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AREA SPEED FLOW RELATIONSHIPS : RING-RADIAL NETWORK AGGREGATION USING SATURN

S. P. SHEPHERD

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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.

1. Introduction

This paper describes how to transform the simulation area speed flow results into SATURN buffer flow-delay curves for use in the aggregate buffer network. It also makes some important changes in the definitions and methodology particular to SATURN and SATURN networks. The paper presents two aggregate networks based upon the START aggregation philosophy i.e. aggregating vehicle-km by link direction within an area comprising inbound, outbound, clockwise and anti-clockwise.

2. A Change In Demand For SATURN

The SATURN simulation results are given for two periods. Period 1 gives the flow and times for the first hour (defined as the simulation period) and period 2 gives the flow and times for any excess demand passed automatically to this period. The flow in period 1+2 is equivalent to the assigned flow or demand **after reassignment** in SATURN. The times for period 1+2 also relate to the total time spent by the assigned flow in an area. The flow and times for period 1 are for flows which could enter in period 1 and so are a measure of the performance of the network or area.

The demand in terms of flow (veh-km/hr) is now taken for SATURN to be the **assigned** flow in periods 1+2 together. The time/km is calculated from the times and veh-km in periods 1+2 which is similar to the tracking approach in NEMIS. It is still possible to produce a performance curve (speed for period 1 against flow in period 1). The demand is now based on actual routes used rather than the free flow routes. The flow or demand reported from periods 1+2 is that which was actually assigned to period 1 in SATURN.

This definition of demand was not possible using NEMIS as the assigned flow was not known for a particular demand. The reassignment procedure in NEMIS was based upon en-route diversion. This change causes a shift in the x-axis of the supply curves so that the points are no longer equally spaced as the trip matrix factor is increased.

Note that in later papers the flow axis has been defined in terms of trips assigned rather than vehicle-km and times have been changed accordingly to times/trip. The results for the trip based curves were in any case very similar for the method described in this paper.

3. Application to SATURN

3.1. Transforming Results To SATURN Buffer Curves

SATURN buffer links are normally associated with the outer area of a SATURN model where less detail may be required. A buffer link does not have any junction detail, it is simply based on a link flow-delay relationship shown in equations 1 and 2 below.

Have the aggregate curves produced by the full SATURN simulation network must be transformed into the normal buffer link flow-delay curves in order to build an aggregate model. Each of the buffer links will be representing a directional link within an area, rather than the more ususal single link.

SATURN buffer flow-delay curves are of the form :-

$$t = t_0 + A\,V^n \qquad V < C \tag{1}$$

$$t = t_c + B\,(V - C)/C \qquad V > C \tag{2}$$

where

$t_0$is the free flow travel time (seconds)
$t_c$is the travel time at capacity (seconds)
Cis the link capacity (veh/hr)
Vis the assigned flow (veh/hr)
Bis a constant worked out by SATURN (=30 in my case)
A,nare constants defined in the curve fitting process

The parameters required for a SATURN buffer link are :-

$t_0$the free flow travel time (seconds)
$t_c$the travel time at capacity (seconds)
Cthe link capacity (veh/hr)
nthe power for the curve
dthe link distance (m)

The buffer parameters were fitted to each curve by ensuring that the curve in equation 1 passes through 3 points (t_0,V_0), (t_1,V_1), (t_c,C). The only problem was to choose V_1 and to define C. In general t_0 was defined as 0.99 times the lowest time simulated, V_1 was usually chosen where the curve begins to rise sharply and C is generally point 8 or 9 on the curve.

3.2. Transforming to SATURN Parameters

The most important parameter required is the aggregate link distance as this affects the assignment procedure in the buffer network and is also used to transform flow (veh-km/hr) to the SATURN definition of flow (veh/hr) or trips assigned and to define the capacity of the link in veh/hr.

The aggregation of links means that we need an average distance travelled through an area or set of link types. This average distance actually changes as demand is increased and different routing patterns occur. Using the SATURN P1X program it was noted that run number 7 produced multiple routes for all OD pairs which seemed sensible. With greater demand some of the routes become right turn avoiding routes; with lower demand the routes tend to be closer to single free flow routes.

SATDB was used to create select link matrices by link capacity index. This calculated the total number of trips assigned to an area for run 7. The flow assigned (veh-km/hr) divided by the trips (veh/hr) for run 7 gives the average distance travelled in each area.

Dividing all flows by their associated average trip lengths and converting from hours/km to seconds to cover this trip length gives curves in SATURN units i.e. time in seconds versus assigned trips or vehicles/hour.

4. Aggregated Buffer Network Design

Two alternative aggregate networks will be presented in this paper based upon the same buffer link flow-delay curves.

The SATURN plots of the ring-radial network for both the full simulation network and the aggregate buffer networkare shown in figures 1-8. Figure 1 shows the simulation network with link types shown by capacity index. The same 9 areas and link type definitions were used for SATURN as for NEMIS described by Shepherd (1995a). Figure 2 shows the node numbers for the full simulation network.

Figures 3-6 show the aggregated buffer network zones and nodes starting with a full network view and zooming into the central area. Figure 7 shows the aggregate link types or capacity index used in defining the aggregate buffer links corresponding to those used for the full network in figure 1.

The aggregated network has been implemented with two zones for each area (using SATURN notation zones are now origin/destinations and area replaces what were termed zones in the NEMIS work) for example zone 61 and 62 for area 6. Zone 61 is the major zone and zone 62 is used to generate and receive internal trips only via the orbital links. A similar numbering system is used for the other areas apart from the central area which has no internal trips.

The first aggregate or buffer network has only one internal zone in the central area, zone 101 representing eight O/Ds (zones) in the full network. The central area comprises two orbital links 103 and 104 from nodes 15-16 and 13-14 respectively. Figure 6 shows how the central zone 101 is connected to the rest of the network by free dummy or connector links. Note also that the radials are connected to both orbitals via free dummy links and vice versa.

With this representation in the central area all trips to and from the central zone 101 must use one of the central orbitals 103/104. **This network will be referred to as buffer-net1** and aggregates the trip matrix from 24x24 to 17x17 although 8 of the above 17 zones are used to represent internal trips only. It is basically a 9x9 matrix with extra cells for internal area trips.

Figure 8 shows an alternative central zone topology, the central area being modelled by four zones 101-104 each zone represents two O/Ds (zones) in the full network. This arrangement with the associated free connecting links allows a degree of route choice between appropriate radials and inner orbitals. For example trips between node 3 and zone 101 do not have to use links 103/104 whereas trips between node 12 and zone 101 must use an orbital route. This network also allows the possibility of taking the nearest radial from the centre followed by one of the outer orbitals. There is obviously more detail in this network and the matrix is now 20x20 (again sparse for the reasons stated above). **This network will be referred to as buffer-net2 in the figures and results.**

5. Results for buffer-net1 and buffer-net2

The same number of trips has been assigned to the aggregate buffer networks as was assigned to the simulation network, however the assigned flow is not directly comparable between the buffer networks or between the buffer and simulation network as the route choice is limited in different ways and the distance for each buffer link has been averaged in some form from the full network.

The results are shown in the form of four figures per link type. The first figure shows the simulation output in terms of time/km versus assigned flow and the proposed curve used to define the buffer link characteristics used for both buffer networks. The second figure shows the same fitted curve labelled buffer-fit and the resulting curve from the buffer-net2 runs. This figure is used to show that the curve fitted to the simulation data is used by the buffer networks but it may be used over a different range of flows compared to those in the first figure. It also shows the general buffer results of time/km versus assigned flow for buffer-net2.

The third and fourth figures show the two buffer network and simulation network flows and times/km versus run number which is basically related to the **demand factor** rather than demanded flow as this is the only common x-axis.

5.1 Links 103

Figures 9-12. Note from figure 11 that the buffer network 1 assigns twice as much flow on this orbital compared to the simulation. This is because with this topology all inbound and outbound trips must use one of the inner orbitals to enter or leave the network. The second buffer network gives some route choice within the central area and so models the simulated flow quite well until run number 8 where the routing patterns in the simulation differ from the buffer network.

5.2 Links 104

Figures 13-16. Again the buffer network flow is greater than in simulation as a result of the compulsory routing, although for low demand the cost of using this orbital is greater than the cost of using link 103 and it is therefore not used. (Time and distance being greater at free flow).

The second buffer network again reduces the flow on the orbital by providing route choice. Notice that the choice between link 103 and 104 is more marked for this network as there is less total flow on the two links than the first network.

5.3 Links 201

Figures 17-20. Here it can be seen that the buffer-net1 flow is approximately half that simulated and so the fitted curve is only used in its lower range. The second buffer network attracts some more flow as a result of other trips routing through the central area attracted by the relatively free inner orbital. However there is still a large discrepancy between the buffer and simulated flows.

Loss of flow could be due to a combination of three factors :-

(i) Loss of compulsory flow to and from the middle zones. In the real network all flow to and from the mid-zones had to use either link type 201 or 202 whereas in the buffer network zones are connected directly to the nodes with a choice of orbital or radial movements. The zones can be accessed directly from the orbital links. This is thought to be the major leak.

(ii) Buffer link average distance too low. This may be a problem but as figures 17 and 18 show, the curve fits very well to the simulated flow, the only problem being that the buffer network assigns trips not flow.

(iii) Loss of flow due to circular routing. At high demand levels it was noted that the simulation produces circular routing to avoid right turns; this means increased flow in terms of vehicle-km without increases in the number of trips assigned. The buffer network does not allow circular routing as there is no concept of separate turn delay. This point is more obvious for links 601/602.

Routing patterns will be discussed in more detail later.

5.4 Links 202

Figures 21-24. The same points apply here as for links 201.

5.5 Links 203

Figures 25-28. Again the curve fitting process is accurate for this link type (figs 25+26). However the flow assigned in buffer-net1 is half that of the simulated network. This is due to the limited route choice available.

In buffer-net2 each central zone has a free link to one of the radial links, this means that there is more route choice involving the outer orbitals and in fact the flow is over-estimated for the first six points. Again as demand increases the flow is under-estimated due to the difference in routing patterns in the simulation and the buffer network (see later).

5.6 Links 204

Figures 29-32. Again at higher demand levels where re-routing to the orbitals takes place in the simulated network the buffer networks do not re-assign flow due to the compression of route choice. Similar comments to links 203.

5.7 Links 601

Figures 33-36. These inbound links have the same link length in both networks. The flow and hence trips assigned is the same until run number 7 then the flow in the simulation is greater. This could be due to a difference in the routing patterns of external to external trips taking the outer orbital only e.g. zone 61 to 81.

Alternatively it could be due to the circular routing patterns in the simulated network whereby trips entering from an outer zone avoid a right turn by going straight-on and turning left then left again to form a loop. This increases the flow on the inbound, outbound and orbitals in the simulation without increasing the number of trips assigned. Circular routing does not occur in the buffer network as there is no distinction between turning movements on a buffer link.

Note that the results are identical for both buffer networks which implies the costs between outer orbital and radial movements for external to external trips is the same for both networks.

5.8 Links 602

Figures 37-40. Similar points to links 601 above.

5.9 Links 603

Figures 41-44. The difference in flow between the two buffer networks is attributed to the compulsory use of the inner orbitals 103/104 in buffer-net1. The difference in flow between the buffer-net2 and the simulation is due to the compression of route choice between inner and outer zones and the circular routing problem.

5.10 Links 604

Figures 45-48. Similar points to links 603.

5.11 Total Network

Figures 49-52. Here in figure 50 the buffer-net2 curve is a summation of the link types whereas the buffer-fit line represents the curve fitted to the simulated total network. This curve was not fed into the buffer network design. However as can be seen from figure 52 the buffer-net2 gives a far better estimate of total time/km than buffer-net1 although for similar overall flows (fig 51). This shows that fitting the total network results well does not imply that trips between particular OD pairs are modelled accurately.

6. Sources of Error

6.1 Network aggregation /design and routing patterns

Figures 53-61 show the routing patterns or forests for various combinations of origin and destination for the simulation network and the buffer networks for the highest demand level. The origin is the dark star and the destination the light star with the numbers representing percentage of trips using the associated links.

Figure 53 shows a typical external to external trip in the simulation network whereby most of the trips route clockwise to avoid the right turn on entry to the network. There are also some 16% demanding a circular route to avoid the right turn.

Figure 54 shows the route choice for what will be an internal trip in the buffer networks. Note that 45% of the trips choose a circular route to avoid the right turn. There is even a loop beyond the destination to avoid the final right turn. These routes may actually be realistic because of the short link lengths (radials 250m, orbitals 390 and 590m).

Figure 55 shows the simple routing pattern for the second buffer network which represents both trips shown in figures 53 and 54. There is obviously a great difference in flow which results from the fact that there is no distinction between turning movements in the buffer network.

Figure 56 shows a typical routing pattern for the simulation network between an outer origin and a slightly offset inner destination (i.e. not a direct route inbound). Notice the use of orbitals and some 15% circular routing. Figure 57 shows the routing pattern for the second buffer network. This is an example of route compression whereby the orbital movements between two adjacent radials have been compressed to zero.

Figures 58 and 59 show a similar problem for the reverse trips (with destination offset slightly). Note that in both case the buffer network only has one route used.

Figures 60 and 61 show the difference between the buffer networks for trips from origin 61 to the West of the centre. For the second buffer network (fig 61) most of the traffic routes round the outer orbitals with only 8% using the inner orbital. The first buffer-net1 (figure 61) forces all such trips to use an inner orbital so that none choose to use the outer orbitals. Note that 71% use the cheaper clockwise orbital.

This section has highlighted major differences in routing patterns and hence flow for some of the possible OD pairings between the simulation and the two buffer networks and indeed between the two buffer networks. These differences are multiplied as the network is symmetrical and the above patterns are repeated. These differences in routing patterns go a long way to explaining the differences in the aggregated and the full networks. However the routing patterns may be a little extreme due to the size of the network and this problem may be less significant for a real network such as the Cambridge network.

One of the major problems with the aggregated network is the positioning of zone connectors which then affects the route choices. For example the middle areas such as area 2 have zones which connect to nodes at the intersection of inbound, outbound and orbital routes whereas in the full network the choice for these mid-zones was inbound or outbound. This resulted in a loss of flow for link types 201 and 202. Problems such as this could be overcome by adding dummy nodes half-way along a link to feed traffic onto the network or to provide better route choice, however this is heading back towards the full network and away from the concept of aggregation.

6.2 Average distance

The buffer network is made up from average distances (calculated for run 7). The distance for each link affects the assignment in the buffer network. The average distance travelled increases with demand, this is not due to circular routing patterns (as SATURN recognises the extra trips through an area) but is due to routing patterns such as those in figures 53 and 56 which do not occur in the buffer network.

The curve fitting process uses the "average" distance for each link to convert the curve parameters from veh-km/h to "trips" based on this distance. It is merely a constant divisor. However this transforms the x-axis into "trips" which would produce the same flow as simulated when multiplied by the average distance but we may actually be assigning a different number of actual trips from the trip matrix. This error is inevitable as we need a constant topology for the network, however it seems from this network at least that the major sources of error are due to the network aggregation design and routing patterns. Note that the process was repeated using trips as the explanatory variable in place of vehicle-km/hr and similar results were obtained.

7. Conclusions

The results for both forms of aggregate network do not give adequate representation of the full ring-radial network although the second topology offering route choice in the central area gives better results than the first topology. Both networks suffer from the problems stated above such as route compression, lack of turn dependency in the buffer network and averaged distances. Basically the route choice offered by the aggregate network is different from that offered by the full network.

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