travel time through each zone for each generating sub-period and for each OD pair according to the overall level of demand and the appropriate time slice curve. Having calculated the travel time required to cross to the central zone the appropriate time slice can be chosen in zone 2 to calculate the central zone travel time. This is depicted in figure 31 for an average vehicle from generating slice 1 in the outer zone.

Where the trajectory crosses time slices within a zone the speed or time/km could be calculated in a proportional manner i.e. it may spend 5 minutes in slice 1 travelling at 10 km/h followed by 10 minutes in slice 2 travelling at 8 km/h. It would be possible for the strategic model to calculate an average trip time per origin-destination per generating time slice for a given level of demand by constructing the trip through the relevant time slice curves. The only assumption is that all vehicles have constant speed throughout a particular time slice on a particular link type.

This proposed method would use reliable time slice data, allow for different travel times to reach central zones and would not suffer from overlapping data or flow displacement problems. It would however require further thought and development within the strategic model.

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Appendix A: Area Speed Flow Publications

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