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# AREA SPEED FLOW RELATIONSHIPS BY MICRO-SIMULATION: GRID NETWORKS

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**Abstract**

This working paper is the second 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 reports on the collection of the four measures described by May and Shepherd (1994) for a 6x6 grid network for various origin destination patterns.

The grid is divided into zones. Within each zone the simulated links are defined as either inbound, outbound or orbital in nature and the data is aggregated according to link type and vehicle generation time or period. This form of data aggregation is required by the strategic model START.

The aim of this paper is to determine the area speed flow relationships within the zone links and to test whether they are sensitive to changes in OD pattern. Six different OD patterns have been simulated across a similar range of demand.

## 1. Introduction

The speed flow measures defined by May and Shepherd (1994) were simulated using NEMIS for the 6x6 grid network shown in figure 1 with the same data collection approaches over a range of demands levels each one hour in duration.

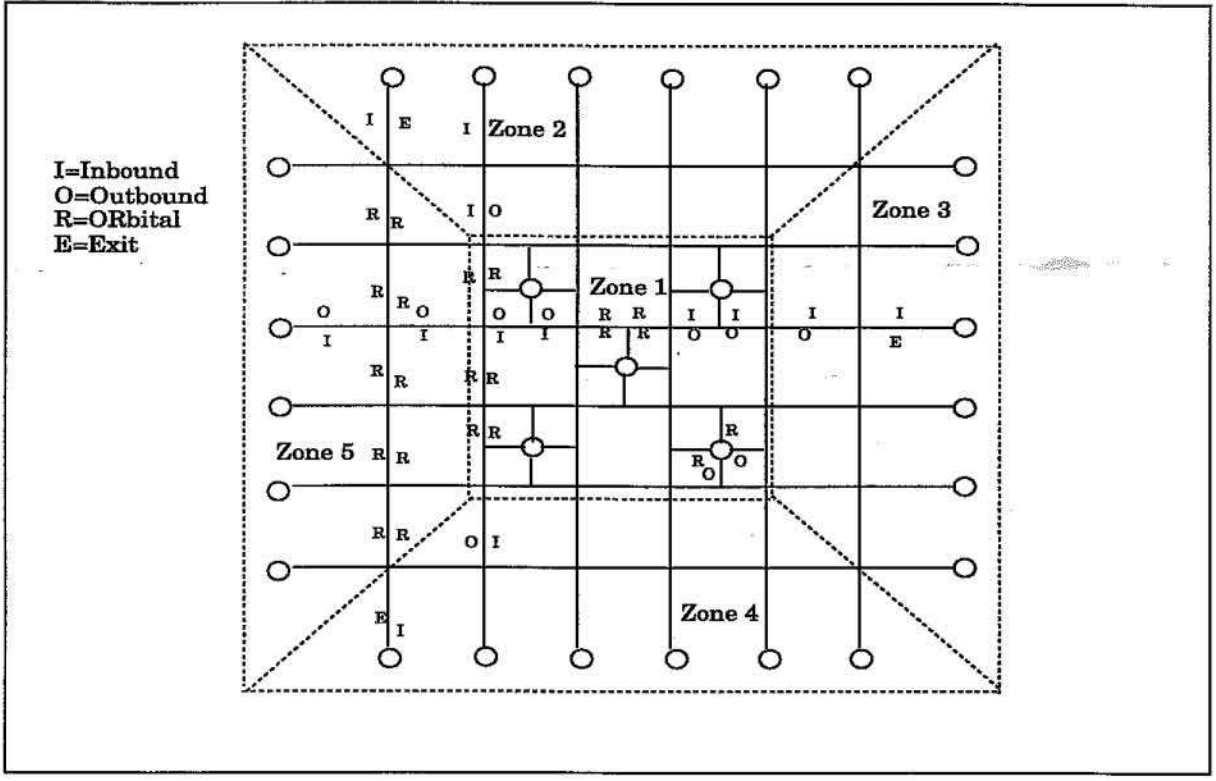



Figure 1. The 6x6 grid network

The network was divided into five zones, within each zone the simulated links are defined as either inbound, outbound, orbital or exit links. The data is then aggregated according to zone, link type and time of generation at the vehicle's origin. This method of data aggregation is similar to that used by the strategic model START. The exit link data will be omitted from the analysis as the exit links in NEMIS are assumed to be free running links.

Zone 1 is the central zone; zones 2-5 are identical for symmetric OD patterns. All zones contain origins and destinations indicated by circles in figure 1. The vehicles drive on the right in the network (as NEMIS is Italian) and some of the links have been marked as inbound, outbound, orbital or exit. From the symmetry of the network it is possible to deduce the nature of all unmarked links.

All four measures (i) speed vs actual flow, (ii) speed vs demanded flow, (iii) average time/km vs demanded flow and (iv) actual flow vs demanded flow will be given for the total network for the mid-peak slices (2+3) with the average time/km versus demanded flow by link type for zones 1 and 2. The method used is a direct extension, to grids containing zones and different link types, of that described by May and Shepherd (1994).

## 2. Matrices Tested

Six matrices A-F were tested with varying OD patterns. The approach taken was as follows : consider the origins and destinations in figure 1 to be made up from 1-6 North, 7-12 West, 13-18 East, 19-24 South and 25-29 Central. Then the base matrix A is as follows :-

| Matrix A | North | West | East | South | Central |
|---|---|---|---|---|---|
| North | 0 | 10 | 10 | 10 | 10 |
| West | 10 | 0 | 10 | 10 | 10 |
| East | 10 | 10 | 0 | 10 | 10 |
| South | 10 | 10 | 10 | 0 | 10 |
| Central | 10 | 10 | 10 | 10 | 0 |

The value 10 corresponds to the number of vehicles per hour demanding to travel from a single origin node to a single destination node for the lowest demand level. Each of the measures is calculated for 10 simulations by factoring the trip matrix from 1-10 to form a curve for each measure. The origins and destinations have been grouped to simplify the presentation, the real matrix is 29x29. The other matrices B-F are made up from the base matrix plus a doubling of demand between certain OD pairs as follows :-

Matrix B: Inbound

| Matrix B | North | West | East | South | Central |
|---|---|---|---|---|---|
| North | 0 | 10 | 10 | 10 | 20 |
| West | 10 | 0 | 10 | 10 | 20 |
| East | 10 | 10 | 0 | 10 | 20 |
| South | 10 | 10 | 10 | 0 | 20 |
| Central | 10 | 10 | 10 | 10 | 0 |

Matrix C : Outbound

| Matrix C | North | West | East | South | Central |
|---|---|---|---|---|---|
| North | 0 | 10 | 10 | 10 | 10 |
| West | 10 | 0 | 10 | 10 | 10 |
| East | 10 | 10 | 0 | 10 | 10 |
| South | 10 | 10 | 10 | 0 | 10 |
| Central | 20 | 20 | 20 | 20 | 0 |

Matrix D : Clockwise

| Matrix D | North | West | East | South | Central |
|---|---|---|---|---|---|
| North | 0 | 10 | 20 | 10 | 10 |
| West | 20 | 0 | 10 | 10 | 10 |
| East | 10 | 10 | 0 | 20 | 10 |
| South | 10 | 20 | 10 | 0 | 10 |
| Central | 10 | 10 | 10 | 10 | 0 |

Matrix E : Anti-clockwise

| Matrix E | North | West | East | South | Central |
|---|---|---|---|---|---|
| North | 0 | 20 | 10 | 10 | 10 |
| West | 10 | 0 | 10 | 20 | 10 |
| East | 20 | 10 | 0 | 10 | 10 |
| South | 10 | 10 | 20 | 0 | 10 |
| Central | 10 | 10 | 10 | 10 | 0 |

Matrix F : Through

| Matrix F | North | West | East | South | Central |
|---|---|---|---|---|---|
| North | 0 | 10 | 10 | 20 | 10 |
| West | 10 | 0 | 20 | 10 | 10 |
| East | 10 | 20 | 0 | 10 | 10 |
| South | 20 | 10 | 10 | 0 | 10 |
| Central | 10 | 10 | 10 | 10 | 0 |

As the total vehicle-km/hour demanded varies between matrices this must be borne in mind when viewing the graphs with demanded flow as the x-axis. Basically the $n^{th}$ point from one matrix does not correspond to the same demand in veh-km/h as the $n^{th}$ point of another matrix.

## 3. Discussion Of Results

The discussion of the results has been limited to the four basic measures for the total network plus the average time/km measure for all links combined in each of zones 1+2 and by link type for zones 1 and 2 for each matrix A-F. Each matrix therefore contributes 12 figures to the discussion. The matrix is identified in the main title of each figure as ODA, ODB....,ODF.

### 3.1 Total Network : Speed vs Actual Flow (Figs. 2,14,26,38,50,62)

The free flow regime is very similar for all matrices A-F with a free flow journey speed of 33-34 km/h which compares to Wardrop's 37 km/h for London (Wardrop, 1968) without taking into account the effects of signal and junction frequency.

All matrices give a capacity between 45-50 thousand veh-km/h at a speed of 20 km/h. It is difficult to compare the points near capacity as the curves are changing from a negative to positive gradient i.e. a small increase in demand results in a large decrease in speed and perhaps a reduction in flow. The comparison is not aided by the fact that the $n^{th}$ point on each graph represents a different demand level which is calculated from the vehicle-km/h generated at the lowest demand level in each case. However the actual flows are directly comparable.

### 3.2 Total Network : Speed vs Demanded Flow (Figs. 3,15,27,39,51,63)

Again similar curves are produced with a sudden drop in speed from around 20 km/h to 5 km/h taking place between demand levels of 40-50 thousand veh-km/h.

### 3.3 Total Network : Time/km vs Demanded Flow (Figs. 4,16,28,40,52,64)

Again all the graphs are very similar, all change gradient around the same point 40-50 thousand veh-km/h and at a demand of 100 thousand veh-km/h the time/km is approximately 1.6 hours for all matrices. This indicates that the gradients of the six curves are similar for both portions of the supply curve, the free flow regimes being almost identical.

### 3.4 Total Network : Actual Flow vs Demanded Flow (Figs. 5,17,29,41,53,65)

Again very similar graphs result with actual flow equal to demanded flow until a capacity is reached between 35-40 thousand veh-km/h at a demand level of 40 thousand veh-km/h. All curves display a similar drop off in flow as demand is increased further.

In general the total network measures are insensitive to the changes in OD pattern tested here i.e. a doubling of certain demanded OD pairs as described above.

### 3.5 Zone 1 Total : Av.Time/km vs Demanded Flow (Figs. 6,18,30,42,54,66)

The total curve for zone 1 is made up from the inbound, outbound plus orbital curves. In general the times/km reach a maximum of 0.5-0.7 hours except for matrix C which reaches a time/km of just over 1.6 hours. Matrix C is the heavy outbound matrix and so is the only matrix to factor up the demand from the internal origins (within zone 1) and as demand is increased then "external queues" representing vehicles wanting to leave parking areas form on the entry links which contribute to the higher travel time per km.

### 3.6 Zone 1 Inbound : Av.Time/km vs Demanded Flow (Figs. 7,19,31,43,55,67)

In general the curves break at the same point and the travel time rises with increased demand and then begins to settle around a time of 0.5 hours/km. There are however some drops in time as the demand is increased; this is a problem with the tracking approach. The tracking approach tracks vehicles from internal and external origins through zone 1 generated in the same sub-period, this gives rise to overlapping data in the time-space domain which did not occur for single link or single zone networks. As gridlock occurs at different points in time as demand is increased, a different set or proportion of vehicles contribute to the points on the curve for slice 2+3, i.e. for high demands some trips are not satisfied which gives rise to variations in flows and vehicle hours. This problem will be addressed further in the third paper in this series which deals with sensitivity issues.

### 3.7 Zone 1 Outbound : Av.Time/km vs Demanded Flow (Figs. 8,20,32,44,56,68)

Again very similar curves are generated for the different matrices, with similar times apart from matrix C which has much higher travel times. This is due to the extra time spent in external queues as demand exceeds capacity. The drops in travel time for high demands can be explained by a memory limit in NEMIS which limits the maximum number of vehicles which can be present on the network. This has the effect of producing smaller external queues i.e. less vehicle hours whilst maintaining the vehicle-km as demand is increased.

### 3.8 Zone 1 Orbital : Av.Time/km vs Demanded Flow (Figs. 9,21,33,45,57,69)

Again matrix C produces extra travel time/km as more vehicles contribute to the external queues at the internal origins, the times increase from 0.5 to 1.4 hours/km.

### 3.9 Zone 2 Total : Av.Time/km vs Demanded Flow (Figs. 10,22,34,46,58,70)

The range of times for high demand is between 1.6-2.0 hours/km with the inbound link type contributing most of the time element. This is due to the topology of the outer zones. Only inbound links can generate external queuing time in the outer zones.

### 3.10 Zone 2 Inbound : Av.Time/km vs Demanded Flow (Figs. 11,23,35,47,59,71)

All curves are similar giving a time of around 4 hours/km at a demand of 5000 veh-km/h. At higher demands any levelling off of the curves is due in some part to the limit on number of vehicles in NEMIS and also to the internal inbound links becoming full and hence contributing a constant time to traverse them.

### 3.11 Zone 2 Outbound : Av.Time/km vs Demanded Flow (Figs. 12,24,36,48,60,72)

All curves apart from matrix D settle around a time/km of around 0.25 hours/km whereas matrix D settles around a time/km of 0.3 hours. Matrix D is the heavy through traffic matrix and as such would be expected to generate higher demand and higher travel times as people queue to leave the network.

### 3.12 Zone 2 Orbital : Av.Time/km vs Demanded Flow (Figs. 13,25,37,49,61,73)

The curves break at similar demand levels and settle around travel times between 0.25-0.3 hours/km which is around 4 km/h. This compares to zone 2 inbound speeds of around 0.3 km/h which includes external queuing time.

## 4. Conclusions

In general below capacity the measures seem to be insensitive to the range of OD patterns tested here.

Beyond the free flow regime the performance of the physical network does not seem to be affected, the main changes occur in the position of the external queues as demand exceeds capacity for this particular network. That is to say with a change in OD pattern as described here the main change is in where the external queues form and is reflected in the supply measures.

This may have localised effects on the supply curves as for matrix C (outbound from zone 1) in over capacity situations. However when viewed as a total network the overall effect of changing matrix is negligible. The overall total demand is similar for all matrices and it is not possible to see where the external queues are forming from a total network measure.

Matrices B,D,E and F give very similar results as the total demand from the outer origins is identical in terms of trips generated and the excess demand must queue in the same place irrespective of destination.

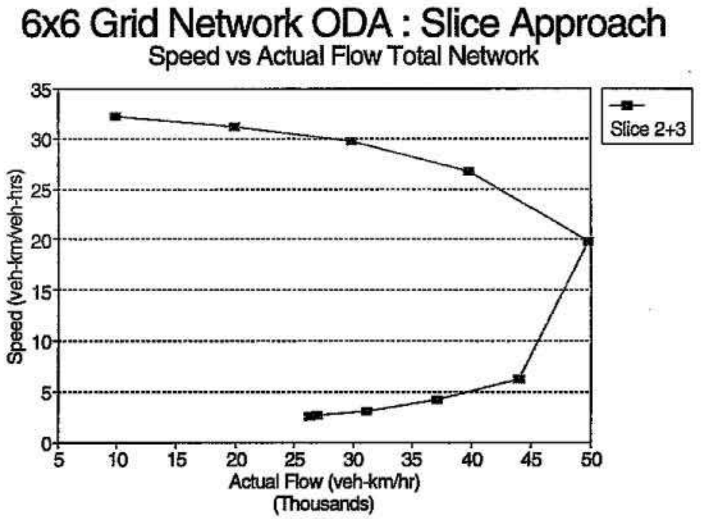
One explanation for the lack of sensitivity to changes in OD patterns for this network may be due to the following : as the capacity of the internal network is exceeded the queues quickly form and transfer congestion to all origins at a similar rate causing external queues wherever demand is generated.

## 5. References


May, A.D. and Shepherd, S.P. (1994). An investigation of area speed-flow relationships by micro-simulation : Single Links. Working Paper 428. Institute for Transport Studies, university of Leeds.

Wardrop, J.G. (1968). Journey speed and flow in central urban areas. traffic engineering and Control 9(11).

**Fig 2**

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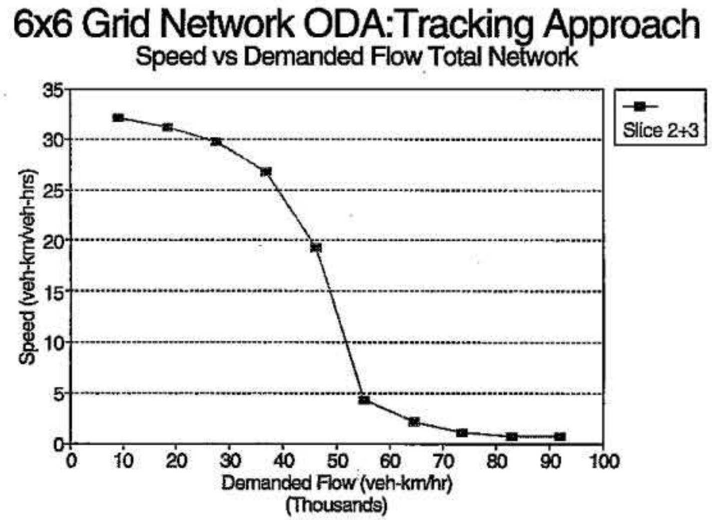


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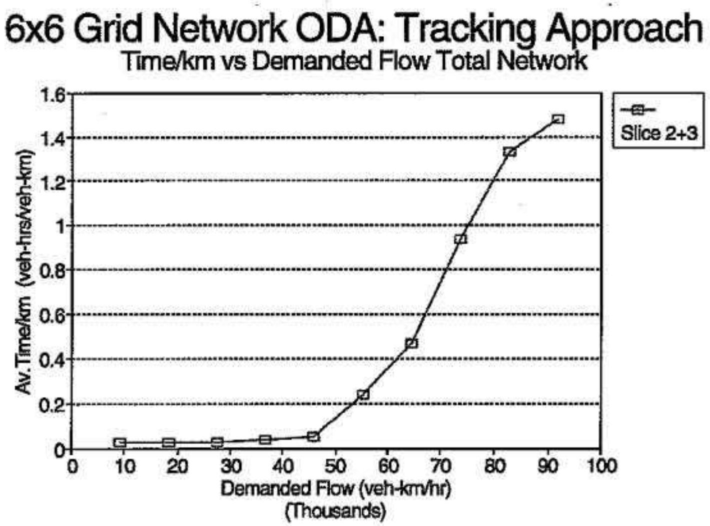


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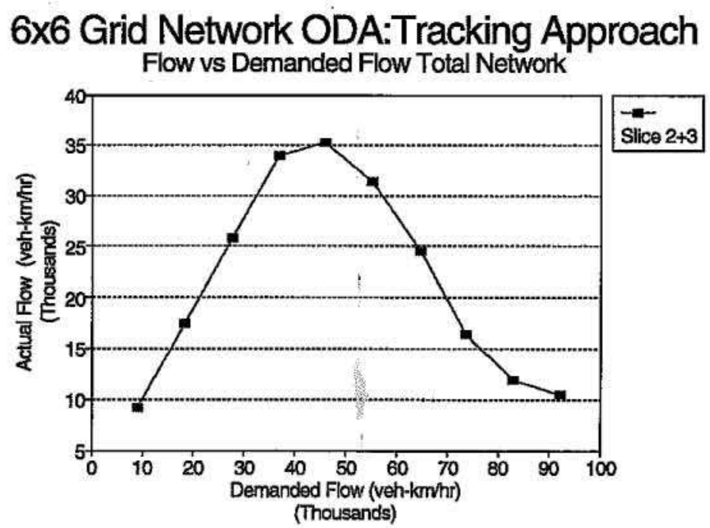

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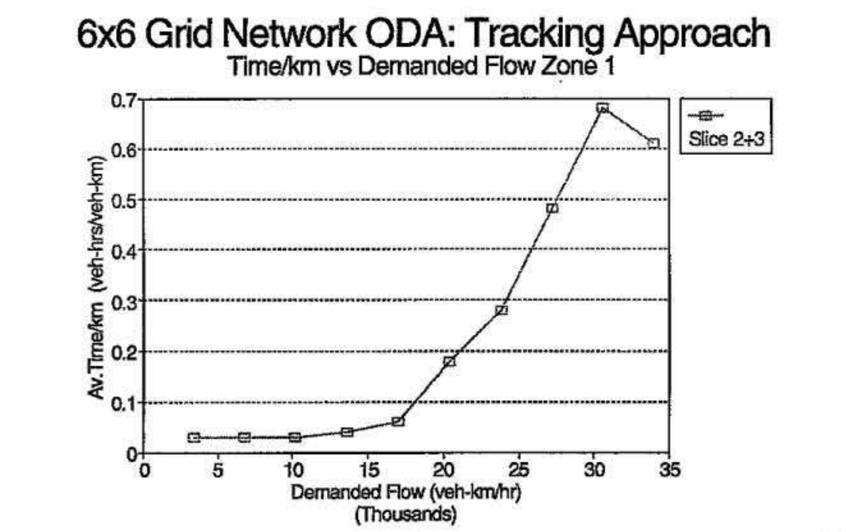


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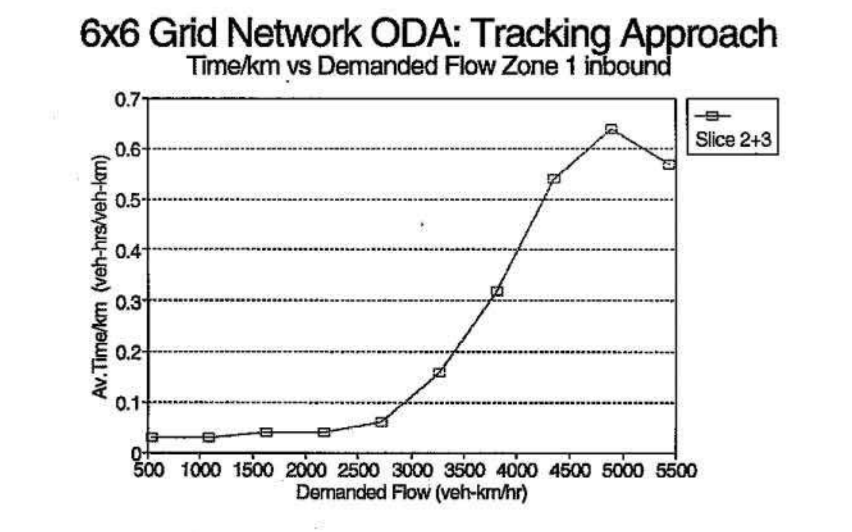


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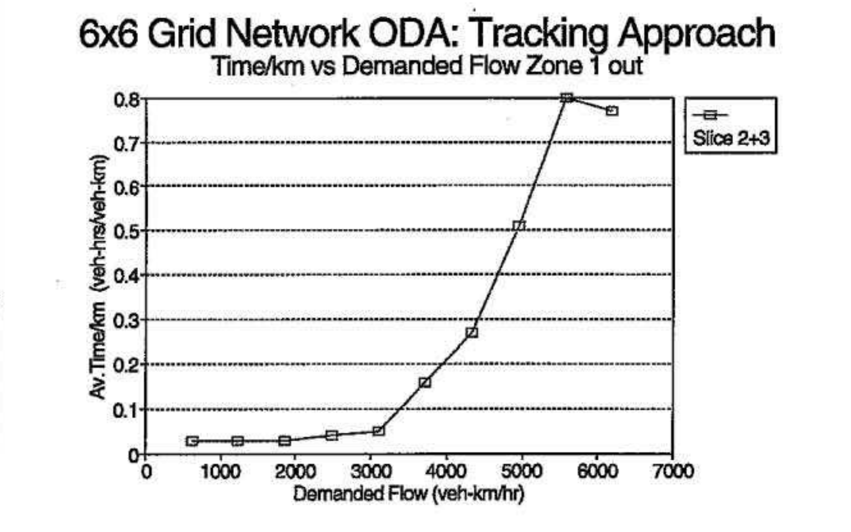


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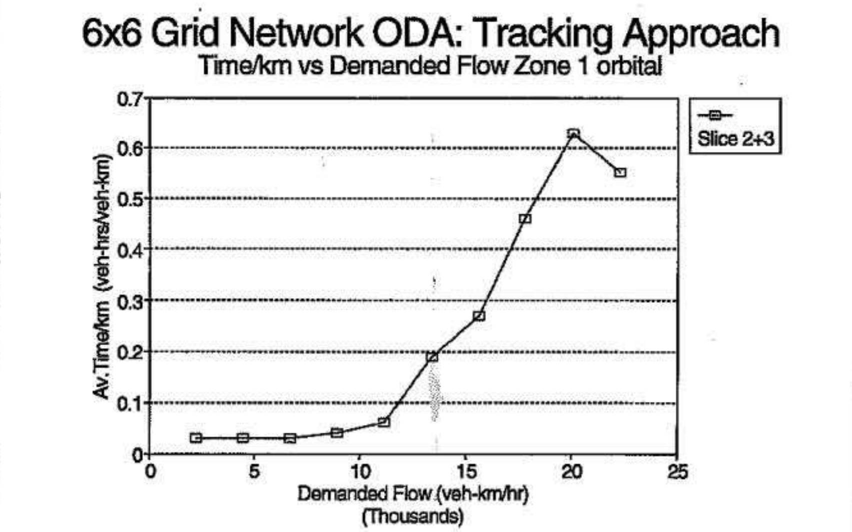

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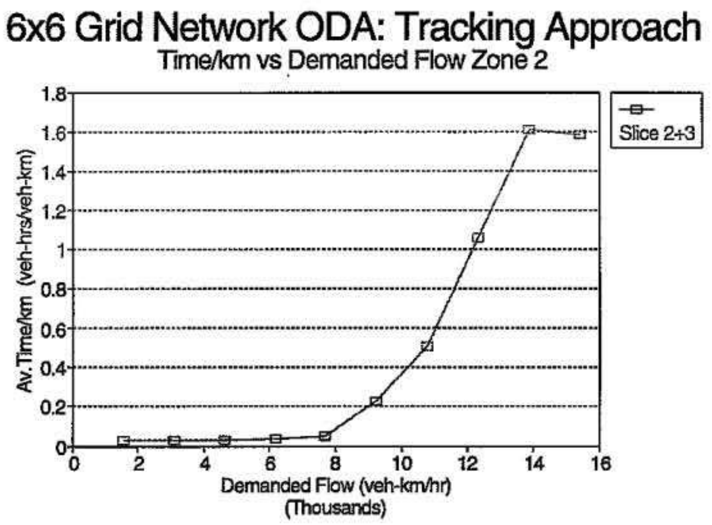


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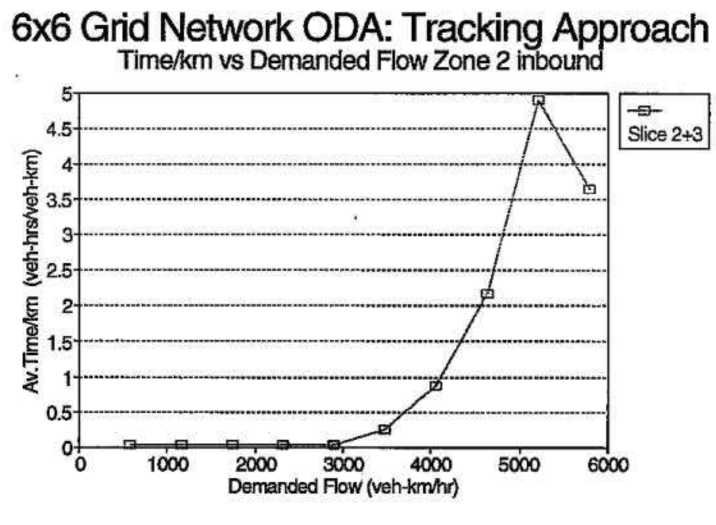


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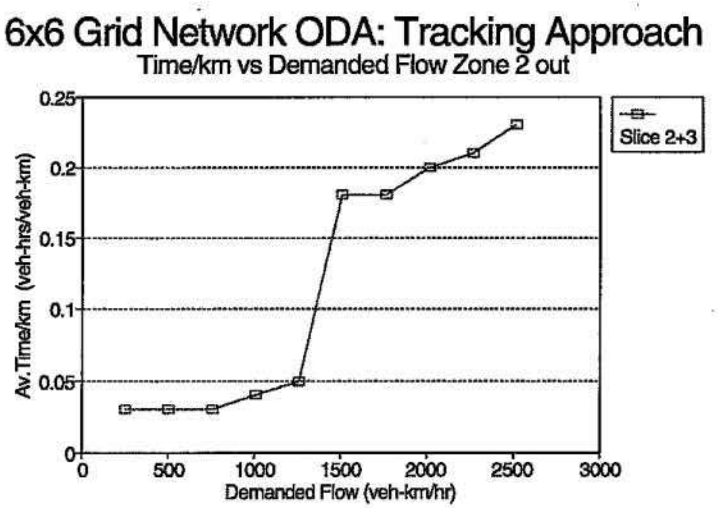


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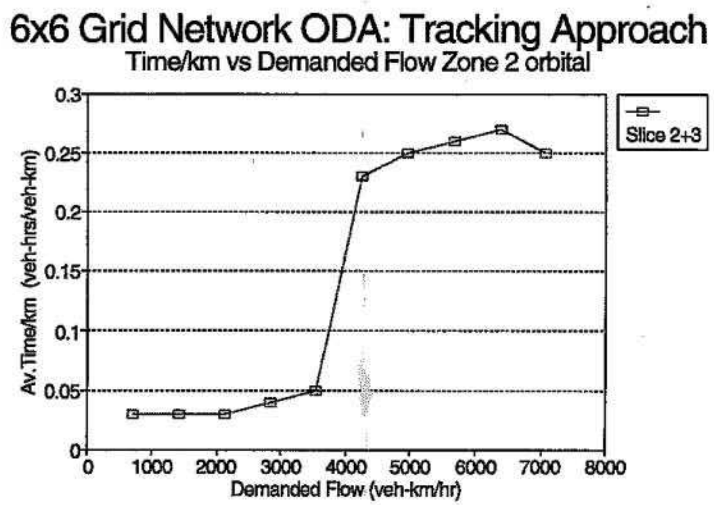

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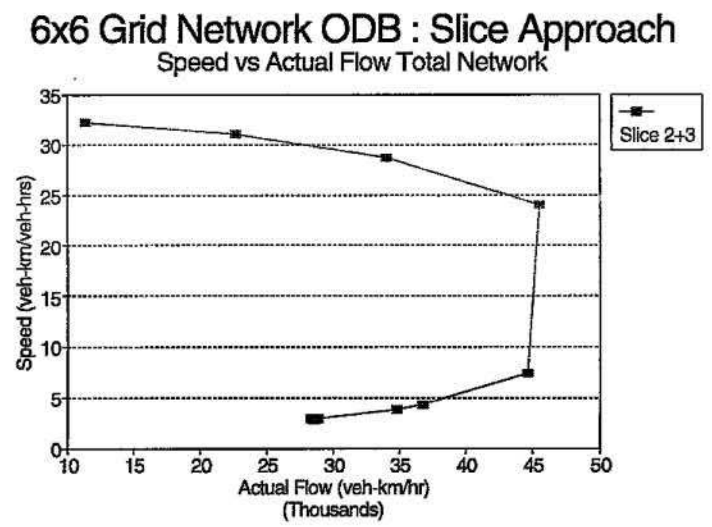


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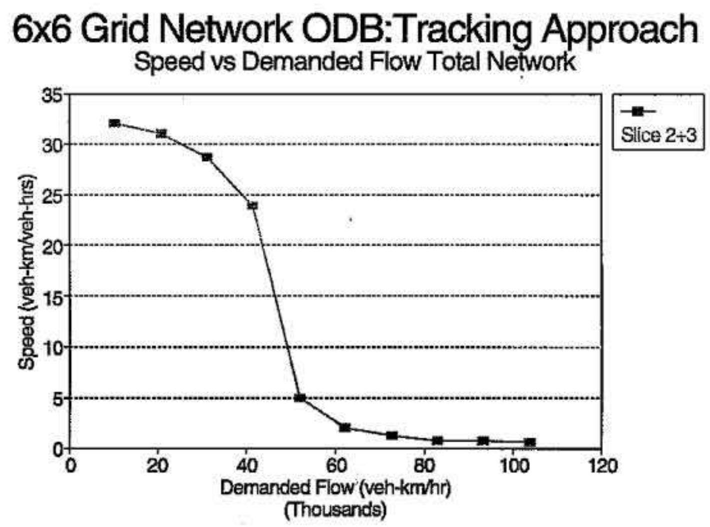


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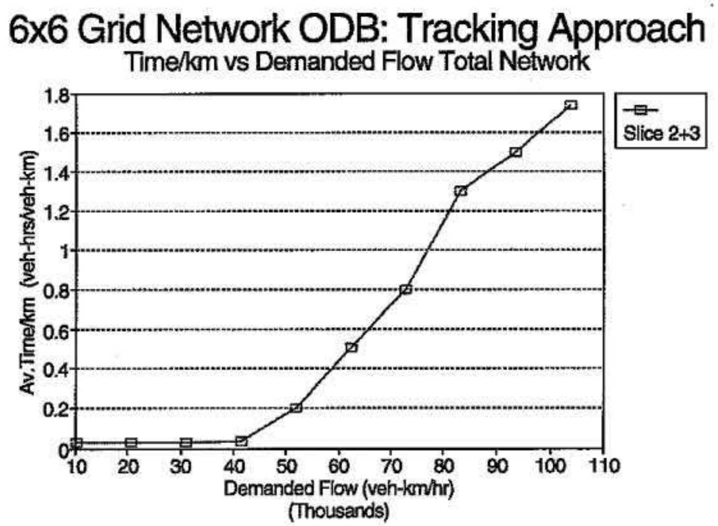


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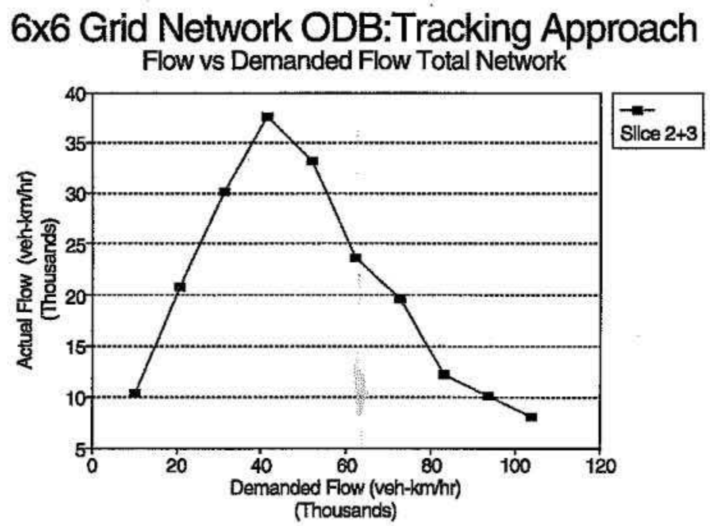

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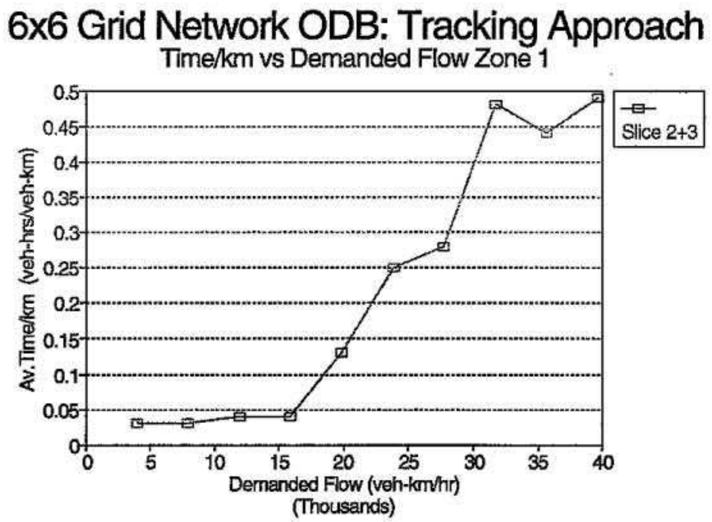


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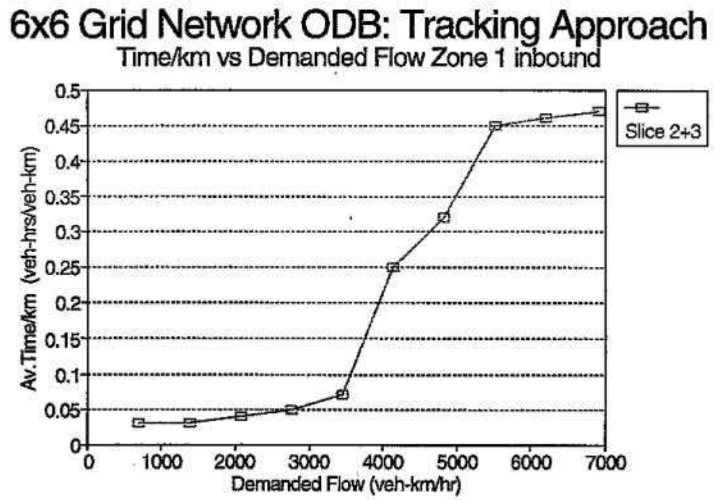


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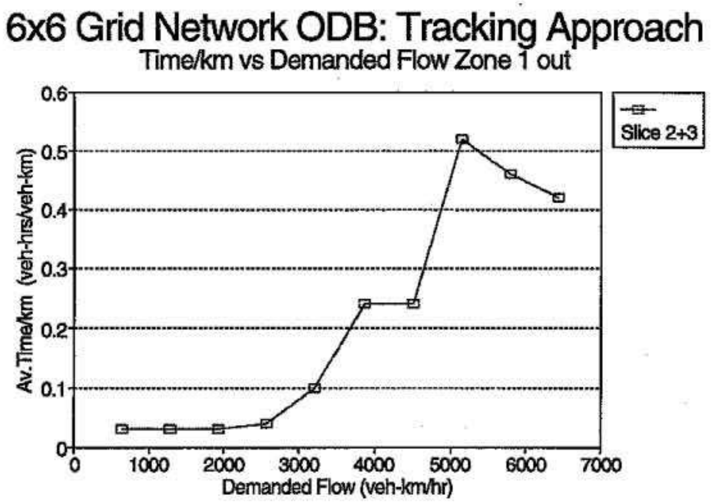


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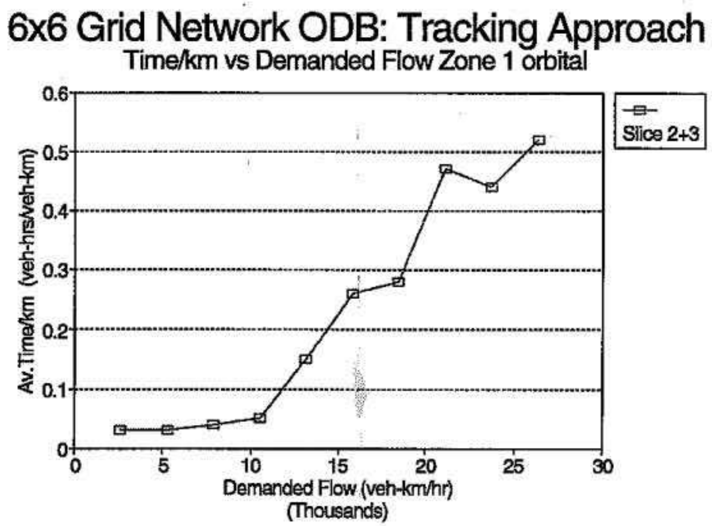

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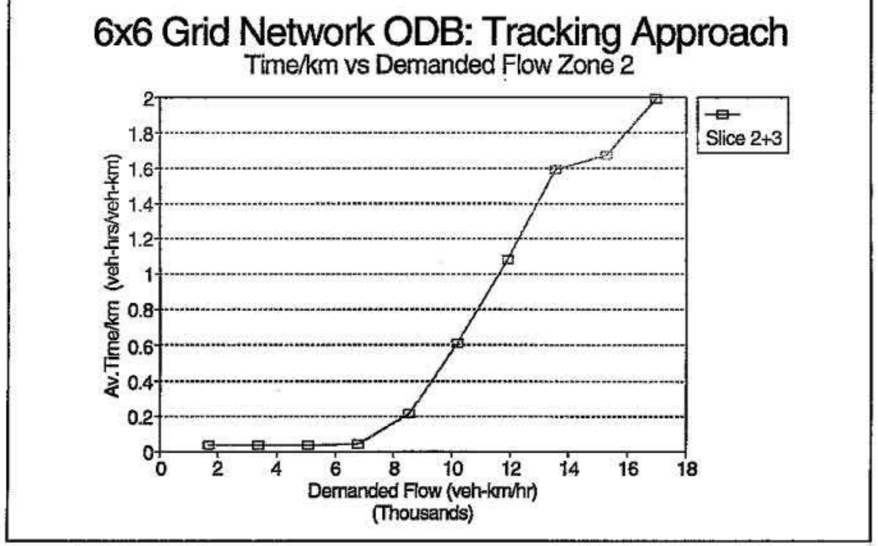


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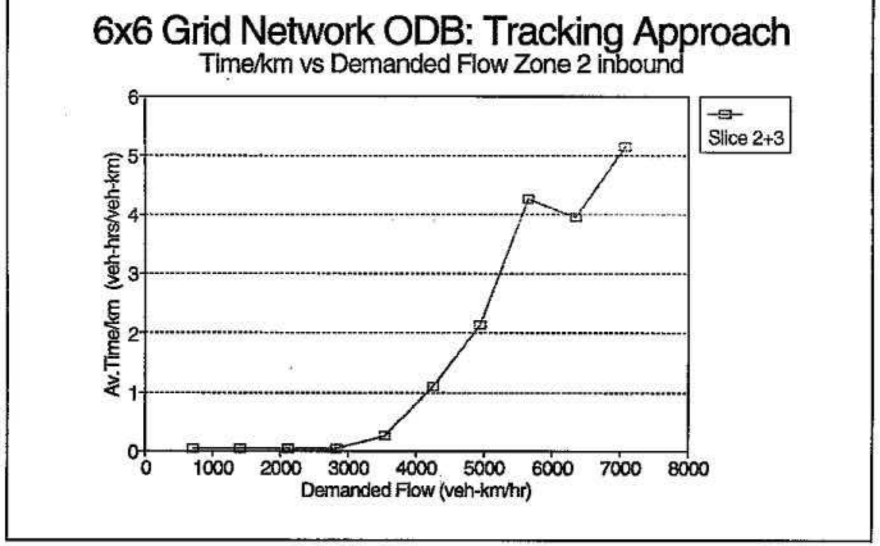


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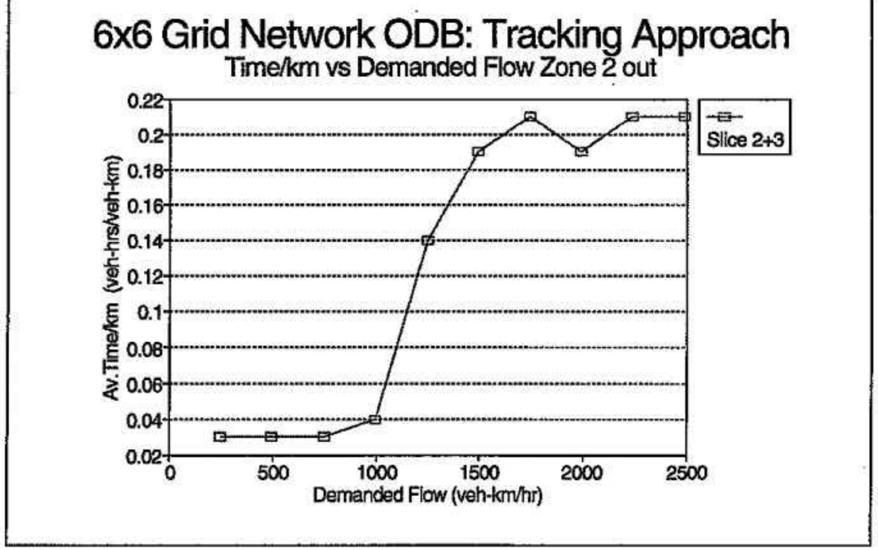


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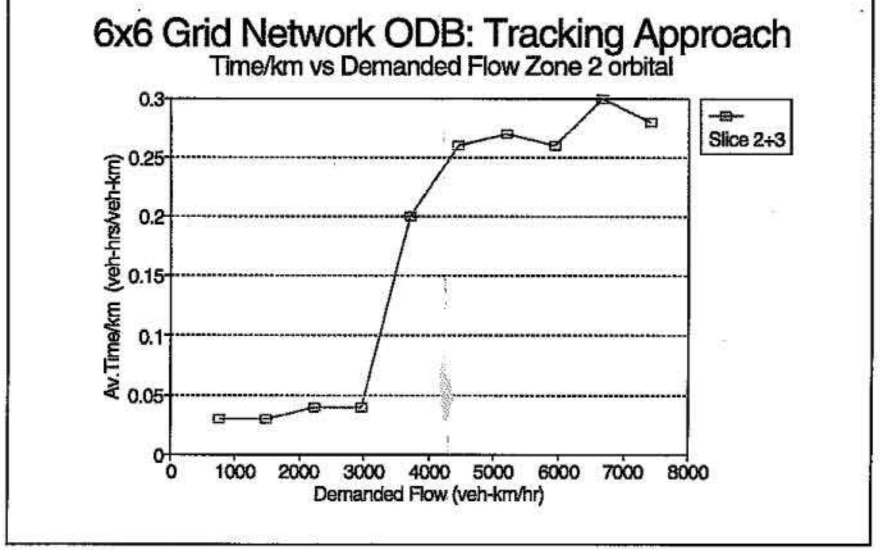

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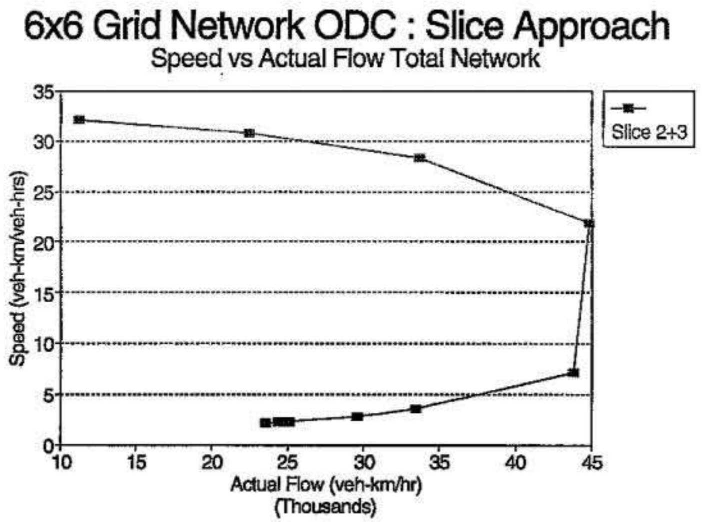


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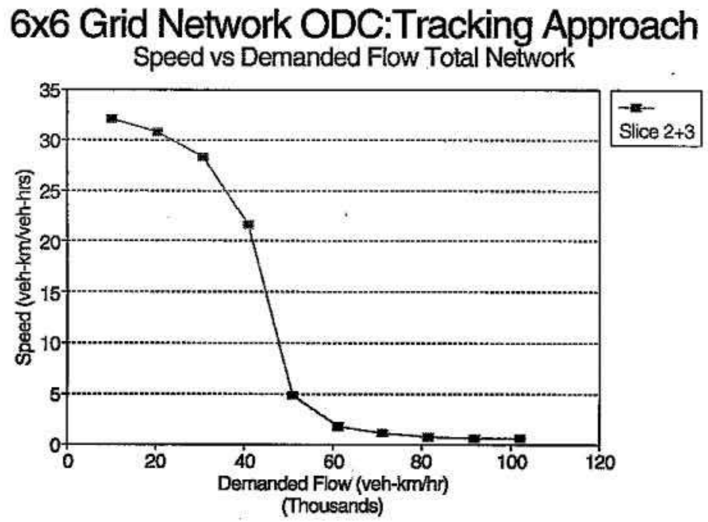


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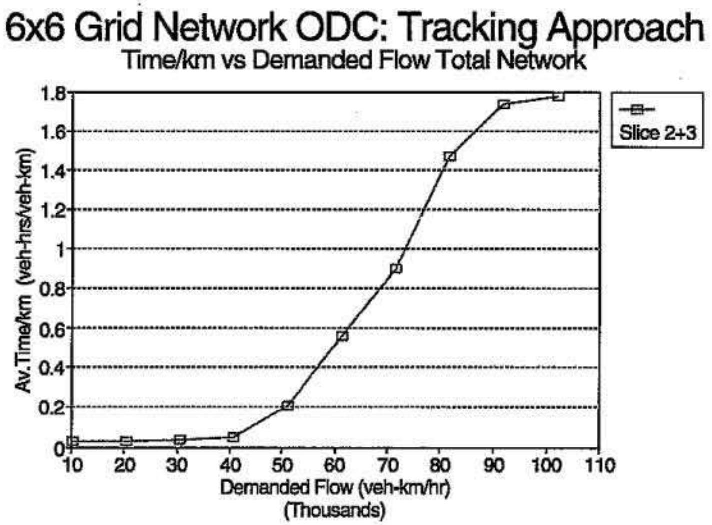


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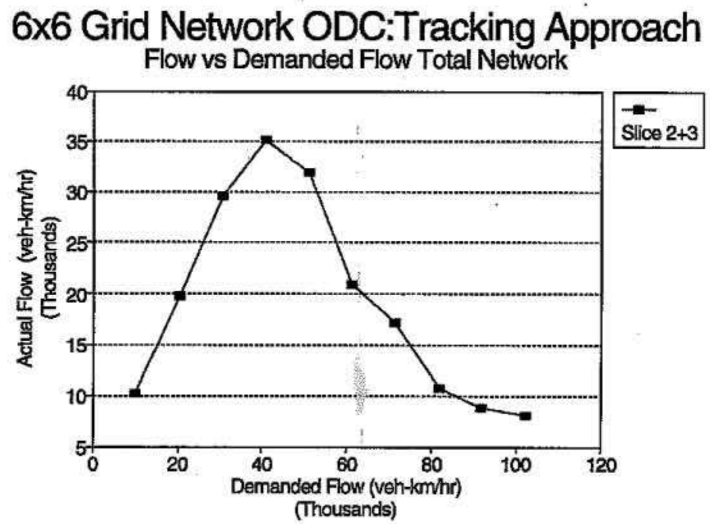

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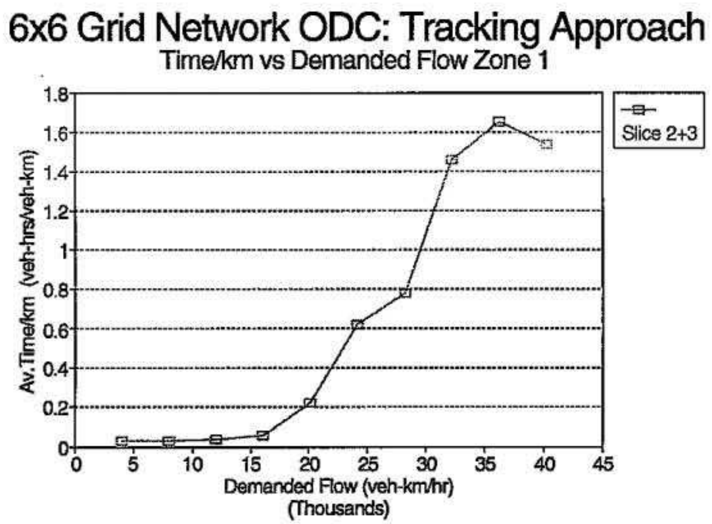


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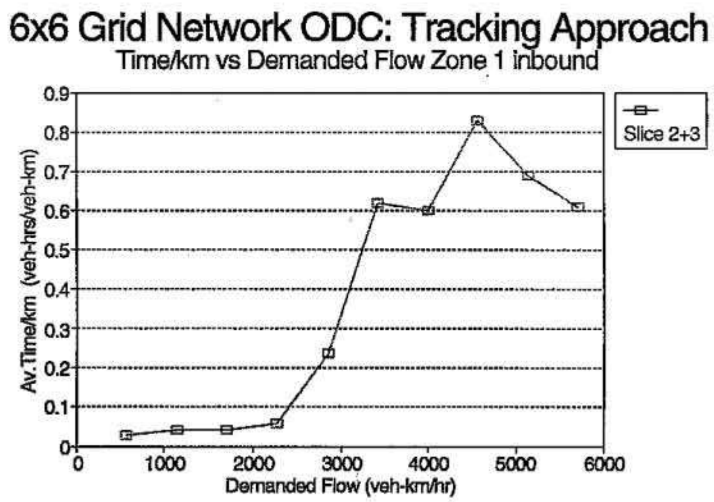


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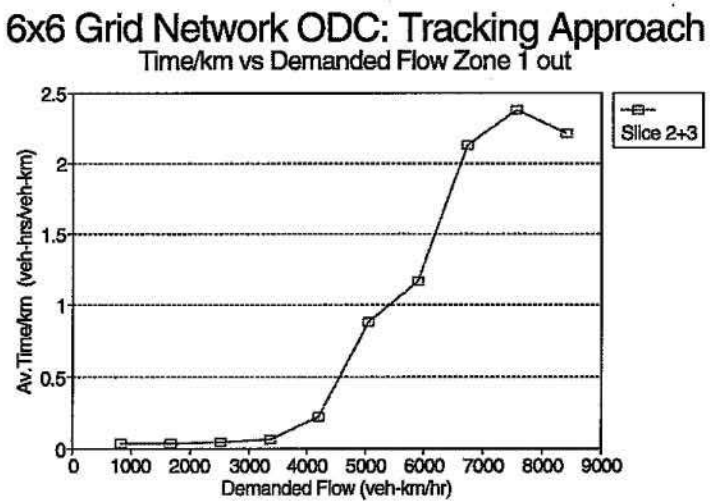


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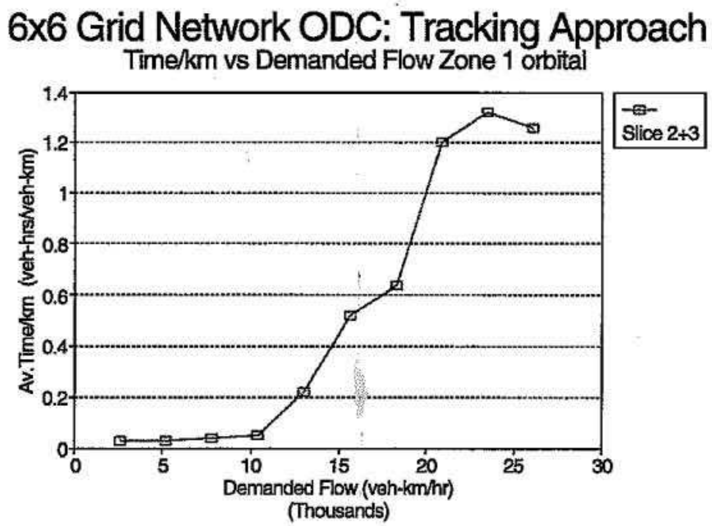

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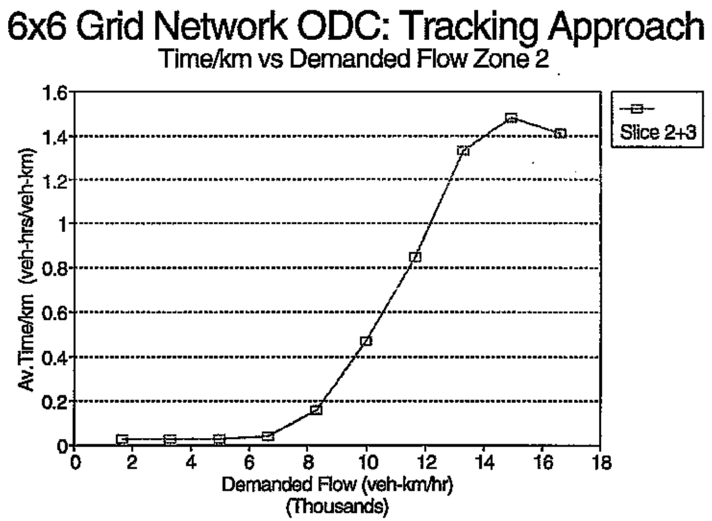


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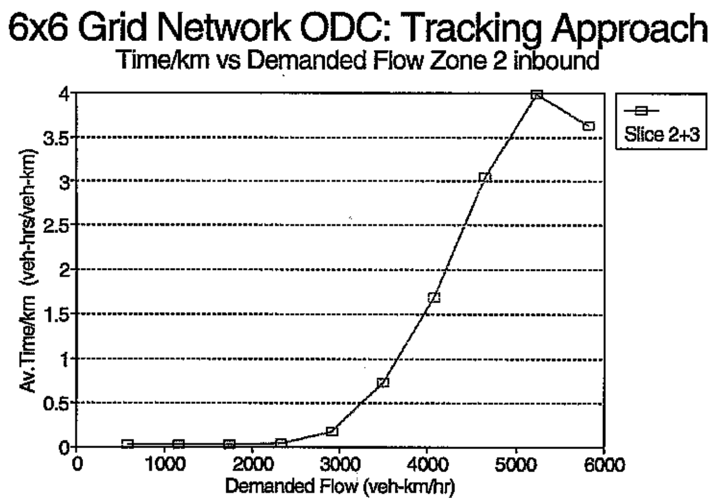


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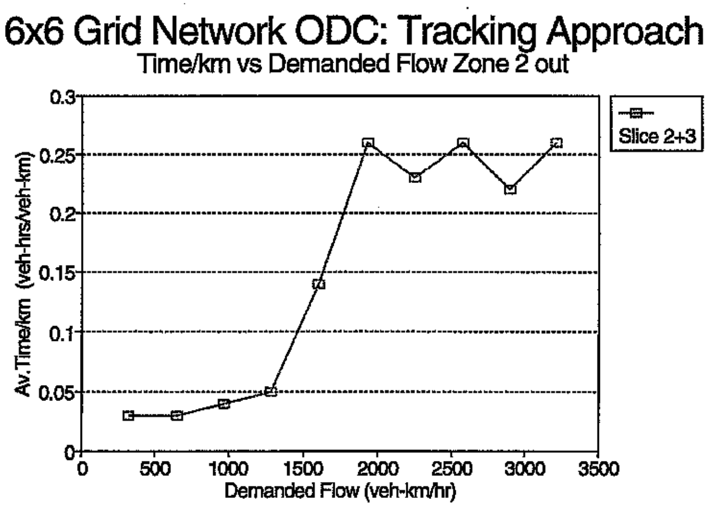


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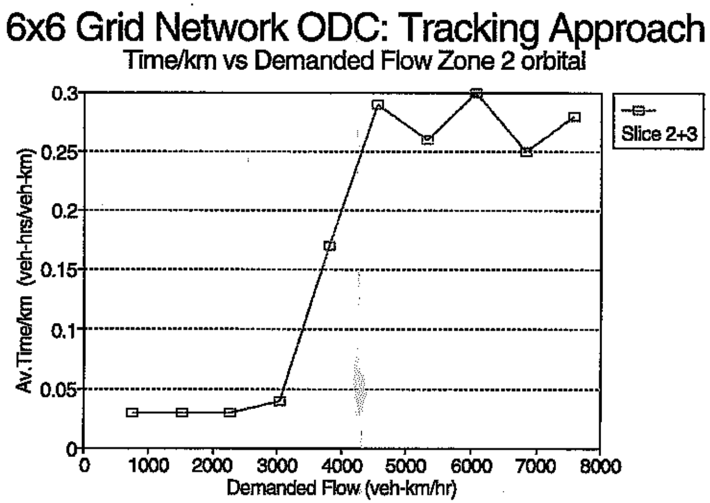

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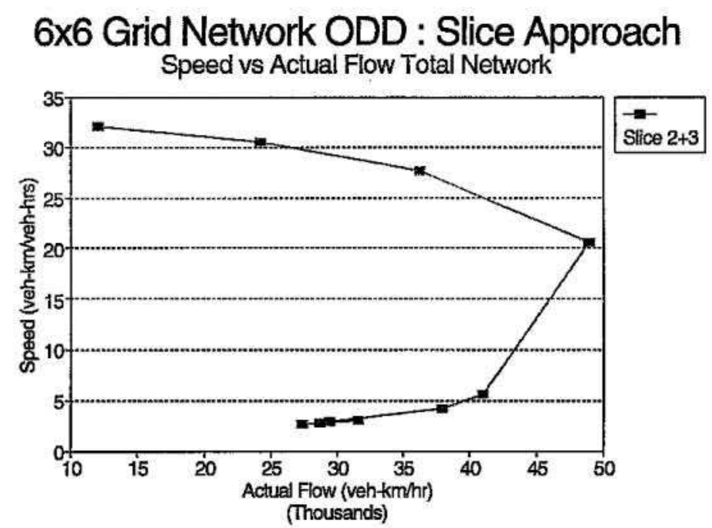


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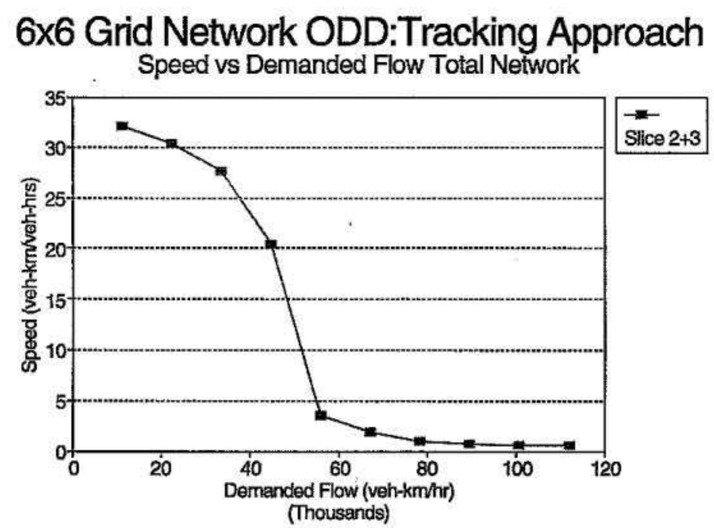


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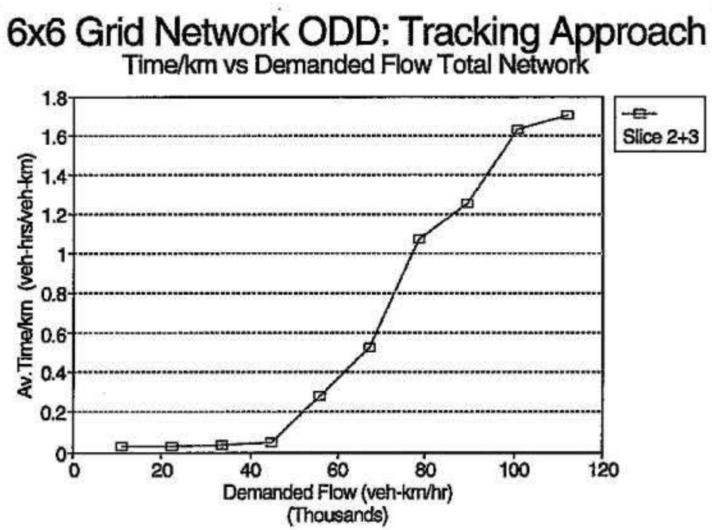


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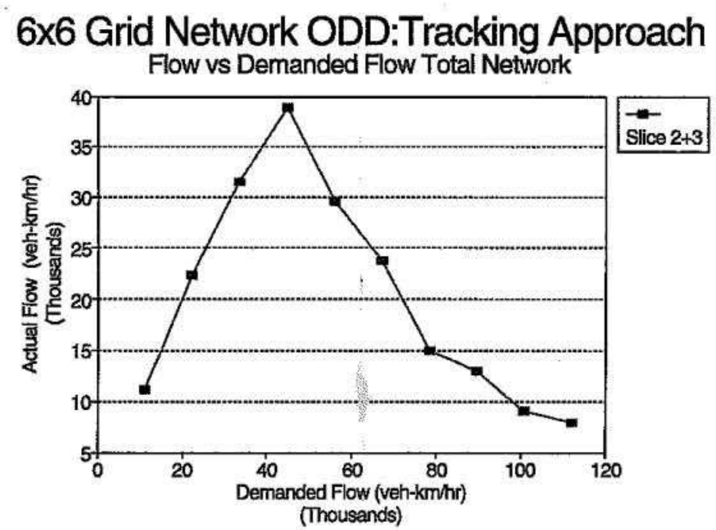

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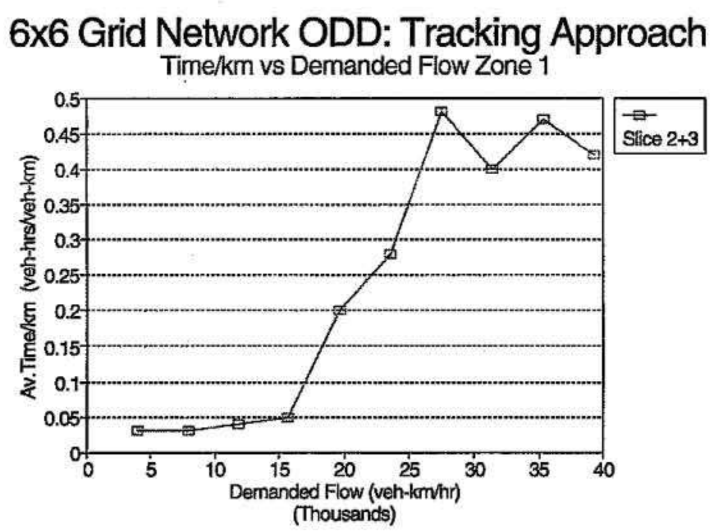



Fig 43

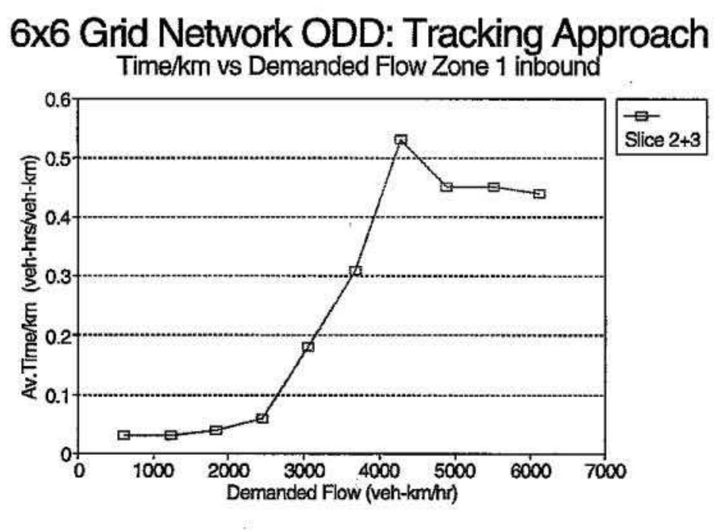



Fig 44

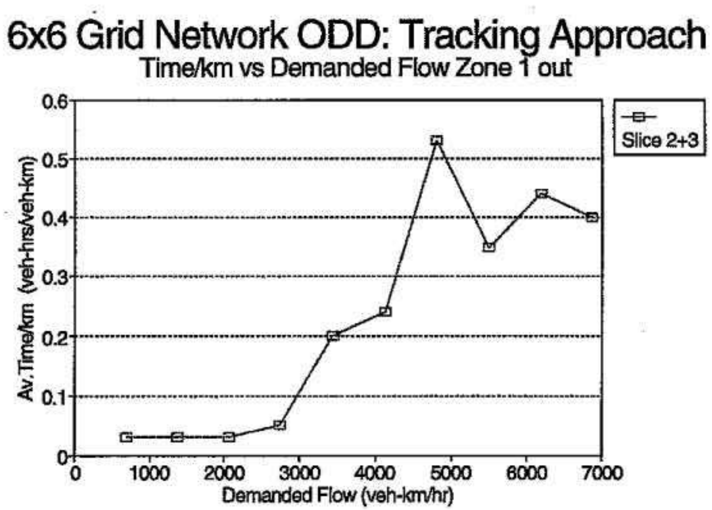



Fig 45

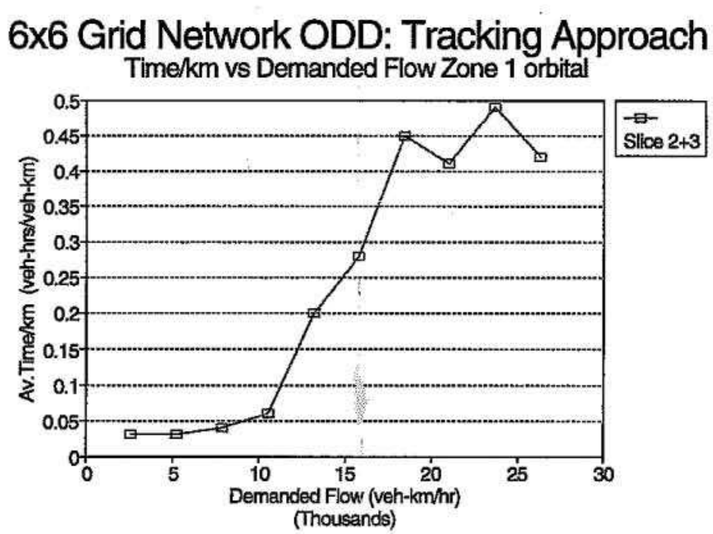


Fig 46

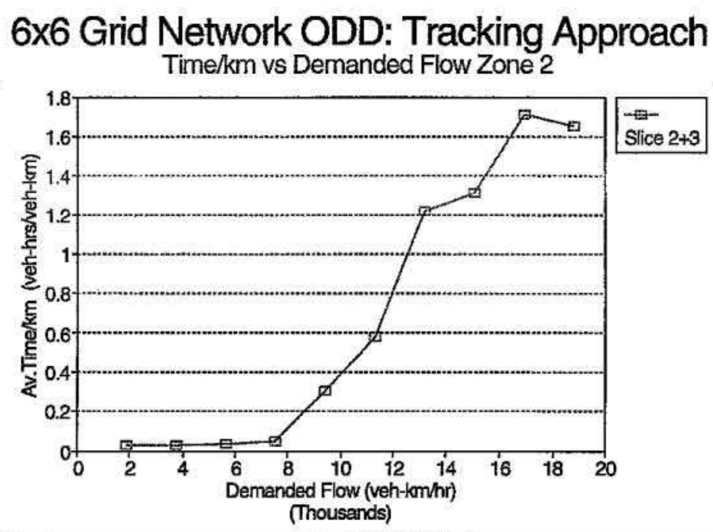



Fig 47

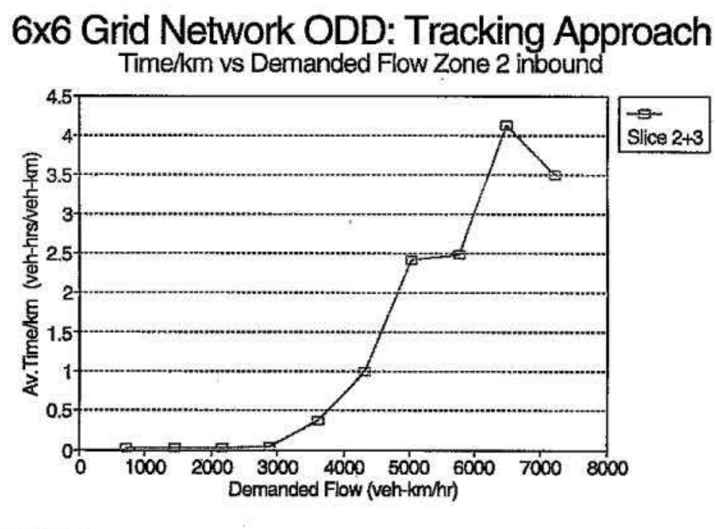



Fig 48

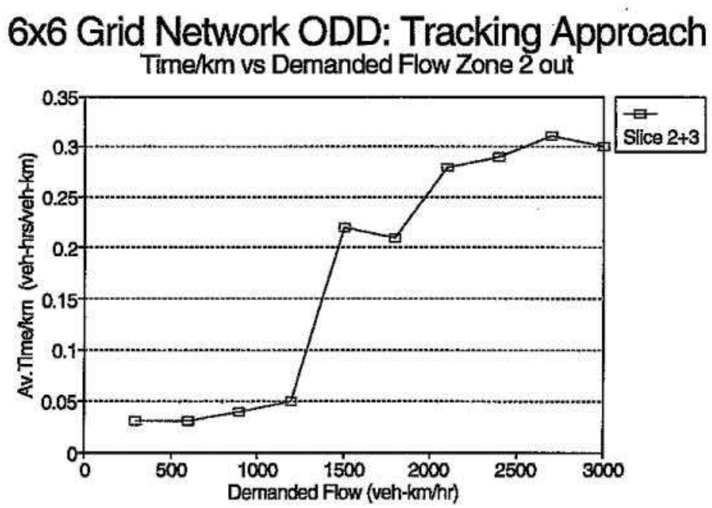



Fig 49

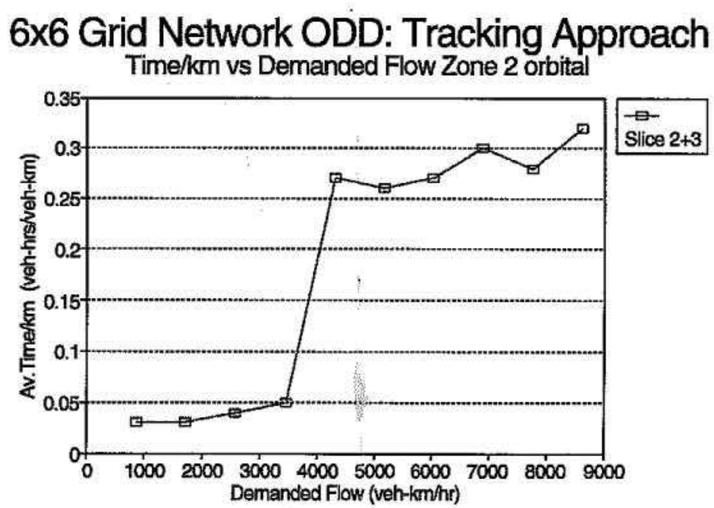


Fig 50

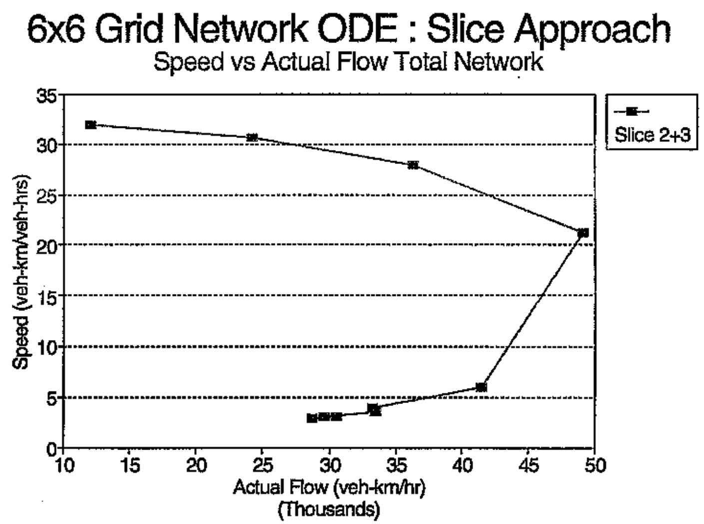



Fig 51

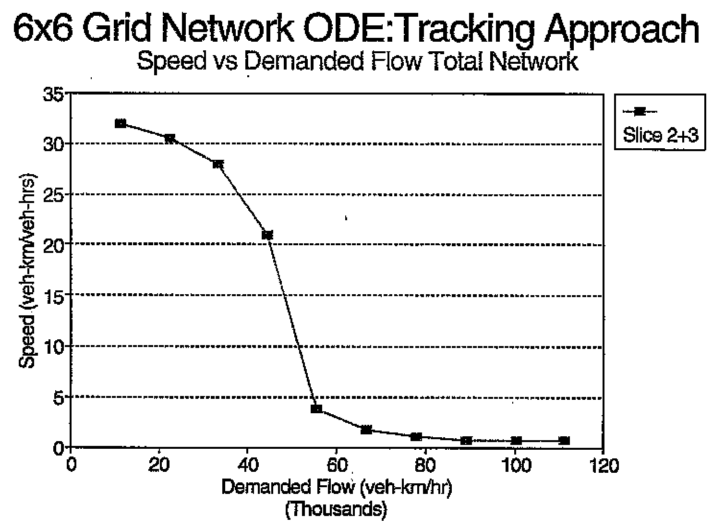



Fig 52

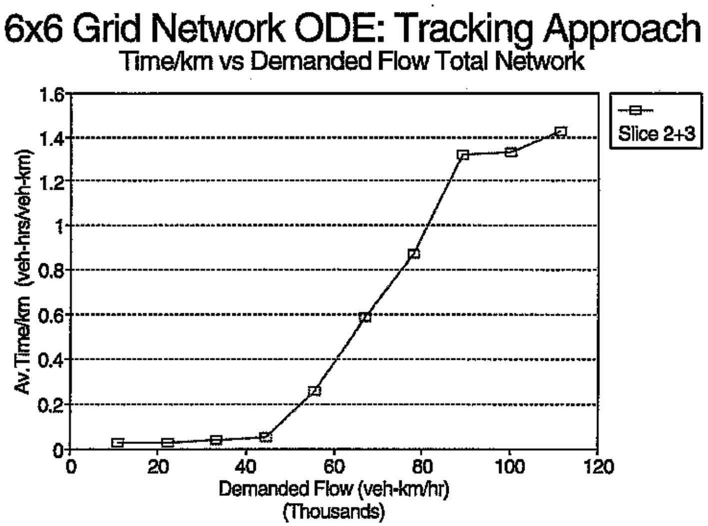



Fig 53

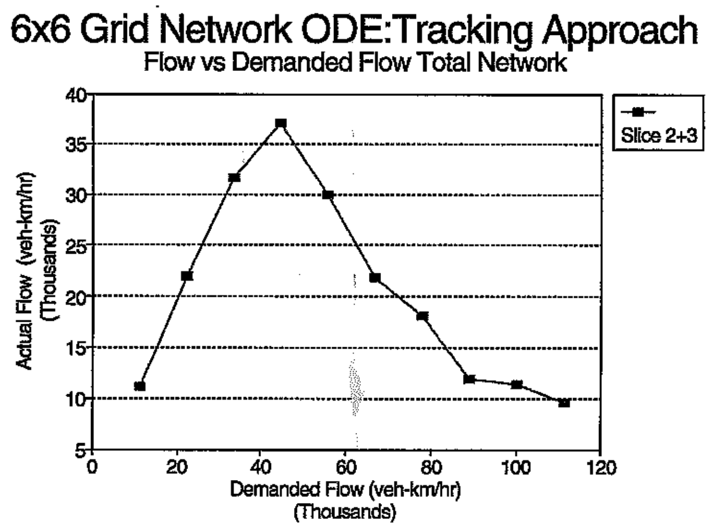


Fig 54

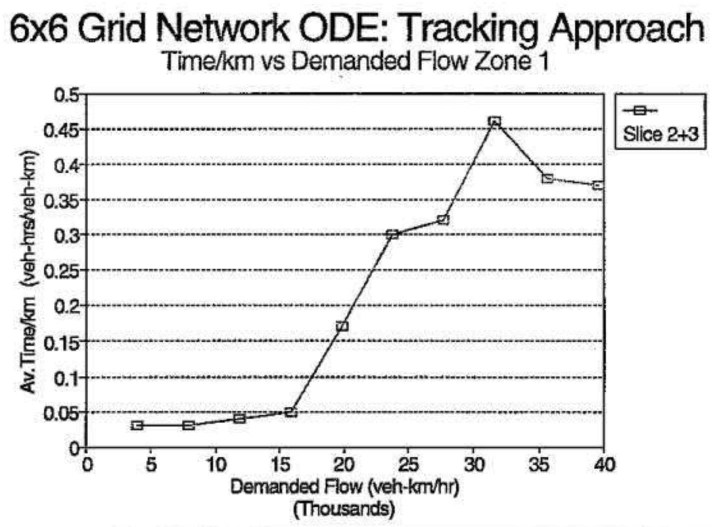



Fig 55

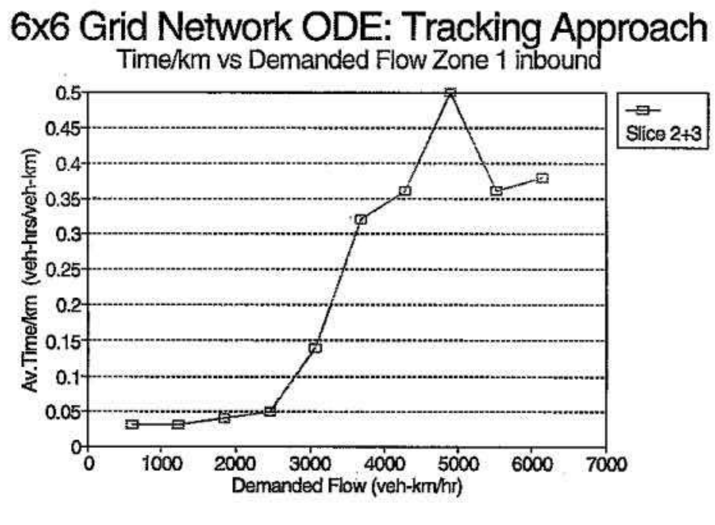



Fig 56

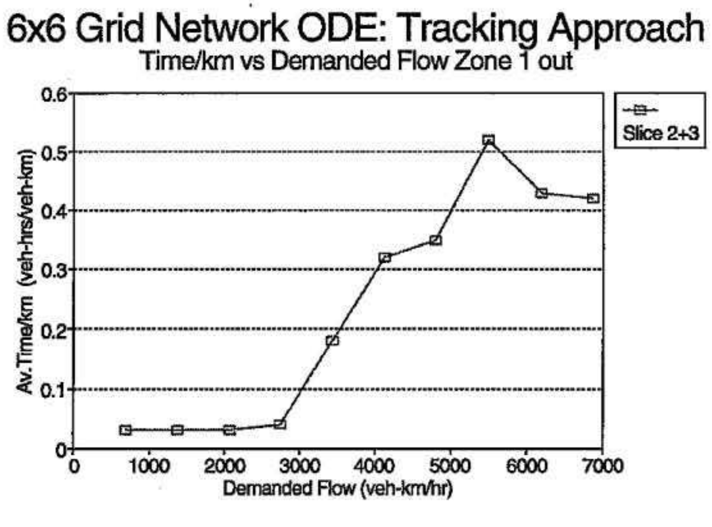



Fig 57

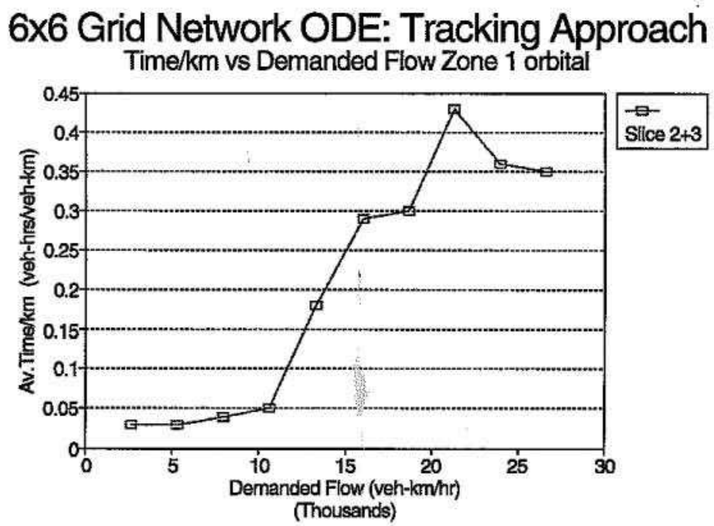


**Fig 58**

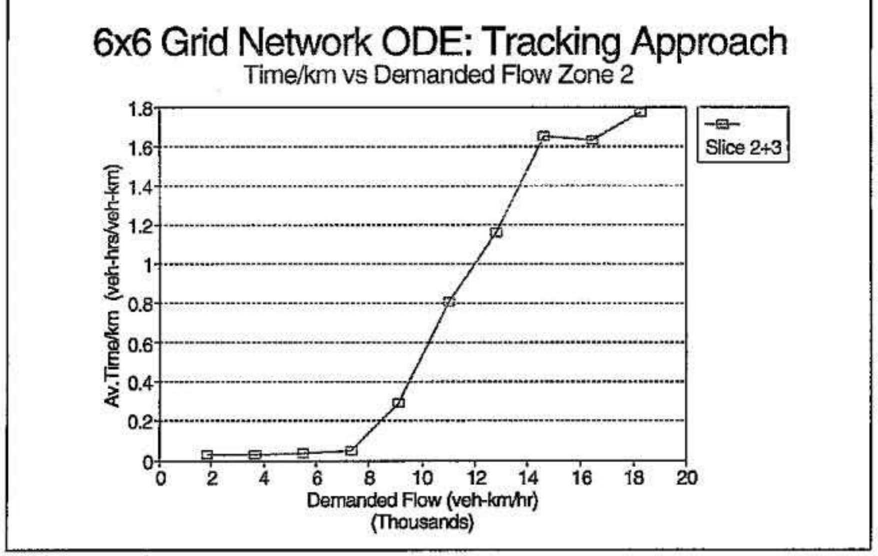



**Fig 59**

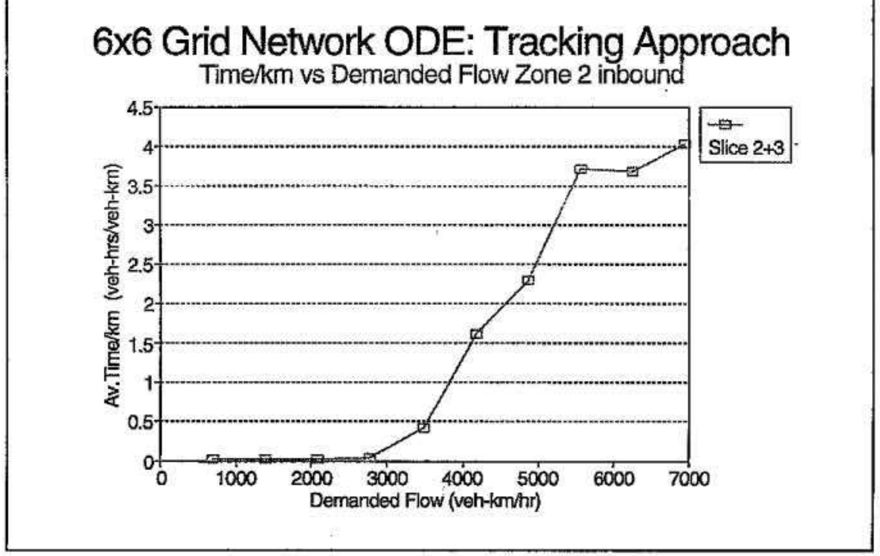



**Fig 60**

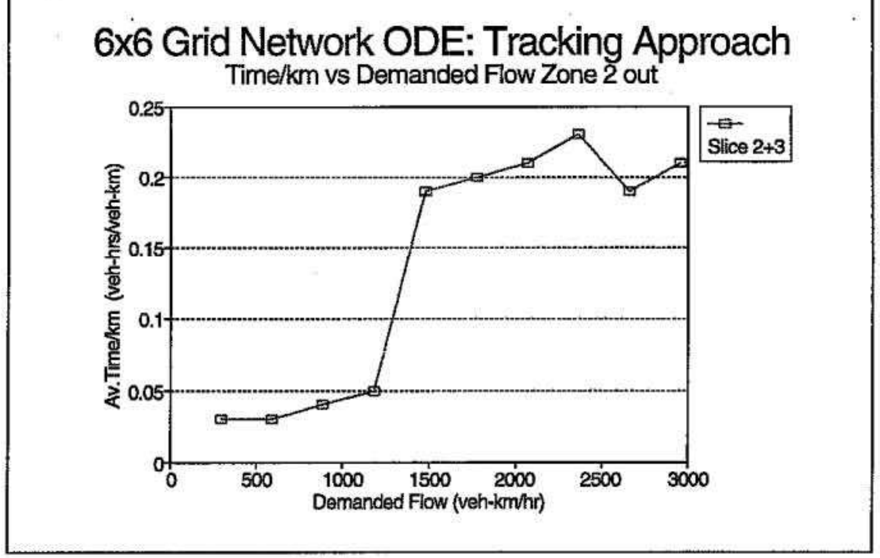



**Fig 61**

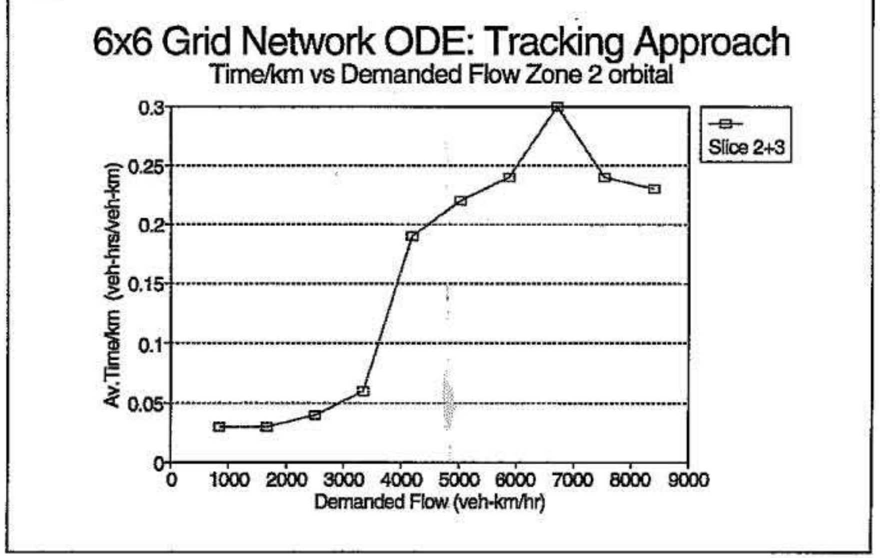


**Fig 62**

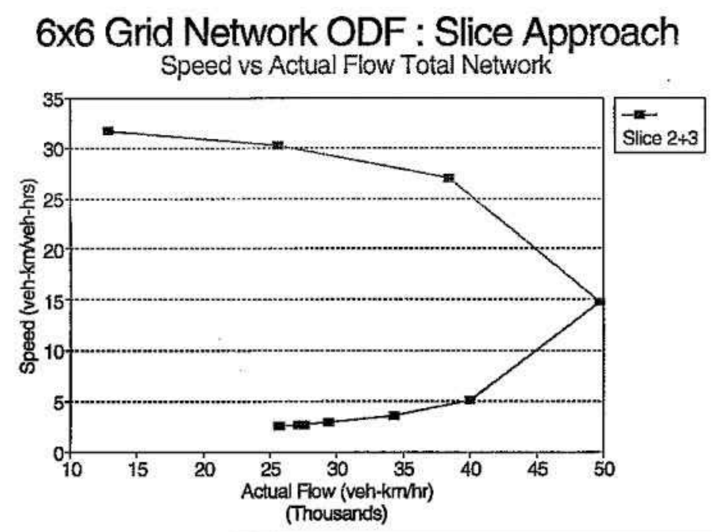
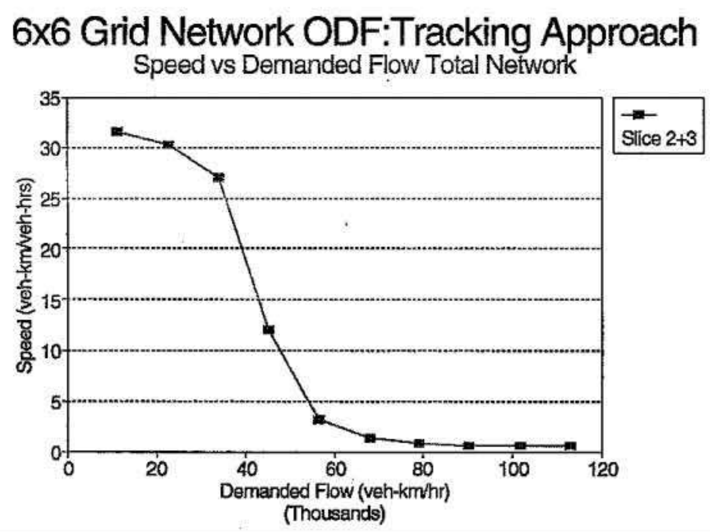



**Fig 63**

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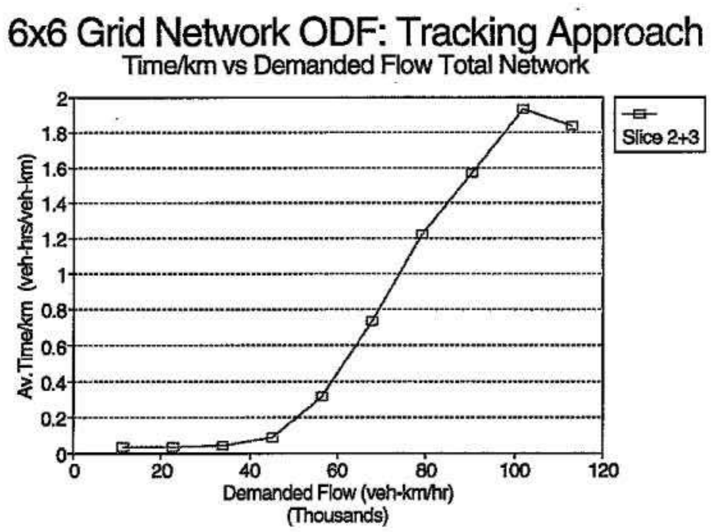


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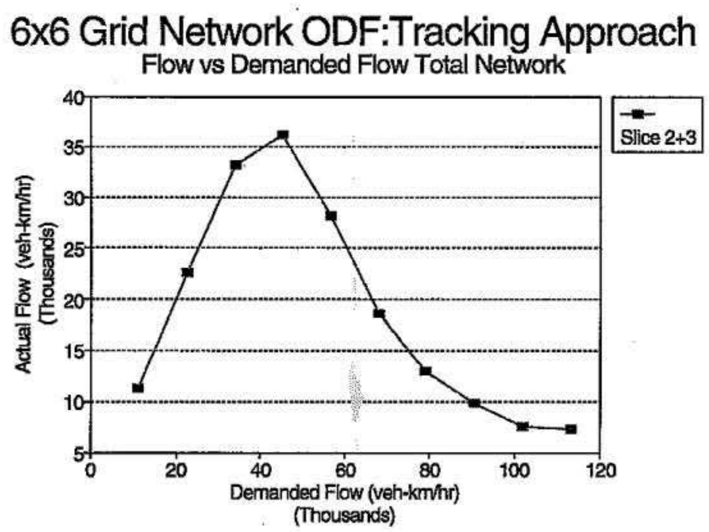

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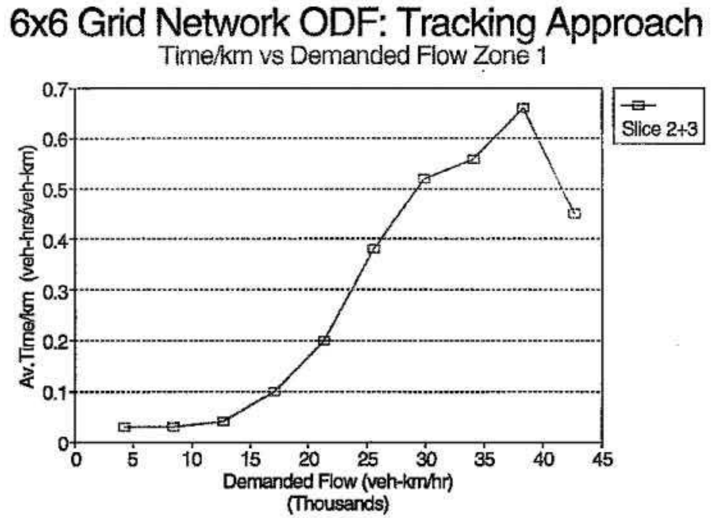



**Fig 67**

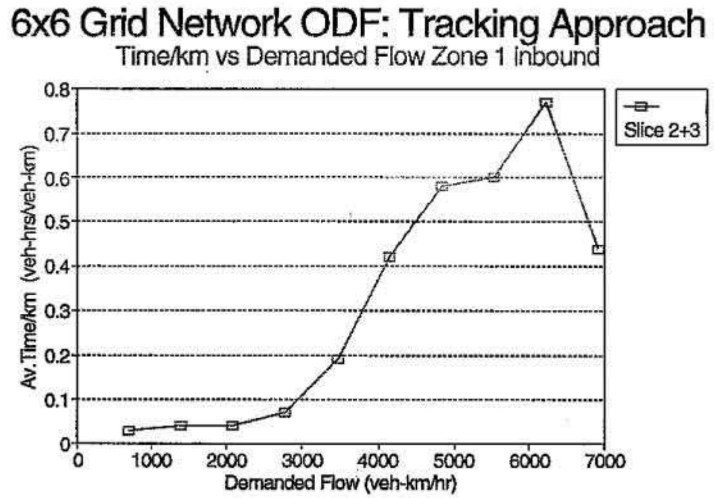
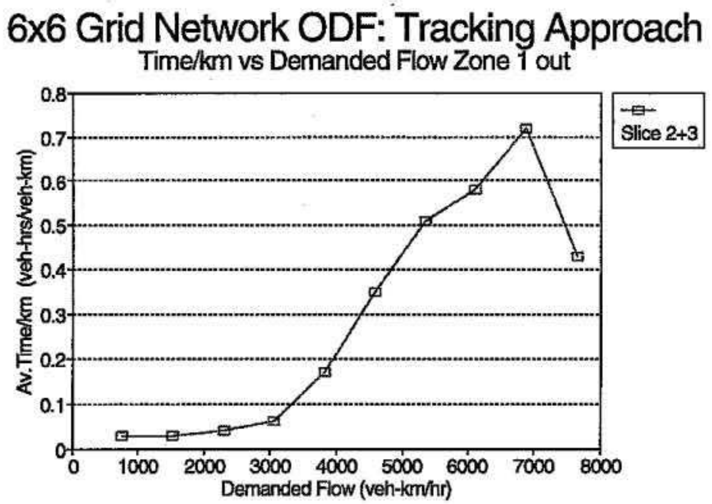



**Fig 68**

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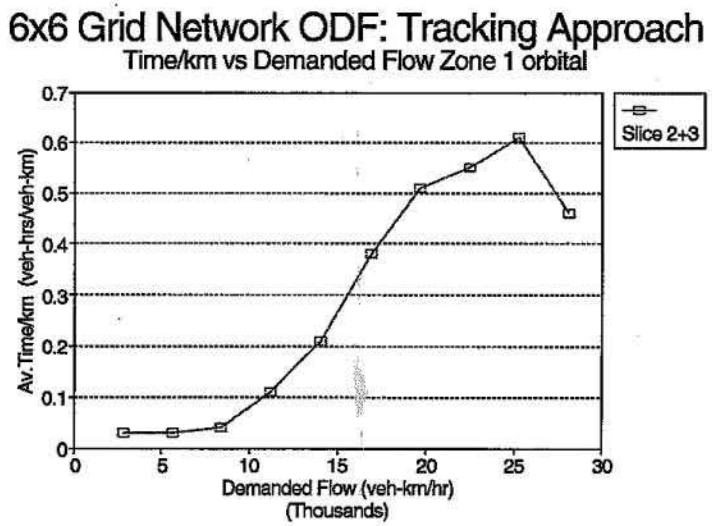

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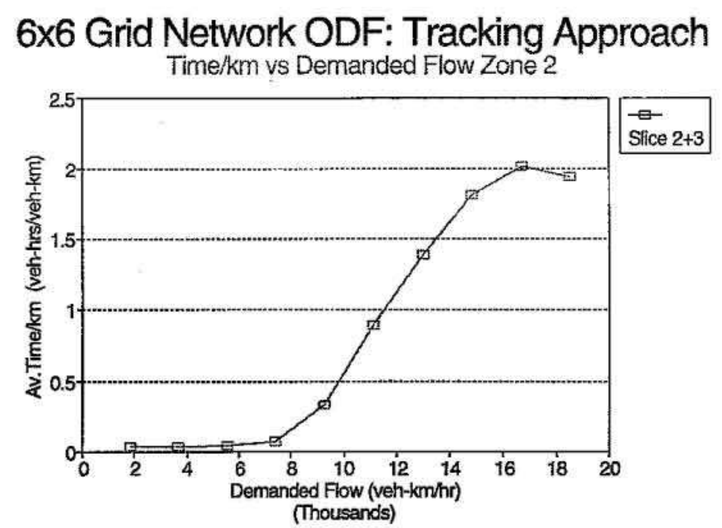
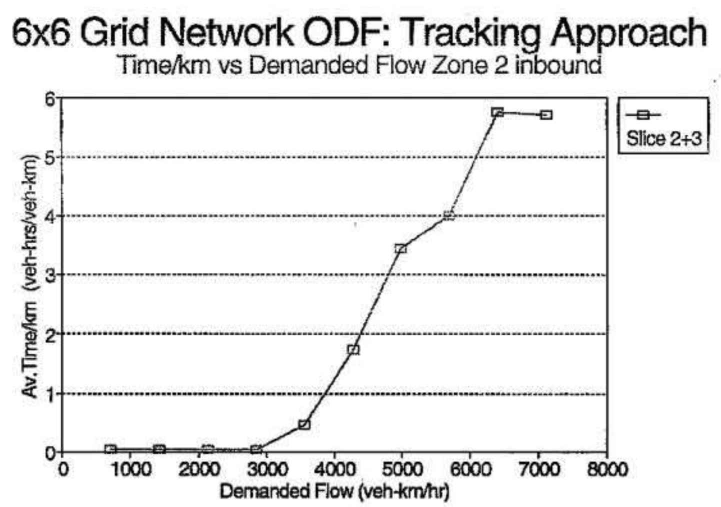



**Fig 71**

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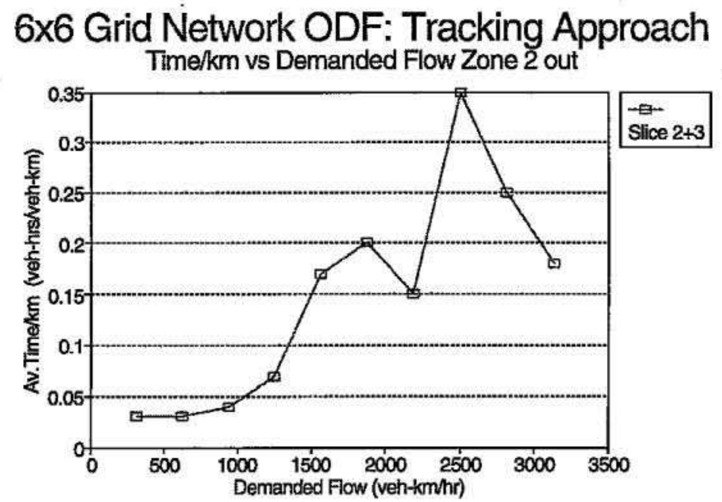


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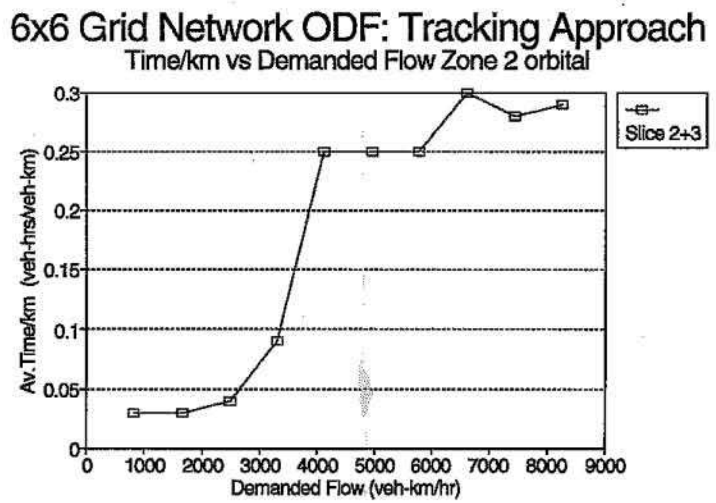

## Appendix A: Area Speed Flow Publications

May, A.D. and Shepherd, S.P. (1996) Area speed flow relationships and network aggregation. Urban transport forum 96 Barcelona, Spain 2-4 October 1996.

May, A.D. and Shepherd, S.P. (1996) Area speed flow relationships and strategic models. Proceedings ISATA96 Florence, June 3-6th 1996.

May , A.D. and Shepherd, S.P. (1995) An investigation of area speed-flow relationships by micro-simulation. 23rd European Transport Forum. PTRC. 11-15 Sept 1995.

May, A.D. and Shepherd S.P. (1994) An Investigation of Area Speed-Flow Relationships By Micro-simulation : Single Links. ITS WP428 Dec.94.

May, A.D. and Shepherd S.P. (1994) Area Speed-Flow Relationships By Micro-simulation : Grid Networks. ITS WP429 Dec.94.

May, A.D. and Shepherd S.P. (1994) Area Speed-Flow Relationships By Micro-simulation : Sensitivity issues and Problems With the Tracking Approach When Extended To Multi-Zone Networks. ITS WP430 Dec.94.

Shepherd, S.P. (1995) Area Speed-Flow Relationships : Summary of the 9 zone ring-radial results using NEMIS. ITS WP447 Dec.95.

Shepherd, S.P. (1995) Area Speed-Flow Relationships : The effects of dependency and reassignment using 2 link networks. ITS WP448 Dec.95.

Shepherd, S.P. (1995) Area Speed-Flow Relationships : The effect of varying signal capacity. ITS WP449 Dec.95.

Shepherd, S.P. (1995) Area Speed-Flow Relationships : Initial SATURN results for the ring-radial network. ITS WP450 Dec.95.

Shepherd, S.P. (1995) Area Speed-Flow Relationships : Ring-radial network aggregation using SATURN. ITS WP451 Dec.95.

Shepherd, S.P. (1995) Area Speed-Flow Relationships : Aggregation by movement type for the ring-radial using SATURN. ITS WP452 Dec.95.

Shepherd, S.P. (1995) Area Speed-Flow Relationships : Aggregation of the Cambridge. SATURN network. ITS WP453 Dec.95.

Shepherd, S.P. (1995) Area Speed-Flow Relationships : Changing the OD pattern and road pricing in Cambridge. ITS WP454 Dec.95.

**Technical Notes**

Shepherd S.P. (1995) Area Speed-Flow Relationships : Considering their future use in START. ITS TN361 Jan 95.

Shepherd S.P. (1995) Area Speed Flow Relationships : Definition of Data Collection Methodology. ITS TN383 June 1995.

Shepherd S.P. (1995) Area Speed Flow Relationships : Initial Ring-radial results using NEMIS. ITS TN384 November 1995.

**To Be Written**

WP SATURN: Summary of Saturn work (joint) Barcelona abstract?